Multifactor Monitoring of the Smart Cities Water Framework as Information Basis for Sustainable Development

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Abstract: The work is devoted to the current problem of urbanization of cities. Conceptual provisions for monitoring the condition of natural objects in a smart city are proposed. The author's methodology for assessing the effectiveness of sustainable development strategies for smart cities is presented using the example of the dynamically developing agglomeration of Kazan. A highly effective natural multiplier for assessing the state of water bodies is proposed - ichthyoproductivity as a function of the objective state of zooplankton and zoobenthos. The results of long-term monitoring studies of the objective state of water bodies in the dynamically developing agglomeration of Kazan are presented. Based on the data obtained, an assessment of ichthyoproductivity was carried out and a conclusion was made about the effectiveness of the implementation of the city's environmental strategy in general and water protection measures in particular.

1 INTRODUCTION

The global trend towards urbanization of territories determines the need for a qualitative change in the principles of constructing urban development strategies, especially in terms of the methodological, informational and organizational foundations of environmental activities. As it turned out, the vast majority of citizens consider the concept of “Smart city” as the main tool for eco-urbanization and the creation of a new type of urban ecosystem based on the principles of sustainable development and a rational approach to the formation of urban space, taking into account the environmental factor.

Urbanization refers to the process of population migrating from rural areas to cities, resulting in an increase in population and the construction of new cities and infrastructure. In turn, the “Smart city” concept implies the use of modern technologies and information systems to improve the lives of citizens, increase the efficiency of urban infrastructure and ensure sustainable development. Thus, smart cities are cities that integrate various science-based methods and digital solutions to improve the quality of life of citizens, reduce negative environmental

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impacts, improve safety and manage resources. As part of the “Smart city” concept, technologies such as data analytics, multifactor analysis, artificial intelligence, sensors, Big data, IoT, cloud computing, and many others are used. In other words, modern “Smart cities” are global ecosystems that unite closely interconnected ecological, recreational, sociocultural, architectural, engineering, industrial, transport, energy, and household frameworks.

Smart cities can offer a number of advantages, such as creating a favorable ecosystem for the life and development of citizens, preserving the biodiversity of the territory’s ecosystem, energy saving, increasing the level of education, health and safety, which means urbanization and the “Smart city” concept play an important role in the modern development of cities and improving the quality of life of its residents.

The environmental strategy of smart cities involves the use of modern technologies and innovations to improve the state of the environment and reduce the negative impact of human activity on the ecosystem.

The main principles of the environmental strategy of smart cities include:

- Application of artificial intelligence and big data analytics to monitor and predict the state of the environment and take effective measures to protect it.
- Development of green technologies and solutions, including increasing the share of renewable energy sources in urban infrastructure.
- Use of energy efficient technologies and solutions to reduce energy consumption and greenhouse gas emissions.
- Reducing air pollution, creating comfortable and safe conditions for residents through the use of smart energy, transport and infrastructure management systems.

The environmental strategy of smart cities contributes to the creation of a sustainable and environmentally friendly urban space, which, in turn, improves the quality of life of its residents and helps preserve the environment for future generations.

When forming an environmental strategy, it is important to choose the right information basis and methodology for monitoring the state of the environment. Architectural and planning solutions can and should take into account not only the factors of insolation and air purity; the urban area must remain a comfortable habitat for a wide range of living organisms inhabiting a given location, including ichthyofauna.

It is important to note that the proximity of water bodies has traditionally attracted people. Water is the most important factor in quality of life. Water bodies serve as a source of nutrition, a recreational area, and a natural biofilter. As a result, they are among the first to experience the full range of anthropogenic pressure. But water bodies are the natural habitat of aquatic biological resources. The key components of aquatic biological resources are zooplankton, zoobenthos and ichthyofauna. The quantitative and qualitative indicators of ichthyofauna directly depend on the quality of the habitat and food supply. In turn, the food supply of water bodies primarily experiences stress from human proximity. The oppressive factors are the well-known dust, hydrocarbons, water-soluble pollutants, various fractions of industrial and household waste, heavy metals and toxic chemicals, which are widely present in the city. The second echelon is the factors of disruption of trophic links and gross interference in the ecosystem (Alimov, A., 2001). During the research conducted under the guidance of Doctor of Biological Sciences, Professor of Kazan University Mingazova N.M. long-term monitoring studies of water bodies in the city of Kazan and the Republic of Tatarstan and regions of the Russian Federation have established that it is advisable to consider ichthyoproductivity as a function of the object as one of the key integral indicators of the quality of a water body.

2 MATERIALS AND METHODS

Fundamental materials for the work were data from inventory studies of 175 lakes in Kazan, environmental passports of these ecosystems developed as part of the inventory and certification of water bodies in Kazan (2007-2010), as well as individual reports on the condition of water bodies within the framework of municipal contracts with MKU "Committee for External Improvement of the City of Kazan" and economic agreements (2010-2023) (Mingazova, N., Derevenskaya, O., Palagushkina, O., 2014). Hydrobiological samples were taken at each reservoir from 2-4 stations. Control stations were selected for research. Sampling of zooplankton and zoobenthos was carried out and processed in accordance with generally accepted hydrobiological methods (Vshivkova, T., Ivanenko, N., Yakimenko, L., 2019, Shchepovskikh, A., 2006, Kutikova, L., Starobogatova, Ya., 1977, Tsalolikhina, S., 1994).

2.1 Zooplankton

Zooplankton is an integral part of lake ecosystems, a key food resource for ichthyofaunal (Derevenskaya, O., 2015, Mingazova, N., Derevenskaya, O., Palagushkina, O., 2008). During the study using databases, the qualitative composition was analyzed, statistical processing of the quantitative composition of zooplankton in lake ecosystems in Kazan was carried out, and an assessment was made of possible fish production based on zooplankton biomass.

Analysis of species composition showed the presence of 204 species of zooplankton, of which the taxa Rotifera include 84 species (41% of the total number of species), Cladocera – 64 species (31%), Copepoda – 56 species (28%). The qualitative composition of zooplankton includes 34 families, seven orders and two classes of rotifers and crustaceans (Fig. 1).

During the analysis, the prevalence of the following representatives of Rotifera (Rotifera) was noted. Among Cladocera crustaceans, the highest occurrence is: Chydorus sphaericus (O.F. Muller), Bosmina longirostris (O.F. Muller), Simocephalus vetulus (O.F. Muller), Daphnia longispina O.F. Muller, Daphnia cucullata Sars, Scapholeberis mucronata (O.F. Muller). Of the copepods (Copepoda), the most frequently found are: Eucyclops serrulatus (Fischer), Mesocyclops leuckarti (Claus), Thermocyclops oithonoides (Sars).

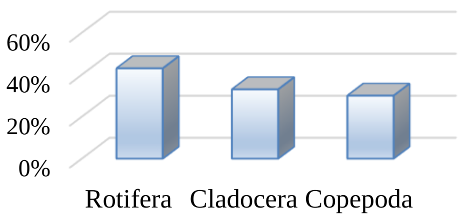

Figure 1: Distribution of zooplankton taxa in the studied area.

The occurrence of zooplankton species in the lakes of Kazan is presented in Table 1. The identified number of zooplankton species in the lakes ranged from 1 species (Lake-marsh complex in the village of Lagerny) to 85 species (Lake Sredny Kaban).

Table 1: Taxonomic composition of zooplankton in lakes of Kazan (according to dominant and rare species for 46 lakes studied in summer).

Taxon / Predominantly occurring species	Occurrence
Rotifera	
Keratella quadrata (Muller)	27%
Brachionus angularis (Gosse)	19%
Cladocera	
Chydorus sphaericus (O.F. Muller)	47%
Bosmina longirostris (O.F. Muller)	26%
Copepoda	
Eucyclops serrulatus (Fischer)	29%
Mesocyclops leuckarti (Claus)	28%

The analyzed lakes are very diverse in terms of the abundance and biomass of zooplankton. According to quantitative characteristics, the average value of zooplankton abundance is 181 thousand specimens/m^3, the average value of zooplankton biomass is 2.32 g/m^3 (Table 2). The poorest lake in this regard is. Rotanovoe (number of zooplankton – 0.4 thousand specimens/m3 and biomass – 0.0004 g/m^3). The highest abundance was found in the lake. Peschanoye (2120 thousand specimens/m^3), and the highest zooplankton biomass is in lake. Bead (37.70 g/m^3).

As part of the study, an assessment of zooplankton biomass was carried out from the point of view of the food supply of ichthyofauna (Kitaev, S., 2007). To estimate possible fish production based on zooplankton biomass, a regression equation was used (1):

$$Y=4.408*X^{0.698}, \quad (1)$$

where Y, kg/ha – fish production;
X, g/m^3 – zooplankton biomass.

Calculations of fish productivity based on zooplankton biomass for lake ecosystems in Kazan are shown in Table 24; the average fish productivity of all studied lakes was 5.68 kg/ha. The lake turned out to be the most highly productive per unit area. Businka (55.53 kg/ha), the least productive lake. Rotan (0.02 kg/ha).

Table 2: Number, biomass and estimated fish productivity based on zooplankton biomass in lakes in Kazan.

№	Number (ind./m²)	Biomass (g/m²)	Fish products activity, kg/ha
1	396	37,7	55,53
2	49	18,5	33,79
3	588	10,2	22,3
4	2120	8,36	19,41
5	243	4,1	11,8
6	86,2	2,9	9,27
7	52	2,67	8,75
8	66	2,6	8,59
9	204	2,2	7,64
10	24	1,77	6,57

11	41	1,7	6,38
12	1310	1,6	6,12
13	124	1,56	6,01
14	277	1,3	5,29
15	104	1,2	5,01
16	101	1,2	5,01
17	37,3	0,86	3,97
18	82	0,7	3,44
19	18,6	0,63	3,2
20	50,2	0,59	3,08
21	24,9	0,5	2,72
22	781	0,5	2,72
23	72	0,5	2,72
24	338	0,48	2,64
25	65	0,37	2,21
26	226	0,32	1,99
27	69	0,24	1,63
28	49	0,16	1,25
29	8,47	0,15	1,17
30	65	0,15	1,17

All studied lakes by zooplankton biomass in accordance with the division of I.N. Sorokin, can be divided into 4 groups: I – with biomass less than 1 g/m^3, II – with biomass from 1 to 5 g/m^3, III – with biomass from 5 to 10 g/m^3 and IV – with biomass more than 10 g/m^3 m^3 (Table 3). 64% of the studied lakes are included in group I with low zooplankton biomass (very low productivity), i.e. They are classified as low-nutrient in terms of bioresources.

The qualitative composition of zooplankton in the lakes of Kazan shows a significant anthropogenic impact on aquatic ecosystems (the most common species of zooplankton are species that inhabit mainly eutrophic and polluted lake ecosystems).

Table 3: Groups of lake ecosystems in Kazan by zooplankton biomass.

Number of lakes	% of lakes	Biomass (g/m^3)
I (very low productivity)		
30	64 %	less 1
II (low productivity)		
12	25 %	1 - 5
III (medium productive)		
1	2 %	5 - 10
IV (highly productive)		
3	9%	more 10

According to quantitative characteristics, the average value of zooplankton abundance is 181 thousand specimens/m^3, the average value of zooplankton biomass is 2.32 g/m^3. Most of the studied lakes belong to the group with low plankton biomass (poor food or very low productivity, in terms of bioresources). The possible average fish production based on zooplankton biomass was 5.68 kg/ha.

2.2 Zoobenthos

Zoobenthos is an important part of the food supply of fish resources; assessment of potential fish productivity based on zoobenthos can be carried out to analyze promising ichthyoproducts, as well as for measures for restoration and improvement of fish biological resources (Nabeeva, E., 2010).

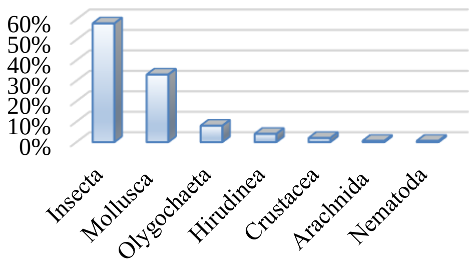

Figure 2: Distribution of taxa within the qualitative composition of zoobenthos in lake ecosystems of Kazan.

Based on the analysis of the database on hydrobiological indicators, 163 species of organisms from seven taxonomic groups of benthic aquatic invertebrates were identified, of which insects (Insecta) - 91 species (56%), mollusks (Mollusca) - 51 species (31%), oligochaetes (Olygochaeta)) – 11 species (7%), leeches (Hirudinea) – 6 species (4%), crustaceans (Crustacea) – 2 species (1.2%), arachnids (Arachnida) – 1 species (0.6%) and nematodes (Nematoda) – 1 species (0.6%) (Fig. 2).

The predominant group in terms of species composition in the zoobenthic community of lake ecosystems of Kazan is Insects (species of beetles Hydroporus, chironomids Chironomus plumosus, Polypedilum nubeculosum, mayflies Cloen dipterum, hemiptera Corixa sp.). Among the Mollusca group, the dominant species were Planorbis planorbis and Anisus spirorbis. Among the oligochaetes, the most common were Limnodrilus hofmeisteri, Tubifex tubifex, among leeches - Erpobdella octoculata, among crustaceans - Asellus aquaticus. The occurrence of macrozoobenthos species (by dominant species and rare species) in the lakes of Kazan is presented in Table 4. Complete information on the number of zoobenthos species found in all studied lakes in the regions of Kazan is presented.

In the lake ecosystems of Kazan, rare species listed in the Red Book of the Republic of Tatarstan were discovered: Ranatra linearis (Ranatra rod-shaped, living in Lake V. Kaban) and Nepa cinerea (aquatic scorpion, living in Lake V. Kaban), Argironeta aquatica L. (silver spider, living in lake - oxbow No. 2 of the Kazanka River, Sovetsky district).

The identified number of zoobenthos species in the lakes ranged from 1 species (Lake Shosseynoye) to 14 species (Lake Sredny Kaban).

According to quantitative characteristics, the average value of zoobenthos abundance in lake ecosystems in Kazan is 287 specimens/m3, the average value of zoobenthos biomass is 2.84 g/m3 (Table 5). Lake is the poorest in terms of zoobenthos abundance. Kharovoe (12 specimens/m2) and biomass – lake. Eastern (0.04 g/m2). The highest abundance of zoobenthos was found in lake. Verkhniy Kaban (2800 ind./m2), and the highest biomass is near lake. Medium Boar (16.2 g/m2).

Table 4: Taxonomic composition of zoobenthos in lakes of Kazan (by dominant and rare species for 31 studied during the summer period of the lake).

Taxonomic group	Species
Olygochaeta	*Limnodrilus hofmeisteri* (Claparède, 1862)
	Tubifex tubifex (Müller, 1774)
Leeches (Hirudinea)	*Erpobdella octoculata* (Linnaeus, 1758)
Shellfish (Mollusca)	*Planorbis planorbis* (Linnaeus, 1758)
	Anisus spirorbis (Linnaeus, 1758)
Insects (Insecta)	*Chironomus plumosus* (Linnaeus, 1758)
	Polypedilum nubeculosum (Meigen, 1804)
	Hydroporus (Clairville, 1806)
	Cloen dipterum (Linnaeus, 1758)
	Corixa dentipes (Thomson, 1869)
	Coenagrion armatum (Charpentier, 1840)
	Ischnura elegans (Vander Linden, 1820)
	Mistacides niger (Linnaeus, 1758)
	Nymphula stagnata (Donovan, 1806)
	Elophila nymphaeta (Linnaeus, 1758)
Arachnids (Arachnida)	*Argyroneta aquatica* (Clerck, 1757)
Crustaceans (Crustacea)	*Asellus aquaticus* (Linnaeus, 1758)

All studied lakes can be divided into 4 groups according to zoobenthos biomass: I – with biomass less than 1 g/m2, II – with biomass from 1 to 5 g/m2, III – with biomass from 5 to 10 g/m2, IV – with biomass more than 10 g/m2 (Table 4).

Lakes of group IV, as reservoirs with high and very high biomass of zoobenthos, are highly food-rich and make up 10% of the studied lakes (in terms of bioresources). 58% of the studied lakes are included in group I with very low biomass (very low productivity) and 19% are in group II with low biomass of zoobenthos (low productivity), respectively, low-forage. Group III of lakes - medium-feeding (medium-productive), makes up 13% of the studied lakes. Thus, most of the studied lakes in Kazan (58%) are very low-productive (i.e., low-nutrient in terms of biological resources).

To calculate the possible production of benthophages based on zoobenthos biomass, the formula was used (2):

$$P_{benthophages} = 0.2P_{bent}. \quad (2)$$

where P is fish productivity, kg/ha;
P_{bent} - benthos biomass, kg/ha.

Calculations of fish productivity based on zoobenthos biomass for lake ecosystems in Kazan are shown in Table 5; the average fish productivity of all studied lakes was 5.68 kg/ha. The lake turned out to be the most highly productive per unit area. Medium Kaban (32.4 kg/ha), the least productive lake in terms of biological resources. Eastern (0.08 kg/ha).

Table 5: Number, biomass and estimated fish productivity based on zoobenthos biomass of lakes in Kazan.

№	Number (ind./m²)	Biomass (g/m²)	Fish products activity, kg/ha
1	250	16,2	32,4
2	192	15	30
3	24	15	30
4	1575	7,95	15,9
5	2800	7,07	14,14
6	2050	6,93	13,85
7	375	4,8	9,6
8	37	1,66	3,32
9	88	1,47	2,94
10	150	1,46	2,92
11	12	1,27	2,54
12	38	1,16	2,32
13	350	1,03	2,05
14	75	0,88	1,76
15	72	0,88	1,76
16	112	0,81	1,62
17	112	0,81	1,62
18	100	0,75	1,5

19	13	0,63	1,26
20	50	0,5	1
21	50	0,4	0,8
22	87	0,4	0,8
23	75	0,35	0,7
24	12,5	0,15	0,3
25	25	0,13	0,25
26	89	0,11	0,22
27	12,5	0,11	0,22
28	25	0,09	0,18
29	12	0,06	0,12
30	12,5	0,06	0,12

Thus, in the biocenosis of zoobenthos of lakes on the territory of the city of Kazan, chironomid species are most often found, and the predominant group in terms of species composition is insects. The average value of zoobenthos abundance was 287 specimens/m3, the average value of zoobenthos biomass was 2.84 g/m3, 58% of the studied lakes were included in group I with very low zoobenthos biomass or very low-productive (poor-feeding) (less than 1 g/m2). When calculating possible fish production based on zoobenthos biomass, the average value was 5.68 kg/ha.

Table 6: Groups of lake ecosystems in Kazan by zoobenthos biomass.

Number of lakes	% of lakes	Biomass (g/m^3)
I (very low productivity)		
18	58 %	less 1
II (low productivity)		
6	19 %	1 - 5
III (medium productive)		
4	13 %	5 - 10
IV (highly productive)		
3	10%	more 10

2.3 Ichthyofauna and assessment of fish productivity of lake

Ichthyofauna is the final link in the trophic chain of an aquatic ecosystem, reflecting its state (Abakumov, V., 1992). Based on the analysis of the database on hydrobiological indicators, 15 species were noted in the composition of the ichthyofauna of lake ecosystems in Kazan (Mingazova, N., 2005). All species belong to the class Bony fishes (Osteichthlyes), to 3 orders (Esociformes, Cypriniformes, Perciformes) and 5 families (Ecocidae, Cyprinidae, Balitoridae, Percidae, Eleotriade). The most diverse order is Cypriniformes; 11 species out of all species represented in the lakes of Kazan belong to this order (Table 7).

Table 7: Occurrence of ichthyofauna species in lake ecosystems of Kazan.

№	Species	Occurrence, %
1	*Esox Lucius* L.	16
2	*Rutilus rutilus* L.	32
3	*Scardinius erythrophthalmus* L.	21
4	*Lecaspius delineates*	47
5	*Alburnus alburnus* L.	26
6	*Abramis brama* L.	11
7	*Blicca bjoerkna* L.	11
8	*Tinca tinca* L.	21
9	*Carassius carassius* L.	68
10	*Carassius auratus gibelio* Bloch	32
11	*Ciprinus carpi L.*	42
12	*Barbatulla barbatulla* L.	11
13	*Perca fluviatilis L.*	39
14	*Acerina cernua L.*	5
15	*Percottus glehni* Dybowsky	42

The occurrence of species ranges from complete absence or one (usually a weed species of Amur sleeper) to 11 species in the lake. The highest species diversity (9-11 species) of ichthyofauna was found in oxbow-karst lakes with a depth of more than 10 m - Nizhny, Middle and Upper Kaban. About 5-8 species were found in stagnant karst lakes (Lake Bolshoye Glubokoe, Lebyazhye, Botanichesky). Most of all within the city of Kazan there are lake ecosystems with 1-4 species of ichthyofauna and completely fishless lakes. It should be taken into account that lakes with one species are most often inhabited by the invasive species Amur sleeper, which has a high tolerance to pollution and ecological plasticity; it is considered a “weed” species that negatively affects the aquatic ecosystem and oppresses local aquatic organisms. Rotan reservoirs probably should not be classified as fish-producing and resource lakes.

Summary Table 8 presents data for calculating the ichthyoproductivity of the studied lake ecosystems in Kazan based on regression equations taking into account the biomass of zooplankton and zoobenthos.

Calculations of fish productivity based on zooplankton biomass showed that the average fish productivity of all studied lakes was 5.68 kg/ha, while the most highly productive per unit area was lake. Businka (55.53 kg/ha), the least productive lake. Rotan (0.02 kg/ha).

In terms of zoobenthos biomass, the average fish productivity of all studied lake ecosystems is 5.68 kg/ha; according to this indicator, lake turned out to be the most highly productive per unit area. Middle Kaban (32.4 kg/ha), the least productive lake. Eastern (0.08 kg/ha).

Table 8: Estimated ichthyoproductivity of lake ecosystems in Kazan.

by zooplankton biomass, kg/ha	by zoobenthos biomass, kg/ha	total, kg/ha
minimum		
0,02	0,08	0,10
maximum		
55,53	32,4	87,93
average		
5,68	5,68	11,36

Thus, the overall average ichthyoproductivity of lake ecosystems in Kazan for all two indicators (biomass of zooplankton and zoobenthos) was 11.36 kg/ha.

As a result of analyzing data on fish resources, the city's lakes can be divided into 4 groups (Table 9).

Table 9: Division of lakes in Kazan into groups according to fish resources.

Group	Name
I	fish with rare species (more than 10 species)
II	fish with rich species diversity (4-10 species)
III	fish with background species, low species diversity (1-4 species)
IV	fishless

The background fish species for the lakes of Kazan are golden crucian carp, perch, silver crucian carp and roach, rare species are ruffe, pike, bream, and silver bream.

3 CONCLUSIONS

In general, for a more in-depth analysis and detailed calculations of ichthyoproductivity, it is necessary to conduct a study of the complex state of ichthyocenoses based on a set of geographical, hydrological, morphometric, hydrochemical, hydrochemical, hydrobiological parameters, including the influence of the trophic structure of the ecosystem, a detailed analysis of fish production, and a comparison of different methods and expert assessments.

The proposed methodology for assessing the effectiveness of strategies for the sustainable development of smart cities using the example of the dynamically developing agglomeration of Kazan based on the determination of the natural multiplier for assessing the state of water bodies - ichthyoproductivity as a function of the objective state of zooplankton and zoobenthos - makes it possible to quickly assess the ecological state of water bodies of urban development. Based on the data obtained, an assessment of ichthyoproductivity was carried out and a conclusion was made about the effectiveness of the implementation of the city's environmental strategy in general and water protection measures in particular. The presented results of monitoring studies of water bodies in the Kazan agglomeration revealed the need to take a set of operational measures to maintain and restore the ecological state of the city's water framework.

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