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PHYTOPLANKTON FORMATION UNDER CONDITIONS OF DIFFERENT TYPES OF POLLUTION AND CHANGES IN THE WATER QUALITY OF THE VOGHJI RIVER (REPUBLIC OF ARMENIA)

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An assessment of the ecological state of the Voghji River and its catchment basin according to chemical and biological indicators in the period 2018–2019. New taxa were discovered in phytoplankton, when contaminated with heavy metals and organic substances. A decrease in community stability and an increase in the role of Cyanoprokaryotes and green algae in plankton were observed, which can be used for phytoremediation of the degraded ecosystem of the Voghji River.

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***Keywords*:** Cyanoprokaryota, heavy metals and organic substances, phytoremediation, Shannon index, environmental and economic conflict.

Introduction. The Voghji River (Araks River Basin) is a part of the Southern Basin of the RA Water Authority, where it undergoes a serious heterogeneous anthropogenic pressure from settlements and mining and metallurgical activities on its catchment. Voghji River (length 82 *km*, in the territory of RA 56 *km*, catchment area is 1175 km^2), originates from the southwestern slope with a height of 3530 *m*. The main tributaries of the river are Geghi River the length of 30 *km*, the left tributary – Achanan River – 29 *km* and Artsvanik River the length of 17 *km* (see Fig. 1). Particular risks are associated with the Norashenik and Artsvanik tailings ponds located on the river's catchment and filled with hazardous metallurgy waste containing heavy metals: Al, Fe, Cu, Mn, Mo, Pb, Zn and Au [1, 2]. As a result of the widespread impact of climate change, risks associated with the vulnerability of water resources, in particular those such as the Voghji River, which are in areas of environmental and economic conflict, increase. Studies of the vulnerability the ability to adapt of water resources in the Republic of Armenia to climate change, carried out in by UNDP in Armenia and "Pure Energy and Water" (2015), that the most vulnerable are Ararat Valley and Syunik marz, where higher warming is observed than in the rest of the country. According to forecasts built for all seasons of climatological models, the annual temperature will rise by 4–7°C by the end of the XXI century [3]. Assessing the ecological health of rivers and streams is a fundamental and increasingly important water management issue worldwide and

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relates directly to the preservation of ecosystem services of aquatic resources [4, 5] The concept of ecosystem services embraces those processes by which the environment produces resources that we often take for granted, such as clean water and other services, the maintenance of biodiversity, mitigation of drought and floodsand, detoxification and decomposition of wastes [6]. Assessment of hydrobiocenoses of phytoplankton, the main component of aquatic ecosystems, and identification of taxonomic composition and quantitative metrics (number of species, diversity indices, taxonomy ratio) or environmental metrics such as habitat preferences, measures of tolerance / intolerance, etc., are widely used to assess river loads [7, 8]. It is believed that an increase in the environmental load is associated with a decrease in diversity caused by the dominance of tolerant species, but an increase in stress levels (e.g. pollution) can either increase or decrease diversity [9]. Therefore, changes in phytoplankton metrics and the obtained data can be estimated by comparisons between sites along the spatial pollution gradient, relative to reference conditions, or relative to historical data [10, 11]. The presence of heavy metal ions can both stimulate the growth of microalgae and cyanobacteria in phytoplankton and also have an inhibitory effect, depending on the specific ion. Numerous studies of metal toxicity show that some metal ions contribute to the growth of algae, for example: Fe and Ca, and the presence of Cu, Pb and Cd cause growth inhibition. Thus, algal cells have varying degrees of tolerance to the ions of these metals [12, 13]. The main risk of a Cyanobacterial bloom in freshwater ecosystems is that bloom-associated cyanobacteria can produce several cyanotoxins, such as hepatotoxin, microcystin, that can cause liver diseases and many other risks to human and animal health [14, 15].

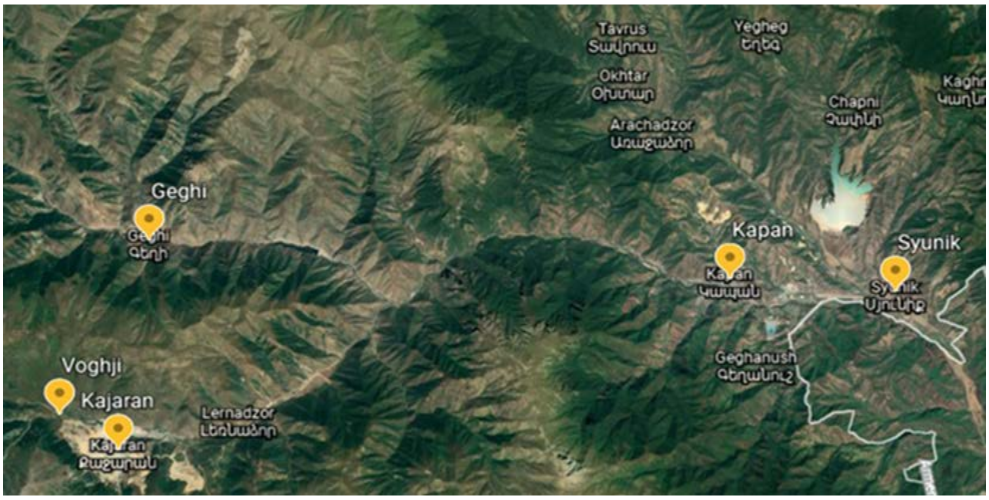

Fig. 1. Map of Voghji River sampling site.

Materials and Methods. Phytoplankton community in the Voghji River was investigated in Spring, Summer and Autumn period of 2018–2019. Samples (totally over 80 samples) was taken from the next river sites: 1 – Voghji R. industrial water intake; 2 – Voghji R. from to "ZCMC" CJSC industrial zone; 3 – from Sakhkar Su River, before mixture with Voghji River; 4 – outfall of Achanan (Norashenik) River; 5 – from Voghji River after Kajaran town; 6 – Voghji River before "Voghji" TFS;

7 – Voghji River before mixsture with Achanan (Norashenik) River; 8 – Achanan (Norashenik) River, after mixture with effluent N4 of "Artsvanik" TFS; 9 – after mixing Voghji and Achanan (Norashenik) Rivers.

Water chemistry data are provided by SNCO (Environmental Monitoring and Information Center) [16]. A method for studying quantitative and qualitative indicators of phytoplankton and calculation of indices is described in detail [2, 17].

Results and Discussion. According to studies of the chemical composition of water by the Environmental Monitoring and Information Center SNCO The water quality of the whole river above the city of Kajaran is rated "good" (2nd grade), below the city of Kajaran – "unsatisfactory" (4th grade), conditioned by ammonium ions and molybdenum, above the city of Kapan – "moderate" (3rd class) due to molybdenum, cobalt, iron and aluminum. Below Kapan airport, "bad" (5th grade), conditioned by manganese and cobalt. The water quality of the Achanan (Norashenik) River has been assessed as "average" (3rd grade) in the area above the village of Achanan, due to vanadium, cobalt, iron and aluminum. with vanadium and potassium. In general, according to chemical parameters, the presence of severe pollution by organic substances and heavy metals in the Voghji River and its tributaries is observed. According to the conclusion of the "Environmental Monitoring and Information Center" SNCO, compared with the data of 2018, in 2019 no significant changes in water quality indicators were observed [16].

Studies of aquatic ecosystems of different regions of the Republic of Armenia under anthropogenic pressure have made it possible to assess their status by various indicators, including phytoplankton. Phytoplankton reflects the ecological state of the aquatic ecosystem, and can also be used as an environmentally friendly component for phytoremediation of contaminated waters [18–20, 22].

In the period from 2018–2019. the development of phytoplankton was not uniform across the seasons, in different parts of the river. In May 2018, cyanobacteria dominated in phytoplankton of Voghji River in terms of quantity, they accounted for 49%, in biomass, dominants of the community were diatoms – 58%. In July, diatoms became dominant – 49 and 40% in number and biomass, and the role of large-cell green species (9% and 30%), such as *Spirogira tenuissima* (120 000 cells/*L*; 2.4 g/m^3), was 25 and 75% of the quantity and biomass of the community, individual species of this family are persistent indicators of water pollution by heavy metals [23]. In autumn, the dominant indicators in terms of quantity and biomass were diatoms, constituting 58 and 56%, an increase in yellow green algae was observed: 11 and 29%. A feature of the development of algae in 2018 was that in autumn favorable conditions were observed for the development of green *Zygnema sp.*, which accounted for 66% of the quantity and 92% of the biomass (664 000 cells/*L* and 13.28 g/m^3) of the community, which had not previously been noted in plankton Voghji River. This type is common in freshwater, when saturated with nitrates and phosphates ("nutrients"). Algae of this genus are widespread in rivers, small streams, and even in sewage, with pH 5–6 [24]. Thus, the development of phytoplankton in 2018 was characterized by the maximum quantitative indicators in the fall, the expansion of diversity in the group of cyanobacteria and diatoms, as well as the development of large-cell species, indicators of pollution from the family of zygnemous (green algae). In the spring of 2019, the dominant group of phytoplankton was blue-green algae: 64 and 50%, in terms of number and biomass. Mass development of Cyanoprokaryotes was observed, colonial prevailed: *Aphanothece clathrata, Microcystis aeruginosa, M. wessenbergii, Pleurocapsa minor, Phormidium foveolarum, Dolichospermum (Anabaena) spiroides, Dolichospermum (Anabaena) flos-aquae, Oscillatoria lacustris, Oscillatoria agardgii, Spirulina platensis.* The species *Lyngbia limnetica*, which is sensitive to low pH 5–6, was first discovered in spring [25]. The summer dominants were diatoms: 40 and 52%, the subdominants of the community were blue-green in number – 34%, and green algae were 31% in biomass. Green algae were not observed at all sampling sites, however, the development of the large-cell species *Ulotrix zonata*, which accounted for about 50% of the phytoplankton biomass in the summer, contributed to an increase in the role of green algae. In summer, in terms of quality indicators, diatoms of *Cymbella helvetica Diatoma hiemale, D. vulgare, Fragilaria capucina, F.construens, F. crotonensis, Gomphonema angustatum, G. olivaceum, Navicula cryptocephala, N. pupula, N. radiosa Pinnularia gibba, Rhoicosphenia curvata, Stauroneis anceps, Surirella robusta, Synedra acus*, the species *Neidium iridis* was first observed. In autumn, the development of large-cell green species *Treuboxia humicola, Ulothrix subtillissima, Ankistrodesmus pfitzerii, Closterium ehrenbergii, Selenastrum gracile, Chaetophora pisiformis* continued, which contributed to an increase in green algae in plankton and they accounted for 14 and 21%. The dominants of the community in terms of number – 41% were blue-green, and biomass diatoms – 50%.

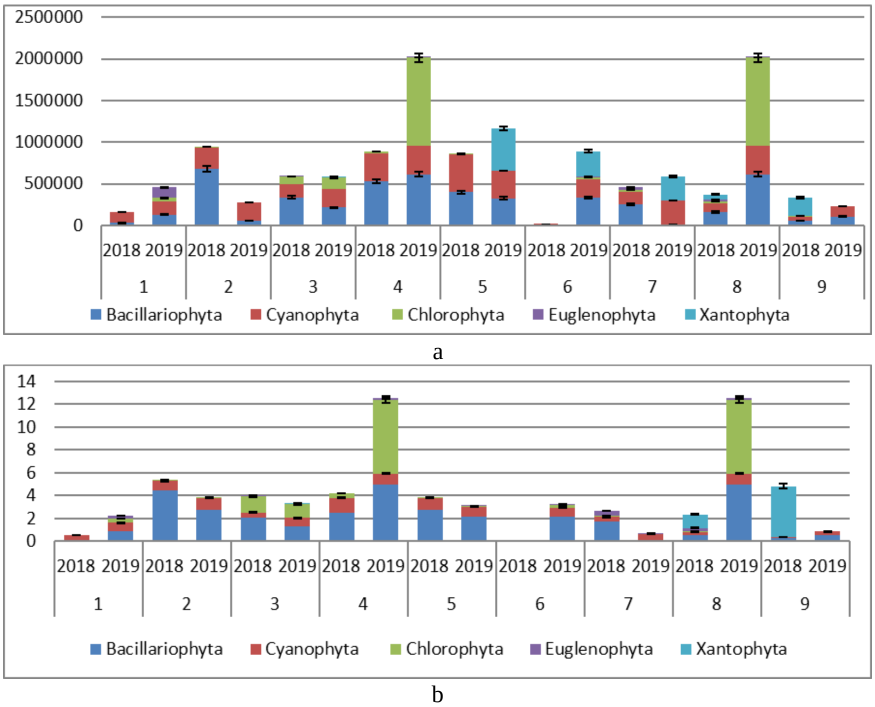

Fig. 2. Dynamics of phytoplankton development at the Voghji River observation points a) by quantity (cell/*L*) and b) by biomass (g/m^3).

In the autumn period of 2019, as well as in 2018, an increase was also observed in the proportion (1 and 3%) of the euglena algae *Phacus oscillans, Trachelomonas oblonga, Trachelomonas volvocina* and yellow-green species *Tribonema vulgare, T. monocloron* and *Gonatozigon brebissonii* (noted for the first time) in community composition.

In general, the dynamics of phytoplankton in different seasons, at different points of sampling, had an uneven distribution of quantitative indicators, the maximum quantity and biomass were recorded in 2019 in points 4 and 8, the minimum indicators in 2018 point 6, as shown in Fig. 2.

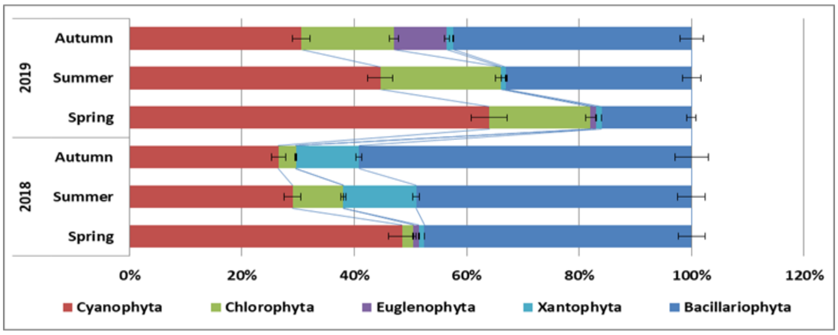

Fig. 3. Comparative analysis of the ratio (%) of the dominant Voghji River phytoplankton groups in different seasons (Spring, Summer, Autumn) 2018–19.

The average quantity and biomass of phytoplankton in 2018 amounted to 509 629 cells/*L* and 3.05 g/m^3, and in 2019 – 653629 cells/*L* and 2.38 g/m^3, respectively. Phytoplankton dynamics in 2019 revealed that the development of algae as a whole, repeated the dynamics of their development in 2018, however, had its own characteristics, for example, in plankton, an increase in the role of blue-green and green algae was observed against a background of a decrease in the dominant role of diatoms (Fig. 3).

Seasonal changes in dominant groups in different years were also expressed by species successions, a decrease in the proportion of individual species, the appearance of new species, as well as the loss (due to pollution) of some of the phytoplankton composition. However, from an environmental point of view, dominant complexes, which include species from different groups of algae, play a large role in predicting changes (see Table).

In the period from 2018–19, more than 125 species were found in the phytoplankton of Voghji River, massively met and were of great importance in 2018 – 89 species, in 2019 – 95 species. From mass species noted in 2018 – 79%, and in 2019 – 95% of the total number of species, were indicators of pollution. β-mesosaprobic species dominated, which corresponds to an average degree of contamination, but p-polysaprobic and α-mesosaprobic indicators were found (Fig. 4).

The river phytoplankton diversity status, expressed as Shannon-Wiener diversity index, is presented in Fig. 5. According to the index values, the loss of phytoplankton diversity generally was registered in data of 2019 (1.4–1.6), compared with 2018 (1.5–2). Shannon Index figures for 2016 amounted to 1.2–2.4 and in 2017 from 0.8 to 2.5 [26].

The composition of mass species (abundance of more than 10%) included in the dominant complexes of Voghji River in different seasons of 2018–2019

Dominant complex of algae	Spring	Summer	Autumn
2018	*Spirulina abbreviata, Oscillatoria geminata, O. formosa, Coelosphaerium kuetzingianum, Pleurocapsa minor, Phormidium foveolarum, Melosira granulate, Diatoma hiemale, Cocconeis placentula, Trachelomonas volvocina*	*Aphanotece clathrata, Oscillatoria breviis, Fragilaria crotonensis, F. capucina, Chaetophora elegans*	*Aphanotece clathrata, Phormidium inundatum, P. foveolarum, Oscillatoria agardhii, O. geminata, Achnanthes minutissima, Epitemia arcus, Navicula radiosa, N. garcilis, Diatoma hiemale, Gomphonema olvaceum, Cymbella lanceolata, Rhoicosphenia curvata, Fragilaria crotonnsis, Nitzschia palea, Zygnema sp., Trachelomonas oblonga*
2019	*Anabaena flos-aquae, A. spiroides, Oscillatoria agardhii, Spiruluna platensis, Phormidium foveolarum, Diatoma hiemale, Cocconeis placentula, Rhoicosphenia curvata, Tribonema monocloron, Binuclearia lauterbornii, Oocystis solitaria*	*Phormidium foveolarum, P. retzii, Oscillatoria chlorina, Spirulina abbreviata, Microcystis aeruginosa, Diatoma hiemale, Navicula cryptocephala, N. radiosa, N. pupula, Stauroneis anceps, Neidium iridis, Nitzschia linearis, Chaetophora elegans, Dictyosphaerium pulchellum*	*Aphanizomenon flos-aquae, Merismopedia elegans, Anabaena constricta, Oscillatoria agardhii, Spiruluna platensis, Spirulina abbreviate, Phormidium foveolarum, Melosira granulata, Didymosphenia geminata, Ceratoneis arcus, Tribonema monocloron, T. vulgare, Ulothrix subtillissima, Chaetophora pisiformis*

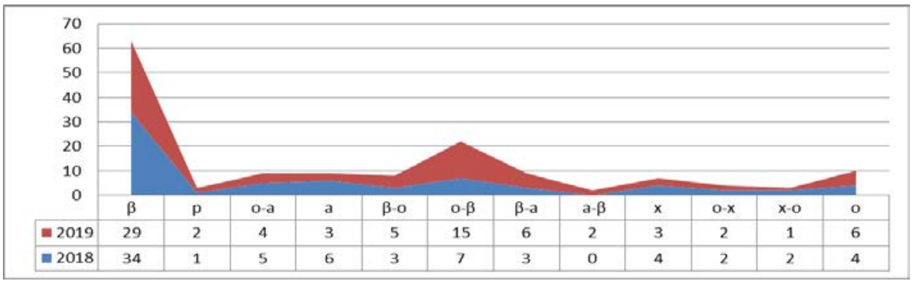

Fig. 4. The number of pollution indicators in the phytoplankton of Voghji River, in 2018–2019.

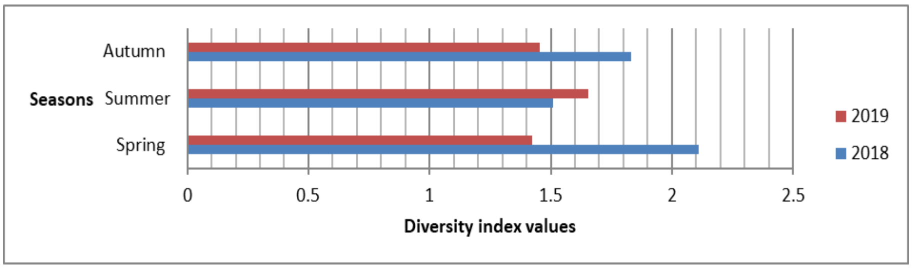

Fig. 5. Shannon-Wiener diversity index values of phytoplankton in the Voghji River.

Conclusion. High quantitative metrics of phytoplankton of Voghji River indicate the presence of a large number of tolerant species of microalgae that can develop under anthropogenic press. The results of hydrobiological studies can be used to replenish the database with the effective management of aquatic ecosystems. Taking into account the seasonal variability and stability of phytocenes, the increasing role of cyanoprokaryotes and green algae, as well as the discovery of new taxa, can be used for phytoremediation of the degraded Voghji River ecosystem.

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Լ. Ռ. ՀԱՄԲԱՐՅԱՆ

ՈՂՋԻ ԳԵՏԻ (ՀԱՅԱՍՏԱՆԻ ՀԱՆՐԱՊԵՏՈՒԹՅՈՒՆ) ՏԱՐԱԲՆՈՒՅԹ ԱՂՏՈՏՄԱՆ ԵՎ ՋՐԻ ՈՐԱԿԻ ՓՈՓՈԽՄԱՆ ՊԱՅՄԱՆՆԵՐՈՒՄ ՖԻՏՈՊԼԱՆԿՏՈՆԻ ԶԱՐԳԱՑՈՒՄԸ

2018–2019 թթ. իրականացվել է Ողջի գետի և նրա ջրհավաք ավազանի էկոլոգիական իրավիճակի գնահատում ըստ քիմիական և կենսաբանական ցուցանիշների: Օրգանական նյութերով և ծանր մետաղներով աղտոտվածության պայմաններում ֆիտոպլանկտոնի կազմի մեջ հայտնաբերվել են նոր տաքսոններ: Նկատվել էր համակեցության կայունության նվազեցում և ցիանոպրոկարիոտա և կանաչ ջրիմուռների դերի ավելացում պլանկտոնում, ինչը կարող է օգտագործվել Ողջի գետի քայքայված էկոհամակարգի ֆիտոռեմեդիացիայի համար:

Л. Р. ГАМБАРЯН

ФОРМИРОВАНИЕ ФИТОПЛАНКТОНА В УСЛОВИЯХ РАЗНОТИПНОГО ЗАГРЯЗНЕНИЯ И ИЗМЕНЕНИЯ КАЧЕСТВА ВОДЫ РЕКИ ВОХЧИ (АРМЕНИЯ)

Проведена оценка экологического состояния р. Вохчи и ее водосборного бассейна по химическим и биологическим метрикам в период 2018–2019 гг. При загрязнении тяжелыми металлами и органическими веществами в фитопланктоне были обнаружены новые таксоны. Наблюдалось снижение стабильности сообщества и повышение роли в планктоне цианопрокариот и зеленых водорослей, что может быть использовано для фиторемедиации деградировавшей экосистемы реки Вохчи.