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Research Article

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Influence of Hydrometeorological Conditions on Methane Content and Emission in the Ivankovo Reservoir During the Summer Period

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ABSTRACT
The Ivankovo Reservoir, part of the Volga-Kama cascade, serves as a key source of greenhouse gas emissions, particularly methane (CH_4), which has a global warming potential 28 times that of CO_2. The present study investigates the impact of hydrometeorological conditions on methane content and emission during summer periods from 2020 to 2024. Key parameters influencing methanogenesis—temperature, precipitation, water levels, flow rates, and oxygen levels—exhibited marked variability: air and water temperatures rose from averages of 20°C (2020) to peaks of 25-30°C (2024), with amplitudes increasing by 50% due to prolonged heatwaves; precipitation was uneven, ranging from droughts (e.g.,<50 mm/month in July 2022) to peaks (243 mm/month in July 2023), correlating with flow variability (exchange coefficients 0.85-1.13, lowest in dry years); water levels declined to 121 m BS in 2022/2024, fostering hypoxia (<2 mg/L O_2 in 70% of bottom waters by 2024 vs. 30% in 2020). These conditions enhanced methanogenesis in hot, dry, low-flow periods by promoting anoxic sediments and organic matter accumulation, yielding peak concentrations (up to 2432.7 µg/L) and fluxes (up to 33967 mg CH_4 m^{-2} day^{-1}). Conversely, wet, high-flow periods increased aeration and dilution, suppressing emissions by up to 80%. Spatial differentiation across zones revealed higher methanogenesis in shallow, organic-rich floodplain and macrophyte areas (e.g., 138.9 µg/L vs. 47.2 µg/L in channel at Shosha, June 2024) compared to sandy channel zones like Gorodnya (15.4 µg/L average); lake-like, low-flow zones such as Korcheva showed 2-5x higher bottom concentrations due to persistent anoxia. Macrophytes contributed significantly via aerenchyma transport, amplifying fluxes in vegetated shallows. Total emissions ranged from 1.38 t CH_4 day^{-1} (May 2023) to 151.94 t CH_4 day^{-1} (August 2024). Balance calculations indicate sediment release as the primary input (up to 674 t CH_4 day^{-1} in August 2024), with net accumulation in hypoxic conditions. Findings highlight the need for water level management to mitigate emissions amid climate change.

Keywords: Methane, Greenhouse Gas Emission, Reservoir Hydrology, Hypoxia, Macrophytes

Introduction

The Ivankovo Reservoir, located on the Volga River at the border of Moscow and Tver regions, was created in 1937 and plays a crucial role in water supply for Moscow, hydropower generation, navigation, recreation, and fisheries. With a length of about 75 km, maximum width of 2-3 km, depth up to 17 m, and surface area of 327 km², it is one of Russia's shallowest large reservoirs, with over 60% of its area less than 2 m deep. The watershed spans 41,000 km², dominated by forests (39%), lakes (2.2%), and bogs (2.8%). Its water exchange coefficient averages 11, classifying it as a fast-flow seasonal regulation reservoir.

However, as an artificial water body, the reservoir is a significant source of methane emissions, formed under anaerobic conditions in bottom sediments by methanogenic archaea. Methane's global warming potential, 28 times higher than CO_2 over 100 years, makes studying its dynamics essential amid climate change and anthropogenic pressures. Emissions depend on hydrometeorological factors (temperature, precipitation, water levels, flow), morphology, sediment composition, and biological productivity.

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The goal of this study is to examine the influence of hydrometeorological conditions on methane content and emission in the Ivankovo Reservoir during summers 2020-2024. Tasks include:

- Analyze hydrometeorological conditions and their impact on methanogenesis.
- Assess spatiotemporal variability of methane concentrations in water
- Calculate specific fluxes and total emissions, differentiating by compartments (channel, floodplain, macrophytes).
- Determine balance components, including tributary inflows and canal discharges.

Materials and Methods

Fieldwork focused on methane concentrations in water, fluxes at the water-atmosphere interface, and ecosystem parameters at 19 points across morphological zones (Gorodnya, Shosha, Konakovo, Korcheva, Dubna, Ploski). From 2020-2022, samples were taken only over the channel; from 2023, sampling included floodplain and macrophyte areas, with surveys in May and August (previously only August). In 2024, bottom sediment fluxes were added [1-3].

Methane fluxes were measured using floating chambers, a standard method for quantifying emissions. Chambers were placed on the water surface for 15-20 minutes, with 3-6 replicates per vertical to capture variability, especially bubble ebullition. Flux was calculated as:

$$Flux\_CH_4 = \frac{Conc\_finish - Cons\_start}{(Chamber\ area \times Exposure\ time)}[mg\,CH_4\,m^{-2}\,day^{-1}]$$

Methane concentrations were determined by headspace degassing: 40 mL water samples were drawn into 60 mL syringes, mixed with 20 mL atmospheric air, shaken for equilibration, and transferred to salt-saturated glass vials for transport. Atmospheric blanks accounted for background methane. Analysis used a Chromatec-Crystal 5000.2 gas chromatograph with flame-ionization detector.

Were used YSI ProODO, Kestrel 5500, Ruttner sampler, Ekman-Birge grab, with organic matter assessed by loss- on-ignition.

Emissions were computed by multiplying specific fluxes by compartment areas. Channel-floodplain separation used area curves F=f(z) for reservoir sections. Macrophyte area was estimated at 12% of total surface (split 6% emergent, 6% floating). Fluxes for each were weighted:

$$Weighted\ flux = \sum\left(\frac{Area_i - Flux_i}{Total\ area}\right)$$

Balance components included tributary inflows and canal discharges. Inflow volumes were multiplied by river-specific methane concentrations; outflows by canal concentrations. Lateral inflows used area-weighted averages.

Results and Conclusions

Hydrometeorological analysis showed increasing temperature amplitude (peaks 25-30°C in 2024 vs. 20°C in 2020) and variability, with hot summers (2022-2024) promoting hypoxia. Precipitation was uneven: peaks in July 2023 (243 mm/month) vs. droughts in 2022/2024. Water levels declined to 121 m BS in 2022/2024, reducing flow (exchange coefficients 0.85-1.13). Seasonal patterns included spring peaks (up to 3.84/month in April 2022) and summer minima (0.143/month in July 2023). Rising annual averages (0.882 in 2020 to 1.13 in 2024) indicate enhanced exchange, suppressing methanogenesis in wet periods via aeration but amplifying in dry, hypoxic conditions. Zone-specific variability underscored higher methanogenesis in floodplains and macrophyte beds (shallower depths, higher organic loading: 2-5x channel fluxes) versus channels, with lake-like zones (e.g., Korcheva) exhibiting persistent anoxia and elevated sediment-derived CH_4 due to low flow and silt accumulation. Methane concentrations varied spatiotemporally. In 2020-2022 (channel only), averages were lowest at Gorodnya (15.4 µg/L, sandy bottom) and highest at Korcheva (74.0 µg/L, lake-like zone). Bottom concentrations peaked in 2022 (369.9 µg/L at Korcheva) with hypoxia (<2 mg/L O_2). From 2023, including floodplain, concentrations rose in August 2024 (2432.7 µg/L bottom at Korcheva), driven by anoxia and heat. Floodplain values exceeded channel (e.g., 138.9 vs. 47.2 µg/L at Shosha, June 2024), due to shallower depths and organics.

Specific fluxes increased: 3.81-296 mg CH_4 m^{-2} day^{-1} in 2020-2021 to 1033 mg CH_4 m^{-2} day^{-1} (August 2024 at Shosha). Bottom fluxes in 2024 surged from 2.21-360 (June) to 73-33967 mg CH_4 m^{-2} day^{-1} (August), highest at Konakovo (deep, organic-rich). Total emissions rose from 4.78 t CH_4 day^{-1} (2020) to 151.94 t CH_4 day^{-1} (August 2024), peaking at Shosha (116 t CH_4 day^{-1}) and Korcheva. Macrophyte emissions contributed up to 14.45 t CH_4 day^{-1} (June 2024), with emergent vegetation dominant.

Balance for June 2024 showed sediment release 4.95 t CH_4 day^{-1}, surface emission 21.83 t CH_4 day^{-1}, tributary inflows 0.146 t CH_4 day^{-1}, canal discharges 0.034 t CH_4 day^{-1}, net accumulation/oxidation -16.77 t CH_4 day^{-1}. For August 2024: sediment 674 t CH_4 day^{-1}, surface 155 t CH_4 day^{-1}, inflows 0.118 t CH_4 day^{-1}, discharges 0.028 t CH_4 day^{-1}, net 519 t CH_4 day^{-1}. Tributaries added minimally; net positive in hypoxia indicates accumulation.

In conclusion, hydrometeorological conditions dominate methane dynamics: heat and drought enhance emissions via anoxia, while rain and flow suppress via aeration. Morphology amplifies variability-shallow zones and organics boost fluxes. Macrophytes significantly contribute. Monitoring and level regulation could mitigate emissions.

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