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Abstract. This article presents the results of visual and instrumental studies conducted at the Kattakurgan reservoir, which is characterized by alluvial properties and is located in the plains region of our Republic. To observe the seepage flow in the dam of the reservoir and determine the state of the depression curve, fluctuations in water levels in 38 piezometers installed within the dam body were monitored along alignment lines. The hydrological regime of the reservoir was analyzed, and the relationship between water level fluctuations in the piezometers located in the dam of the Kattakurgan reservoir and the water level in the upstream pool was established. Based on the conducted field studies, potentially hazardous sections of the dam were identified, the technical condition of soil layers was assessed using engineering-geophysical methods, the reliability of hydraulic structures was evaluated, and initial criteria for monitoring were formulated. Consequently, an efficient operating mode for the reservoir was developed, taking into account its seasonal nature and the multipurpose nature of its utilization.

Keywords: *Reservoir, operating mode, dam, profile, seepage, moistened zones, piezometer, drainage, alignment line, upstream pool, downstream pool.*

I. INTRODUCTION

Globally, the regulation of river flow through reservoirs and the adaptation of natural regimes to consumption patterns is considered one of the critical tasks in the integrated use of water resources. Particular attention is being paid to the reliable and efficient operation of existing reservoirs, the scientific substantiation of optimal operating regimes, and the provision of a consistent water supply to consumers during the vegetation period.

Today, in our Republic, extensive scientific research is being conducted on the construction of reservoirs, enhancing the efficiency and service life of structures, ensuring their reliable operation, implementing effective filling and emptying schedules, and identifying factors influencing the efficient use of water resources. In this regard, the development of novel hydrological and hydraulic calculation methods that enable the improvement and refinement of these processes is of great importance.

During reservoir operation, the safe utilization of the structures and equipment within the system, as well as the efficient use of the water stored in the reservoir, is crucial. Therefore, it is necessary to assess changes in the strength and stability of structures and ensure their integrity during reservoir operation.

The primary objective of this study is to develop an efficient operating regime for the Kattakurgan reservoir, taking into account its seasonal nature and multipurpose use. This involves determining the filling and emptying schedules in a manner that prevents threatening, hazardous, and emergency situations that could compromise the reliability of the structures.[1,2,16,18]

The area of this research was the operating regime of the existing alluvial Kattakurgan reservoir and the seepage processes within its dam body, selected as a case study to investigate the intensity of observed phenomena and to clarify the causes underlying their occurrence (Figure 1).

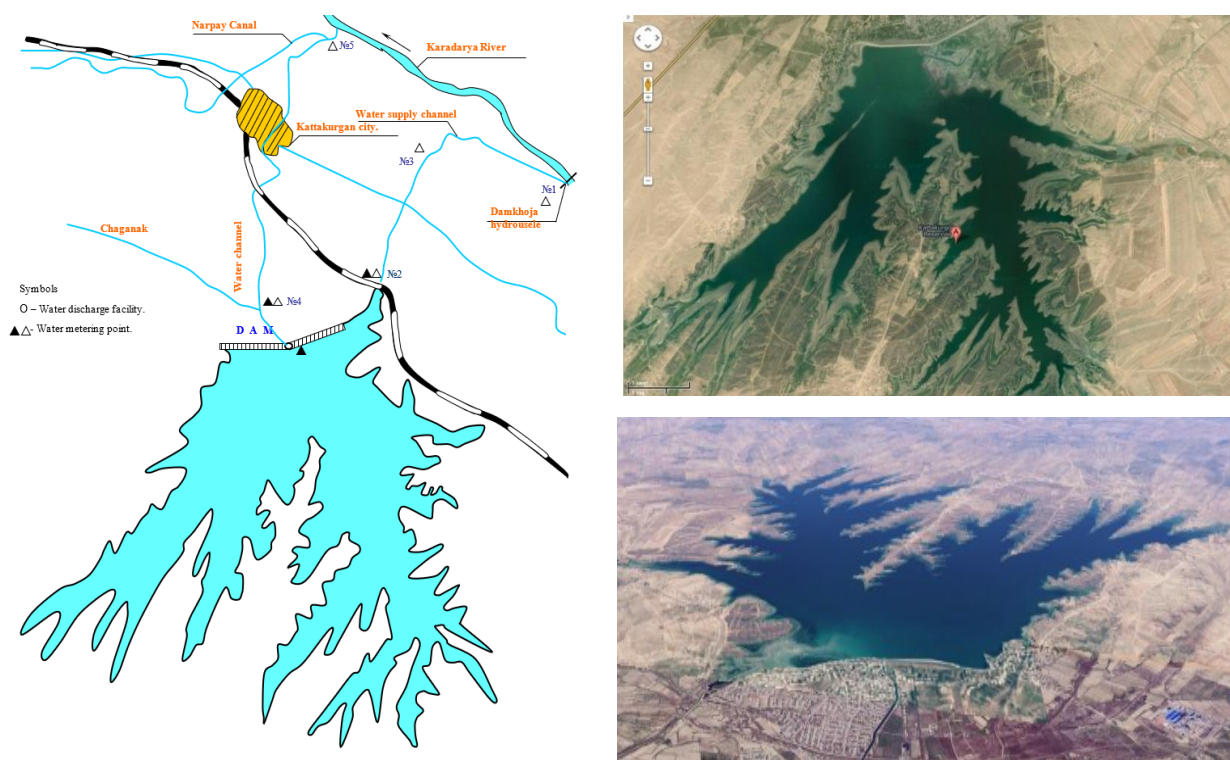


Figure 1. Layout scheme of the Kattakurgan reservoir

The Kattakurgan reservoir is located in the central part of the Republic of Uzbekistan, administratively within the territory of the Kattakurgan district of the Samarkand region. This reservoir is a major hydraulic engineering structure of significant importance for supplying water to the irrigated lands of the Samarkand and Navoi regions. It was constructed for the purpose of seasonal regulation of water resources in the Karadarya River basin and to meet irrigation needs during periods of water scarcity. Water is conveyed from the Damkhodzha hydraulic complex to the reservoir basin via a 22 km long supply canal. The location of the reservoir basin in the natural depressions of Shursoy and Uzunkuduk considerably enhances the water accumulation capacity under the natural geomorphological conditions. Filling of the reservoir commenced for the first time on January 27, 1941. At the initial stage, the reservoir's capacity was 100 million m³; by 1953, this indicator had reached 662 million m³. As a result of subsequent reconstruction works, the design maximum capacity of the reservoir was increased to 900 million m³ in 1981. The surface area covered by water at the Kattakurgan reservoir is 8,317 hectares, or 83.17 km². The reservoir plays a crucial role in supplying water to the irrigated lands in the Samarkand and Navoi regions. According to the initial

design, the reservoir was intended to irrigate 375,400 hectares of land. Following the increase in capacity to 900 million m³, the area of irrigated land expanded by an additional 24,000 hectares. Although fishing activities have not yet been established in the reservoir at present, various organizations have developed recreational areas along its coastal zones. This situation indicates that the reservoir also possesses significant recreational potential.[2,14]

II. METHOD AND MATERIALS

Results of Instrumental Observations on the Technical Condition of the Kattakurgan Reservoir.

The technical condition of the hydraulic structures of the reservoir was studied through visual and instrumental methods. Based on the results of visual observations, instrumental monitoring was carried out regarding the technical condition of the structures and equipment within the reservoir complex. The research utilized Georadar OKO-3, Aquaread AP-5000, and Analyzer DW-EX 7000 devices (Figures 2 and 3).



Figure 2. Aquaread AP-5000 device



Figure 3. DW-EX7000 Portable XRF Mineral Analyzer device

The Aquaread AP-5000 device is a professional, multi-parameter probe designed for rapid and accurate measurement of water quality. It is widely used for water quality monitoring in drinking water, rivers, lakes, marine environments, wastewater systems, and other water bodies.[17,18]

The technical specifications of the DW-EX7000 Portable XRF Mineral Analyzer are based on the analytical method of energy-dispersive X-ray

fluorescence. Its measurement range covers elements with atomic numbers from 12 to 92, and its detector can simultaneously analyze up to 40 elements.

During the field studies, samples were collected from the reservoir basin, from piezometers along each alignment line, and in front of the drainage spillway in the downstream pool where seepage water emerges. Samples were obtained from piezometers across all dam alignments using specially prepared containers (0.5 L), which were lowered into the piezometers. The following photographs (Figure 4) document the field observations conducted at the reservoir. [12,13]



Figure 4. Fragments of field observations conducted at the Kattakurgan reservoir.

Based on the instrumental observations, the degree of porosity of the dam body soils, alterations in concrete elements (joints, cracks), the rare (chemical) composition of waters accumulating in the reservoir basin and seeping through the dam body, as well as the turbidity levels of the seepage waters, were determined. The obtained data were subsequently analyzed.

Fluctuations in Water Levels within the Piezometers of the Reservoir Dam:

To ensure the long-term and safe operation of a reservoir dam, it is necessary to study and calculate the seepage occurring within it, specifically the depression curve. These calculations determine the seepage flow rate passing through the dam body and its foundation, the position of the depression curve, the height of its exit on the downstream slope of the dam, and the exit velocity.[5,7,14]

An analysis of water level fluctuations, based on observational data from the piezometers installed in the dam of the Kattakurgan reservoir, is presented in Figure 5.

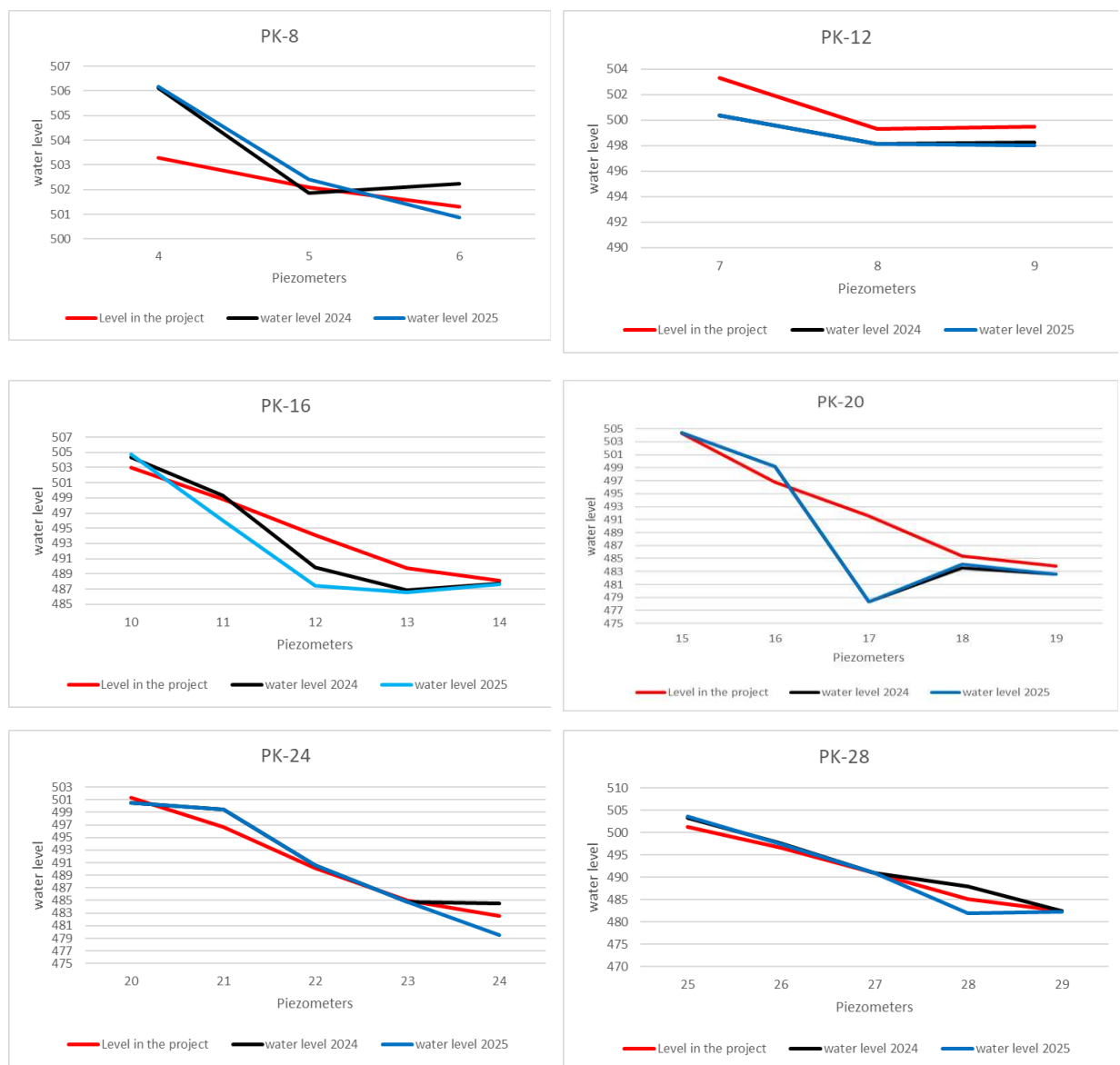


Figure 5. Fluctuation of water levels in piezometers relative to the upstream water level of the Kattakurgan reservoir dam

Analysis of the data obtained from instrumental observations at the Kattakurgan reservoir dam indicates that the water levels measured in the piezometers and the results obtained using the georadar device are consistent with one another. Notably, in piezometer No. 4 at alignment PK-8, No. 10 at PK-16, No. 16 at PK-20, No. 21 at PK-24, and No. 25 at PK-28, water levels are elevated by 1 to 3 meters relative to the design values. Conversely, in piezometer No. 5 at PK-8, No. 12 at PK-16, and No. 17 at PK-20, water levels are lower compared to the design levels.

The height of capillary rise of water above the depression curve depends on the particle size of the soil. In sandy soils, this rise can range from 0.1 to 0.4 m; in clayey soils, it may vary between 0.5 and 3.0 m or even higher. In the dam of the Kattakurgan reservoir, a zone of capillary water rise exists above the depression curve. The soil situated below the depression surface becomes saturated with water and remains in a suspended state, which consequently reduces the stability of the dam slopes.[4,8]

III. RESULT AND DISCUSSION

As part of the field research, periodic water sampling was carried out from the water accumulated in the reservoir basin, from all piezometers installed in the dam, and from the seepage water emanating from the drainage system at the downstream toe. These samples were subjected to chemical analysis, and the results were comparatively evaluated. Specifically, changes in the chemical composition of water as it moves through the sequence of structures were assessed based on the comparative analysis of indicator substances present in the water within these structures.

Variation in Total Dissolved Solids (TDS): The results of the 2025 studies indicate that the concentration of dissolved salts in the water within the piezometers located in the dam of the Kattakurgan reservoir and downstream from it can increase by a factor of 2.0 to 7.0 compared to the water in the reservoir basin. Specifically, TDS values rose from 0.35 g/L to between 1.4 and 1.5 g/L. According to the results of studies conducted in 2015, the TDS content in the

piezometers varied from 0.55 to 1.6 g/L; by 2025, these parameters had changed (Figure 6).

Variation in Chloride Content: According to the results of field studies conducted in 2015, the chloride content in the water of the piezometers exceeded that in the reservoir basin water by a factor of 1.2 to 4.0. In this case, while the chloride content in the reservoir basin water was 0.035 g/L, an increase to 0.08–0.1 g/L was observed in piezometers No. 3 and No. 15, whereas a decrease to 0.06 g/L was recorded in the drainage water. During the continued field studies in 2025, the chloride content in the reservoir basin water was 0.0355 g/L, while in piezometers No. 3–15 it varied between 0.084 and 0.101 g/L (Figure 7).

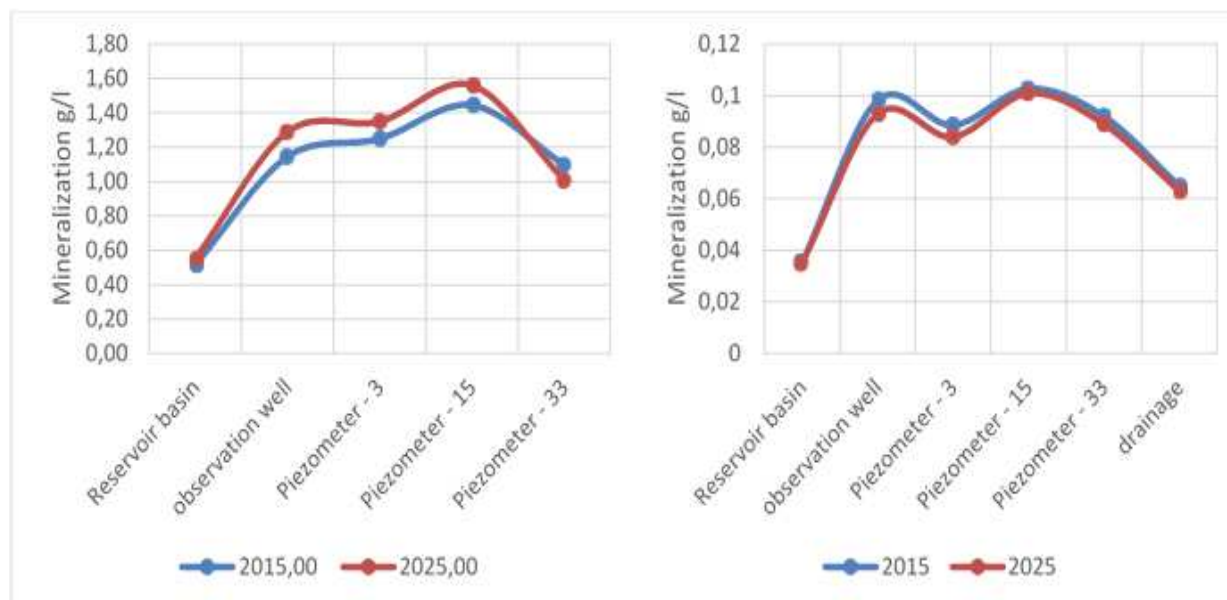


Figure 6. Variation in the total dissolved solids (TDS) content of waters in the reservoir (2015-2025). **Figure 7. Variation in the chloride content of waters in the reservoir (2015-2025).**

Thus, the results of studying the changes in the chemical composition of seepage waters in the basin and structures of the Kattakurgan reservoir, conducted within the framework of field research, indicate that the concentration of dissolved salts and their constituent ions in the waters seeping through the dam and downstream structures is approximately 2-3 times higher compared to the water in the reservoir basin.[3,5]

To prevent the impact of the aforementioned issues, it is essential to identify circumstances that could lead to threatening, hazardous, and emergency situations compromising the reliability of the reservoir structures. Furthermore, it is necessary to ensure that the water volume does not exceed the designated level, guarantee water exchange, and implement the reservoir's operating regime with absolute precision.

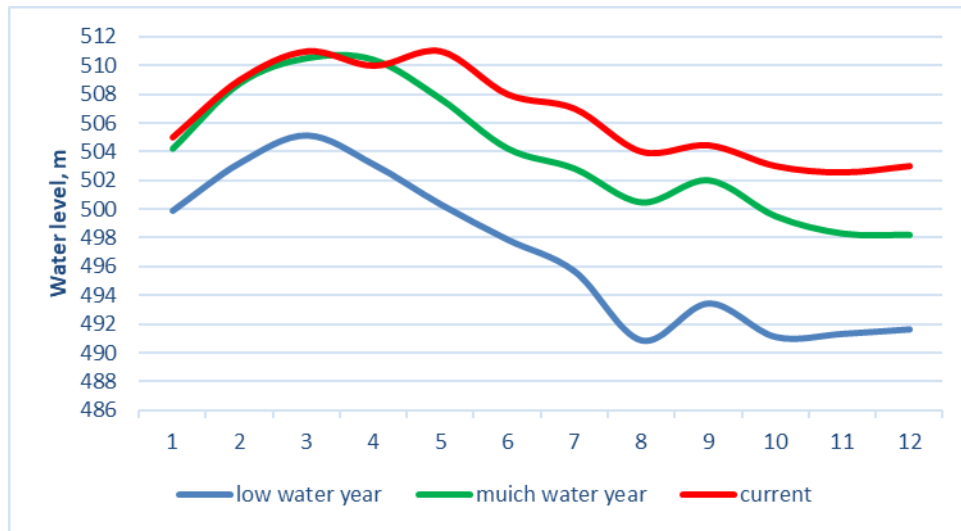


Figure 8. Actual and proposed operating regimes of the Kattakurgan reservoir (for years with different water availability)

In developing the reservoir's operating regime, it is important to consider the natural and technical characteristics of the reservoir, the river flow supplying it, the volume of water accumulated in the reservoir by the beginning of the year, and the plan for water delivery to consumers during the accounting year. An analysis of the actual operating regime of the Kattakurgan reservoir during its operation in recent years has been carried out. This analysis revealed that the reservoir has been maintained at high water levels (505-510 m) for several years, with the drawdown depth amounting to only 2-5 m (Figure 8). This partial (low-amplitude) fluctuation of the reservoir water level affects the movement of seepage water through the dam body and its deviation from the design depression curve. Maintaining the water level at high elevations over many years has led to a rise of 1-3 meters in water levels within piezometers located near the crest of the dam, compared to design levels. This situation may negatively impact the assurance of dam stability.[1,2]

Based on the analysis of long-term research, an efficient operating regime for the filling and emptying of the Kattakurgan reservoir has been developed. This regime takes into account all variable hydrological conditions at the beginning of the year (components of inflow and outflow, water exchange, changes in morphometric indicators, and others), as well as the periodicity of time intervals. The utilization of the developed operating regime will ensure the reliable water supply to all consumers. In water-scarce years, it will mitigate the negative impact of limited water supply by redistributing water to minimize economic damage. In water-abundant years, it will enable the safe operation of the reservoir.

IV. CONCLUSION

Based on the visual and instrumental observations conducted at the Kattakurgan reservoir, involving the study of dam strength and internal voids using georadar devices, as well as the assessment of the aggressiveness of seepage flow waters towards the structures within the dam body, the following conclusions have been drawn:

Understanding the regularities governing the movement of seepage water through the dam body and its impact on structural elements is of significant importance for ensuring the stability of the reservoir dam and its components, particularly for assessing the aggressiveness of the seepage flow towards these elements.

1. The results of instrumental observations at the Kattakurgan reservoir dam indicate that maintaining high water levels in the reservoir for several years has led to a rise of 1-3 meters in water levels within piezometers located near the dam crest, compared to design levels. This situation may negatively impact the assurance of dam stability.
2. Based on its water quality, the water in the Kattakurgan reservoir basin is classified as sulfate-aggressive and alkaline-aggressive towards ordinary cement concrete structures, accelerating the corrosion of structures within the dam.

3. Continuous monitoring of the main characteristics of the reservoir (both natural and technical) and the design parameters of its structures is necessary, in accordance with regulatory documents.
4. Considering the seasonal classification of the reservoir regarding flow regulation and its multi-purpose utilization, the filling and emptying operations should be carried out in compliance with the periodicity of time intervals (autumn, spring). This requires identifying and preventing threatening, hazardous, and emergency situations that could compromise the reliability of the structures.
5. During reservoir operation, it is essential to ensure that the water volume does not exceed the designated level and to implement the reservoir's operating regime with absolute precision. The rates of water level rise and drawdown must not exceed standard values (filling rate for upper layers: - 0.25...0.5 m/day; for the surface 2-3 m layer: -0.05...0.1 m/day; drawdown rate for high levels: -0.3 m/day, medium: -0.5 m/day, low levels: -1.0 m/day).

The conducted studies demonstrate that concrete results are achieved when utilizing the recommendations from the research work titled "Study of the Strength and Internal Voids of the Kattakurgan Reservoir Dam Using Georadar Devices and Development of Measures to Eliminate the Risk of Failure." The application of these findings in the practice of reservoir operation will help prevent malfunctions and emergency situations, further enhancing and improving the reliability of reservoir operation. This will, in turn, lead to efficient use of the stored water and ensure a guaranteed water supply to consumers.

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Data Availability

№3. All data generated or analysed during this study are included in this published article and its supplementary information files.

Ethics approval and consent to participate

This study did not involve human participants, human data, or human tissue. Therefore, ethics approval and consent to participate are not applicable.

Consent for publication

This manuscript does not contain any individual person's data in any form (including individual details, images, or videos). Therefore, consent for publication is not applicable.