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APPLICATION OF INSAR TECHNOLOGY FOR MONITORING OF THE SHERUBAY-NURA RESERVOIR DAM

Abstract. This paper investigates the potential of multi-temporal satellite radar interferometry for monitoring the deformation state of the Sherubay-Nura Reservoir dam. Spatial and temporal displacements of the structure were assessed using the SBAS-InSAR approach based on Sentinel-1 satellite imagery. Trihedral corner reflectors were employed to improve the reliability of interferometric measurements by ensuring stable identification of reference points. The analysis enabled the identification of localized deformation zones and the assessment of displacement rates and their temporal evolution, demonstrating the effectiveness of integrating InSAR technology with corner reflectors for the remote monitoring of hydraulic structures.

Key words: SBAS-InSAR, satellite radar interferometry, Sentinel-1, earth-fill dam, deformation monitoring, corner reflectors, geodetic monitoring.

Шерубай-Нұра су қоймасы бөгетінің мониторингінде InSAR технологиясын қолдану

Аннотация. Мақалада Шерубай-Нұра су қоймасы бөгетінің деформациялық жағдайын мониторингінде көпұақытты спутниктік радиолокациялық интерферометрия технологиясының мүмкіндіктері қарастырылған. Sentinel-1 спутниктік түсірілімдері негізінде SBAS-InSAR әдісін қолдану арқылы құрылыстың кеңістіктік-уақыттық ығысуларына бағалау жүргізілді. Интерферометриялық өлшеулердің сенімділігін арттыру мақсатында бақылау нүктелерін тұрақты сәйкестендіруді қамтамасыз ететін ұшқырлы бұрыштық шағылдырғыштар пайдаланылды. Жүргізілген талдау деформациялардың жергілікті аймақтарын анықтауға, ығысу жылдамдықтары мен олардың даму сипатын бағалауға мүмкіндік берді және гидротехникалық құрылыстардың деформациялық жағдайын қашықтан мониторингінде InSAR технологиясы мен бұрыштық шағылдырғыштарды бірлесіп қолданудың тиімділігін растады.

Түйінді сөздер: SBAS-InSAR, спутниктік радиолокациялық интерферометрия, Sentinel-1, жер бөгеті, деформациялар мониторингі, бұрыштық шағылдырғыштар, геодезиялық мониторинг.

Применение технологии InSAR для мониторинга дамбы Шерубай-Нуринского водохранилища

Аннотация. В статье рассмотрены возможности многовременной спутниковой радиолокационной интерферометрии для мониторинга деформационного состояния дамбы Шерубай-Нуринского водохранилища. На основе метода SBAS-InSAR по данным спутниковой съемки Sentinel-1 выполнена оценка пространственно-временных смещений сооружения. Для повышения надежности интерферометрических измерений использованы трехгранные угловые отражатели, обеспечившие устойчивую идентификацию контрольных точек. Выполненный анализ позволил выявить локальные зоны деформаций, оценить скорости и характер развития смещений, подтвердив эффективность совместного применения технологии InSAR и угловых отражателей для дистанционного мониторинга гидротехнических сооружений.

Ключевые слова: SBAS-InSAR, спутниковая радиолокационная интерферометрия, Sentinel-1, земляная дамба, мониторинг деформаций, угловые отражатели, геодезический мониторинг.

Introduction

Hydraulic structures are classified as critical infrastructure facilities whose safe operation largely depends on the timely detection and assessment of deformation processes. The development of settlements and horizontal displacements may reduce the operational reliability of a structure and increase the risk of structural failure. At present, the monitoring of earth-fill dams is primarily based on high-precision leveling, electronic total station surveys, and Global Navigation Satellite System (GNSS) observations. Although these methods provide high measurement accuracy, they yield information only at discrete control points, limiting the assessment of the spatial distribution of deformations over the entire surface of a structure and requiring regular field surveys.

One of the most promising approaches to remote deformation monitoring is Interferometric Synthetic Aperture Radar (InSAR). Modern multi-temporal InSAR (MT-InSAR) techniques, including Persistent Scatterer Interferometry (PS-InSAR) and the Small Baseline Subset (SBAS) method, enable the estimation of line-of-sight (LOS) displacements, the generation of high-resolution deformation maps, and the analysis of deformation dynamics over time. Advances in time-series processing algorithms have substantially reduced the effects of atmospheric delays, temporal decorrelation, and noise, making InSAR one of the most effective tools for monitoring slowly evolving deformation processes affecting engineering structures [1].

A review of recent studies indicates that the application of InSAR has expanded considerably and now encompasses the monitoring of hydraulic structures, landslides, mining areas, transportation infrastructure, and urban environments [2].

A major milestone in the development of this technology was the launch of the Sentinel-1 satellite constellation, which provides regular revisit intervals, global coverage, and free access to archived SAR data. These capabilities have significantly enhanced the feasibility of long-term deformation monitoring without the need for continuous on-site field inspections. Recent investigations have demonstrated the high potential of MT-InSAR for monitoring various types of hydraulic structures. In the case of the Upper Atbara earth-fill dam, Sentinel-1 time-series analysis revealed the spatial heterogeneity of deformation across different sections of the dam [3]. For the Beninar Dam (Spain), the integration of MT-InSAR results with engineering modeling was shown to improve the effectiveness of comprehensive structural health assessment and provide a more reliable evaluation of dam stability [4]. Studies conducted on the Xiaolangdi and Banqiao dams (China) confirmed the capability of MT-InSAR to identify the spatial distribution of deformations, analyze their seasonal variability, and assess the influence of reservoir water-level fluctuations on displacement patterns [5, 6]. Similar findings have been reported for tailings dams, where multi-temporal interferometry enables the identification of zones affected by non-uniform deformation and facilitates the early detection of potentially hazardous geotechnical processes [7, 8].

Despite these advantages, published studies indicate that the application of InSAR is subject to several limitations. The quality of the derived deformation measurements is influenced by the coherence of the radar signal, satellite imaging geometry, the spatial resolution of SAR data, and the orientation of the displacement vector relative to the satellite line of sight. Consequently, the highest reliability is achieved through the integra-

phase unwrapping, the quality of the generated interferograms was assessed. Interferometric pairs characterized by low coherence and pronounced artifacts, including phase discontinuities, were excluded from further processing. When necessary, coherence threshold values were adjusted, after which the interferometric network was reconstructed using an updated set of image pairs. One of the key requirements for obtaining reliable results in interferometric processing is the presence of targets with stable radar backscattering characteristics within the study area. For this purpose, trihedral corner reflectors were installed as part of the study. The operating principle of a corner reflector is based on multiple specular reflections of the radar signal from mutually perpendicular surfaces, allowing a significant portion of the incident electromagnetic energy to be redirected back toward the satellite antenna. As a result, a bright and stable point target with a high radar cross-section (RCS) is formed in SAR images, clearly distinguishable from the surrounding surface. Aluminum was selected as the material for reflector fabrication due to its high electrical conductivity, which ensures efficient radar signal reflection through minimal energy losses during electromagnetic wave interaction with the surface, as well as its low weight and high corrosion resistance. The edge length of 1 m was selected considering the operating wavelength of the Sentinel-1 C-band radar system, ensuring reliable detection and stable identification of the reflectors during multi-temporal SAR data processing. Corner reflectors serve as reference ground targets, providing high signal amplitude and stable phase characteristics over time. Therefore, they are essential for the calibration and georeferencing of satellite observations within InSAR monitoring applications. Each reflector was installed on an individual concrete foundation equipped with an adjustable inclination mechanism to ensure precise orientation toward the satellite (Figure 3). Monitoring of the reflectors across a series of SAR acquisitions confirmed the stability of signal amplitude and phase consistency over time, enabling their application for: internal calibration of deformation time series; external validation of InSAR measurement accuracy; ensuring metric consistency between satellite-derived data and ground-based observations.

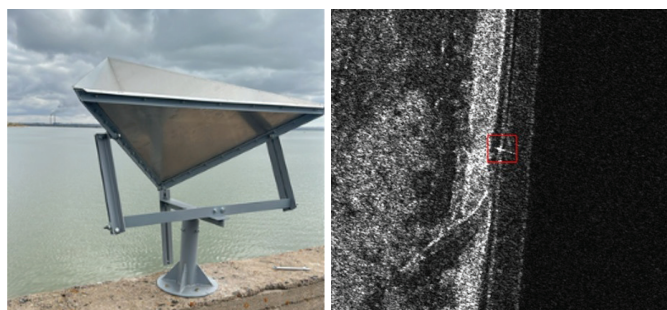


Figure 3. General view of the corner reflector and its angle adjustment.

Сурет 3. Бұрыштық шағылдырғыштың жалпы көрінісі және оның бұрышын реттеу.

Рис. 3. Основной вид отражателя и регулировка угла.

Monitoring of the reflectors across multiple SAR images enabled an increase in the backscatter intensity of individual

reflectors and allowed the optimal orientation angle of each reflector to be adjusted.

Results

The interferometric processing results provided information on displacement velocities characterizing the deformation state of the Sherubai-Nura Reservoir dam. The analysis was performed using more than 26,000 measurement points distributed across the study area. The obtained results showed that the average displacement velocity was 3.1 mm/year. Spatial analysis of the displacement velocity distribution enabled the identification of three deformation concentration zones (Figure 4). Deformation Zone No. 1 is located within the sluice complex area, Zone No. 2 is situated in the central part of the dam body, and Zone No. 3 is located in the southern section of the structure. The most pronounced spatial displacement gradients were observed in the area of the sluice complex, where both positive and negative velocity values were detected within a limited area. A detailed analysis of the deformation time series revealed that, within Zone No. 1, positive displacements are associated with the concrete elements of the sluice structure, whereas negative displacement values are concentrated in the area of the flow energy dissipation structure, including the side walls of the spillway and the bridge roadway.

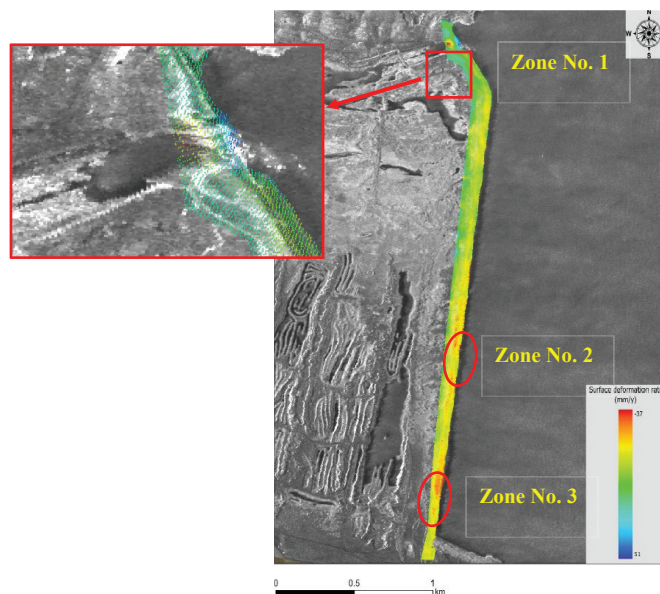


Figure 4. Deformation zones.

Сурет 4. Деформация аймақтары.

Рис. 4. Зоны деформаций.

Analysis of the time series for three control points characterized by the maximum displacement velocities demonstrated a high degree of consistency in both cumulative deformation trends and instantaneous velocity variations. The obtained dependencies indicate the stable nature of the recorded deformation signal.

Over the investigated period of approximately three months, the cumulative displacement reached 0.02 m in the satellite line-of-sight direction. It should be noted that the identified positive displacements exhibit clear spatial localization and

coincide with the location of the concrete structures of the sluice complex.

The absence of a random distribution of the deformation signal and the consistent behavior of the time series indicate that the detected displacements represent a stable characteristic of the investigated area rather than being caused by random errors associated with interferometric processing.

Discussion of the Results

The analysis of the spatial distribution of deformations demonstrated that different structural elements of the dam exhibit varying responses to operational loads. The most intensive displacements detected within the sluice complex area are likely associated with a combination of structural and operational factors. At the same time, the absence of maximum hydrostatic loads during the study period does not allow water pressure to be considered the sole cause of the observed deformations, indicating the need for further investigation of their development mechanisms.

The effectiveness of the SBAS-InSAR approach is attributed to the use of an interferometric network composed of image pairs with small spatial and temporal baselines, enabling the reconstruction of the spatio-temporal displacement pattern while maintaining high coherence of the interferometric data. An additional factor that improved the reliability of the results was the use of corner reflectors, which enhanced the quality and reliability of control point identification.

Compared with traditional geodetic monitoring techniques, the proposed approach provides continuous information on the deformation state of the structure, allowing the localization of deformation zones and the assessment of their temporal evolution. However, the method has several limitations associated with the determination of displacements only along the satellite line of sight (LOS), as well as with the dependence of measurement accuracy on radar signal coherence and imaging geometry.

Further development of this research should focus on integrating InSAR-derived measurements with GNSS observations, high-precision leveling, and total station monitoring, as well as extending the duration of satellite observation time series. This will improve the reliability of deformation interpretation, enable the assessment of seasonal variations, and help identify the primary factors governing the deformation behavior of the dam.

Conclusion

The results of the study demonstrated the applicability of the SBAS-InSAR technique for monitoring the deformation state of the Sherubay-Nura Reservoir dam. The use of multi-temporal Sentinel-1 SAR data enabled the generation of a spatially continuous displacement velocity field, the identification of localized deformation zones, and the assessment of their spatial and temporal variability. The installation of corner reflectors ensured reliable identification of reference points and improved the stability of interferometric measurements. The obtained results indicate the potential of integrating SBAS-InSAR with corner reflectors for the remote monitoring of hydraulic structures, particularly in areas characterized by a limited number of stable natural scatterers. However, a comprehensive evaluation of the proposed approach requires validation against independent reference data, including ground-based geodetic measurements. Future research should focus on extending the satellite observation time series, investigating the influence of seasonal and operational factors on deformation patterns, and further improving the integration of InSAR and conventional geodetic monitoring techniques.

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Conflict of Interest

The authors declare that they have no conflict of interest.

Author Contributions

Ozhigin D. S. – data acquisition, analysis, and data systematization.

Kubaidullina U. A. – research concept, methodology development, manuscript preparation.

Kazantseva V. V. – literature review, investigation, data visualization.

Starostina O. V. – supervision, validation, and manuscript editing.

REFERENCES

1. *Persistent Scatterer Interferometry: A Review* / M. Crosetto et al. // *ISPRS Journal of Photogrammetry and Remote Sensing*. – 2016 – Vol. 115. – P. 78–89 (in English)
2. *InSAR as a Tool for Monitoring Hydropower Projects: A Review* / J. Aswathi et al. // *Energy Geoscience*. – 2022 – Vol. 3 (2). – P. 160–171 (in English)
3. *Displacement Monitoring of Upper Atbara Dam Based on Time-Series InSAR* / Q. Q. Wang et al. // *Survey Review*. – 2020 – Vol. 52 (375). – P. 485–496 (in English)
4. *MT-InSAR and Dam Modeling for the Comprehensive Monitoring of an Earth-Fill Dam: The Case of the Benínar Dam (Almería, Spain)* / M. Marchamalo-Sacristán et al. // *Remote Sensing*. – 2023 – Vol. 15 (11). – Article 2802 (in English)
5. *Dam Surface Deformation Monitoring and Analysis Based on PS-InSAR Technology: A Case Study of Xiaolangdi Reservoir Dam in China* / Q. Wang et al. // *Water*. – 2023 – Vol. 15 (18). – Article 3298 (in English)
6. *Deformation Monitoring and Analysis of Reservoir Dams Based on SBAS-InSAR Technology – Banqiao Reservoir* / Z. Pang et al. // *Remote Sensing*. – 2023 – Vol. 15 (12). – Article 3062 (in English)
7. *SBAS-InSAR Based Deformation Monitoring of Tailings Dam: The Case Study of the Dexing Copper Mine No. 4 Tailings Dam* / W. Xie et al. // *Sensors*. – 2023 – Vol. 23 (24). – Article 9707 (in English)

8. *Application of Sentinel-1 InSAR to Monitor Tailings Dams and Predict Geotechnical Instability: Practical Considerations Based on Case Study Insights* / N. M. Rana et al. // *Bulletin of Engineering Geology and the Environment*. – 2024. – Vol. 83. – Article 204 (in English)
9. *Advanced analysis of satellite data reveals ground deformation precursors to the Brumadinho tailings dam collapse* / S. Grebby et al. // *Communications Earth & Environment*. – 2021. – Vol. 2. – Article 2 (in English)
10. *Towards operational dam monitoring with PS-InSAR and electronic corner reflectors* / J. Jänichen et al. // *Remote Sensing*. – 2025. – Vol. 17. – No. 7. – Article 1318 (in English)

ПАЙДАЛАНЫЛҒАН ӘДЕБИЕТТЕР ТІЗІМІ

1. Тұрақты шағылдырғыштар интерферометриясы: шолу / M. Crosetto [және т. б.] // *ISPRS Journal of Photogrammetry and Remote Sensing*. – 2016. – Т. 115. – Б. 78–89 (ағылшын тілінде)
2. Гидроэнергетикалық жобаларды мониторингтеуге арналған құрал ретінде InSAR: шолу / J. Aswathi [және т. б.] // *Energy Geoscience*. – 2022. – Т. 3 (2). – Б. 160–171 (ағылшын тілінде)
3. Уақыттық InSAR деректері негізінде Жоғарғы Атбара бөгетінің ығысуларын мониторингтеу / Q. Q. Wang [және т. б.] // *Survey Review*. – 2020. – Т. 52 (375). – Б. 485–496 (ағылшын тілінде)
4. Жер үйінділі бөгетті кешенді мониторингтеуге арналған MT-InSAR және бөгетті модельдеу: Бенинар бөгеті (Альмерия, Испания) мысалында / M. Marchamalo-Sacristán [және т. б.] // *Remote Sensing*. – 2023. – Т. 15 (11). – 2802 (ағылшын тілінде)
5. PS-InSAR технологиясы негізінде бөгет бетінің деформацияларын мониторингтеу және талдау: Қытайдағы Сяоланди су қоймасы бөгеті мысалында / Q. Wang [және т. б.] // *Water*. – 2023. – Т. 15 (18). – 3298 (ағылшын тілінде)
6. SBAS-InSAR технологиясы негізінде су қоймасы бөгеттерінің деформацияларын мониторингтеу және талдау: Баньцяо су қоймасы / Z. Pang [және т. б.] // *Remote Sensing*. – 2023. – Т. 15 (12). – 3062 (ағылшын тілінде)
7. SBAS-InSAR негізінде қалдық сақтау қоймасы бөгетінің деформацияларын мониторингтеу: Дэсин мыс кенішінің №4 қалдық сақтау қоймасы бөгеті мысалында / W. Xie [және т. б.] // *Sensors*. – 2023. – Т. 23 (24). – 9707 (ағылшын тілінде)
8. Sentinel-1 InSAR технологиясын қалдық сақтау қоймаларының бөгеттерін мониторингтеу және геотехникалық орнықтылықты болжау үшін қолдану: тәжірибелік мысалдарға негізделген практикалық аспектілер / N. M. Rana [және т. б.] // *Bulletin of Engineering Geology and the Environment*. – 2024. – Т. 83. – 204 (ағылшын тілінде)
9. Спутниктік деректерді кеңейтілген талдау Брумадинью қалдық сақтау қоймасы бөгетінің бұзылуы алдындағы жер беті деформациясының белгілерін анықтады / S. Grebby [және т. б.] // *Communications Earth & Environment*. – 2021. – Т. 2. – 2 (ағылшын тілінде)
10. PS-InSAR және электрондық бұрыштық шағылдырғыштарды пайдалана отырып, бөгеттерді жедел мониторингтеуге қарай / J. Jänichen [және т. б.] // *Remote Sensing*. – 2025. – Т. 17. – № 7. – 1318 (ағылшын тілінде)

СПИСОК ИСПОЛЬЗОВАННЫХ ИСТОЧНИКОВ

1. Мониторинг устойчивых отражателей методом интерферометрии: обзор / M. Crosetto [и др.] // *ISPRS Journal of Photogrammetry and Remote Sensing*. – 2016. – Т. 115. – С. 78–89 (на английском языке)
2. InSAR как инструмент мониторинга гидротехнических сооружений: обзор / J. Aswathi [и др.] // *Energy Geoscience*. – 2022. – Т. 3 (2). – С. 160–171 (на английском языке)
3. Мониторинг смещений плотины Верхнего Атбара по данным многовременной InSAR / Q. Q. Wang [и др.] // *Survey Review*. – 2020. – Т. 52 (375). – С. 485–496 (на английском языке)
4. Комплексный мониторинг земляной плотины на основе MT-InSAR и инженерного моделирования на примере плотины Бенинар (Альмерия, Испания) / M. Marchamalo-Sacristán [и др.] // *Remote Sensing*. – 2023. – Т. 15 (11). – Ст. 2802 (на английском языке)
5. Мониторинг и анализ деформаций плотины водохранилища Сяоланди на основе технологии PS-InSAR / Q. Wang [и др.] // *Water*. – 2023. – Т. 15 (18). – Ст. 3298 (на английском языке)
6. Мониторинг и анализ деформаций плотины водохранилища Баньцяо на основе технологии SBAS-InSAR / Z. Pang [и др.] // *Remote Sensing*. – 2023. – Т. 15 (12). – Ст. 3062. (на английском языке)
7. Мониторинг деформаций хвостовой дамбы на основе SBAS-InSAR на примере хвостохранилища № 4 медного рудника Dexing / W. Xie [и др.] // *Sensors*. – 2023. – Т. 23 (24). – Ст. 9707 (на английском языке)
8. Применение Sentinel-1 InSAR для мониторинга хвостовых дамб и прогнозирования геотехнической неустойчивости: практические аспекты на основе анализа примеров / N. M. Rana [и др.] // *Bulletin of Engineering Geology and the Environment*. – 2024. – Т. 83. – Ст. 204 (на английском языке)
9. Анализ спутниковых данных выявляет предвестники деформаций грунта перед обрушением дамбы Брумадинью / S. Grebby [и др.] // *Communications Earth & Environment*. – 2021. – Т. 2. – Ст. 2 (на английском языке)
10. Оперативный мониторинг дамб с использованием PS-InSAR и электронных уголкового отражателей / J. Jänichen [и др.] // *Remote Sensing*. – 2025. – Т. 17. – № 7. – Ст. 1318 (на английском языке)

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Авторлар туралы мәліметтер:

Ожигин Д. С., Ph.D, «Маркшейдерлік іс және геодезия» кафедрасының қауымдастырылған профессоры, «Әбілқас Сағынов атындағы Қарағанды техникалық университеті» коммерциялық емес акционерлік қоғамы (Қарағанды қ., Қазақстан)

Кубайдуллина У. А., т. ғ. м., «Маркшейдерлік іс және геодезия» кафедрасының оқытушысы, «Әбілқас Сағынов атындағы Қарағанды техникалық университеті» коммерциялық емес акционерлік қоғамы (Қарағанды қ., Қазақстан)

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Старостина О. В., т. ғ. к., «Маркшейдерлік іс және геодезия» кафедрасының қауымдастырылған профессоры, «Әбілқас Сағынов атындағы Қарағанды техникалық университеті» коммерциялық емес акционерлік қоғамы (Қарағанды қ., Қазақстан)

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