INTEGRATING MULTISPECTRAL, THERMAL AND RGB UAV IMAGERY FOR THE DOCUMENTATION AND PROTECTION OF THE ARCHAEOLOGICAL SITE OF STAROSELTSI-KALETO

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Abstract: *This study shows the potential of multisensor UAV-based remote sensing for the assessment and preliminary investigation of endangered archaeological sites. The Kaleto fortress near Staroseltsi is a neglected archaeological site, which has long been affected by looting and, to a lesser extent, by erosion. RGB, multispectral, and thermal imagery acquired using UAV platforms were integrated to investigate and characterize its features photogrammetrically. The results revealed the fortress perimeter, a possible internal building, and two external earthworks potentially associated with the site's defensive system. Although all three data types contributed to the identification of these features, the multispectral products enhanced the visibility of the external linear defensive feature, whereas the thermal map provided a clearer representation of the U-shaped earthwork east of the fortress. The investigation also identified recent treasure-hunting pits, indicating continued illicit disturbance of the site. The results demonstrate the complementary value of RGB, multispectral, and thermal data for archaeological remote prospection and provide a baseline to support future monitoring and heritage protection.*

ИНТЕГРИРАНЕ НА МУЛТИСПЕКТРАЛНИ, ТЕРМАЛНИ И RGB ИЗОБРАЖЕНИЯ ОТ БЛА ЗА ДОКУМЕНТИРАНЕ И ОПАЗВАНЕ НА АРХЕОЛОГИЧЕСКИЯ ОБЕКТ СТАРОСЕЛЦИ-КАЛЕТО

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Ключови думи: *дистанционни изследвания с БЛА, мултисензорна фотограметрия, недеструктивно изследване, опазване на културното наследство*

Резюме: *Настоящото изследване показва потенциала на мултисензорното дистанционно изследване с БЛА за оценка и предварително проучване на застрашени археологически обекти. Крепостта Калето край Староселци е един пренебрегнат археологически обект, който отдавна е подложен на иманярска дейност, и в известна степен на ерозионни процеси. RGB, мултиспектрални и термални изображения, придобити с помощта на БЛА, са интегрирани за фотограметричното изследване и характеризиране на археологическите структури. Получените резултати позволяват да се разграничат очертанията на крепостта, една вероятна вътрешна постройка и две външни землени структури, които е възможно да са свързани с отбранителната система на обекта. Въпреки че и трите типа данни допринасят за идентифицирането на тези структури, мултиспектралните продукти осигуряват една по-добра визуализация на външната линейна отбранителна структура, докато термалната карта позволява по-ясното разграничаване на U-образното землено съоръжение, разположено източно от крепостта. В рамките на изследването са установени и скорошни иманярски изкопи, свидетелстващи за продължаващо незаконно разрушаване на археологическия обект. Получените резултати демонстрират взаимнодопълващия се потенциал на RGB, мултиспектралните и термалните данни при дистанционно археологическо изследване и осигуряват база за бъдещ мониторинг и опазване на културното наследство.*

Introduction

The application of unmanned aerial vehicles (UAVs) in archaeological research began to emerge in the early 2000s, offering new possibilities for the documentation, mapping, and investigation of archaeological sites [1; 2; 3]. Initially used primarily for aerial photography and site documentation, UAVs became increasingly accessible during the 2010s owing to advances in platform design, sensor technology, and photogrammetric processing software. The integration of structure-from-motion (SfM) photogrammetry enabled the efficient generation of high-resolution orthophotos, digital elevation models, and three-dimensional reconstructions, significantly enhancing the spatial documentation and interpretation of archaeological landscapes. Furthermore, the flexibility of UAV-based surveys allowed researchers to acquire detailed spatial data at relatively low cost and with greater temporal and spatial resolution than many conventional aerial survey methods [4, 5].

By the mid-2010s, the integration of multispectral and thermal sensors had expanded UAV applications in archaeology beyond conventional visual documentation, offering new opportunities to detect archaeological features that are not readily discernible to the human eye [6, 7]. The ability to acquire data across multiple spectral regions enabled researchers to identify and investigate archaeological features based on their distinctive spectral and thermal signatures. These developments strengthened the role of UAV-based remote sensing in archaeological investigation, particularly in surveying extensive areas where systematic geophysical prospection may be prohibitively costly, as well as for investigating sites where dense vegetation restricts accessibility and limits the effectiveness of conventional prospection methods [8, 9].

Multispectral and thermal imagery provide complementary approaches to detecting subtle variations in vegetation and soil properties that may indicate the presence of buried archaeological remains. Their combined application enables the assessment of differences in spectral reflectance and surface temperature associated with vegetation vigour, soil moisture, and subsurface conditions, thereby enhancing the detection and spatial delineation of archaeological features [10–12].

In alignment with the conference's thematic framework, particularly the dimension of "Safety", the present study broadens its scope to encompass the safeguarding and long-term preservation of cultural heritage. The present study addresses the Kaleto archaeological site, which is currently in a state of severe neglect, has sustained partial damage, and remains at risk of further destruction. To address these challenges, the study employs a state-of-the-art, non-destructive remote sensing approach, combining RGB-derived photogrammetric products, multispectral imagery, and thermal data. This multisensor methodology aims to document the site's current condition, identify and spatially delineate as many archaeological features as possible, and raise awareness of its archaeological significance. Furthermore, the resulting datasets provide a basis for future site monitoring and condition assessment with the goal of protecting the site against further deterioration.

Case study and current state of archaeological research

The site is located in the northern outskirts of the village of Staroseltsi, approximately 30 km northwest of Pleven. It lies in the Danubian Plain, on the right bank of the Iskar, about 25 km upstream from its confluence with the Danube. As the toponym of the place "Kale" indicates, the site constitutes a fortress. The fortress lies on a promontory-like extension of the upland plateau (Moesian Platform) formed by the confluence of the Iskar and a small stream. The steep slopes of this promontory-like protrusion provide natural protection on three sides. Its upper part is flat and constitutes an excellent vantage point, overlooking the low-lying valleys of Iskar and of the small stream. The fortress had a very strategic position in the past as it controlled an important road that ran along the lower valley of Iskar and connected the major ancient city of Oescus with other large urban centres south of the mountain passes of Stara Planina, such as Serdica or Philippopolis.

The fortress was first mentioned by Dimitrina Mitova-Dzhonova in her monograph on the archaeological sites of the Pleven District [13], where she provides a very brief description of the site, noting its location, extent, and dating. D. Mitova-Dzhonova also notes that the fortress walls had remained preserved and clearly visible above ground until shortly before she wrote her account, but that they had subsequently become entirely covered and were no longer discernible. In addition, she reports abundant construction ceramics, stones, and pottery fragments, including dolia, found on the site. Based on these observations, D. Mitova-Dzhonova attributes the fortress to the Classical Antiquity.

An additional source of information on the fortress is the Bulgarian website *Български крепости* (Bulgarian Fortresses), which features a brief description of the site published by Milko Gardev, an economist by profession, in 2024. Although the account was not written by an archaeologist and contains several inaccuracies, it provides a more detailed description of the visible archaeological traces than that offered by Mitova-Dzhonova. Gardev also reports that, in recent years, treasure hunters have disturbed the site using heavy machinery, including bulldozers, and that stones from the fortress walls have been reused

in the construction of buildings in the nearby village. This information is particularly significant, as it indicates the reason for the site's severely degraded condition.

The assessment indicates that no formal archaeological investigation has been conducted at the site to date. Consequently, the fortress remains inadequately documented and has not been officially registered in the Archaeological Map of Bulgaria, a specialised information system for recording archaeological sites that incorporates geospatial data and is maintained by the National Archaeological Institute with Museum at the Bulgarian Academy of Sciences (NAIM–BAS). Furthermore, the assessment shows that, for about half a century, the site has been subjected to illicit looting and the removal of stones for use as building material, with heavy machinery reportedly employed in the more recent decades.

Methodology

Two UAV-based photogrammetric surveys were conducted by the research team on 10 May 2026, between approximately 14:00 and 16:00 local time. Data acquisition was performed using UAVs equipped with multispectral and thermal sensors. Both surveys were conducted with the sensors oriented in nadir direction, employing flight plans with 80% forward overlap and 70% side overlap. The flight missions were planned and configured using DJI Pilot 2, with terrain-following enabled to maintain a nominal flight altitude of 50 m above ground level (AGL).

The multispectral survey was conducted using a DJI Mavic 3 Multispectral UAV, equipped with four 5-megapixel multispectral sensors operating in the green, red, red-edge, and near-infrared (NIR) spectral bands, as well as a 20 MP RGB camera with a 4/3-inch CMOS sensor. The survey covered an area of approximately 340,000 m². A total of 3,980 multispectral images were acquired, yielding a ground sampling distance (GSD) of approximately 2 cm/pixel. Additionally, 995 RGB images were captured at a GSD of approximately 1.33 cm/pixel. Radiometric calibration of the multispectral imagery was facilitated by the integrated Downwelling Light Sensor (DLS), which records incident solar irradiance during image acquisition.

The thermal survey was conducted using a DJI Mavic 3 Thermal UAV, equipped with a thermal camera featuring a resolution of 640 × 512 pixels and an uncooled vanadium oxide (VOx) microbolometer sensor, in addition to wide-angle RGB and telephoto cameras. The thermal survey covered approximately 69,000 m² and yielded 787 thermal images, with an approximate GSD of 6.60 cm/pixel. The original radiometric JPEG (R-JPEG) images were converted into thermal TIFF (.tif) files using DJI Image Processor, available from the DJI-Tools-and-Stuff GitHub repository. Although RGB imagery was also acquired during the thermal survey, it was excluded from the analyses presented in the current study.

To improve the absolute positional accuracy of the photogrammetric products, six ground control points (GCPs) were established across the survey area and measured using a Leica GS08 Plus GNSS receiver with real-time kinematic (RTK) corrections. Four of the GCPs were optimised for thermal imagery. The estimated positional accuracy of the GCP measurements is approximately 1–3 cm. The GCPs were incorporated into the photogrammetric processing workflow to improve the georeferencing of the resulting products.

Photogrammetric processing was performed using Pix4Dmapper version 4.10.0 to generate orthomosaics and digital terrain products, as appropriate for each dataset. Subsequent GIS processing was performed in QGIS and included the generation of vegetation indices from the multispectral imagery, as well as the integration and spatial analysis of the resulting photogrammetric products. Ten vegetation indices were calculated: DVI, GCI, GNDVI, MRESRI, NDRE, NDVI, NLI, OSAVI, SAVI and SR.

Results

The orthomosaic and digital surface model (DSM) generated from the RGB imagery (Fig. 1) proved effective for identifying and preliminarily interpreting several architectural and topographic features associated with the fortress and its immediate surroundings. The fortress has an approximately rectangular plan, enclosing an area of ca. 2.5 ha. The northeastern and southeastern walls are the most clearly identifiable features in the RGB-derived datasets. These walls meet at a right angle, and a possible tower appears to have stood at their junction. A ditch is discernible along the exterior of both walls. The northeastern wall extends for approximately 190 m. In its central section, a distinct feature is visible that may represent either a tower or a gate. The southeastern wall is approximately 95 m long. The northwestern wall is also identifiable, although its visibility is considerably reduced by tall vegetation. The southwestern side of the fortress presents the greatest interpretative difficulties. The extent to which the wall is preserved is uncertain, as its visibility is affected by vegetation, erosion, and possible damage resulting from anthropogenic activities. The angle between the southwestern and southeastern walls is approximately 120°. Furthermore, the local

terrain morphology suggests that the southwestern perimeter of the fortress may deviate from the straight alignment observed along the other sides. Instead, it may comprise two distinct wall segments forming the southwestern and western sides of the fortress. If this interpretation is confirmed, the fortress would have a pentagonal rather than a rectangular plan. However, further investigation is required to establish the original configuration of this section of the fortification.

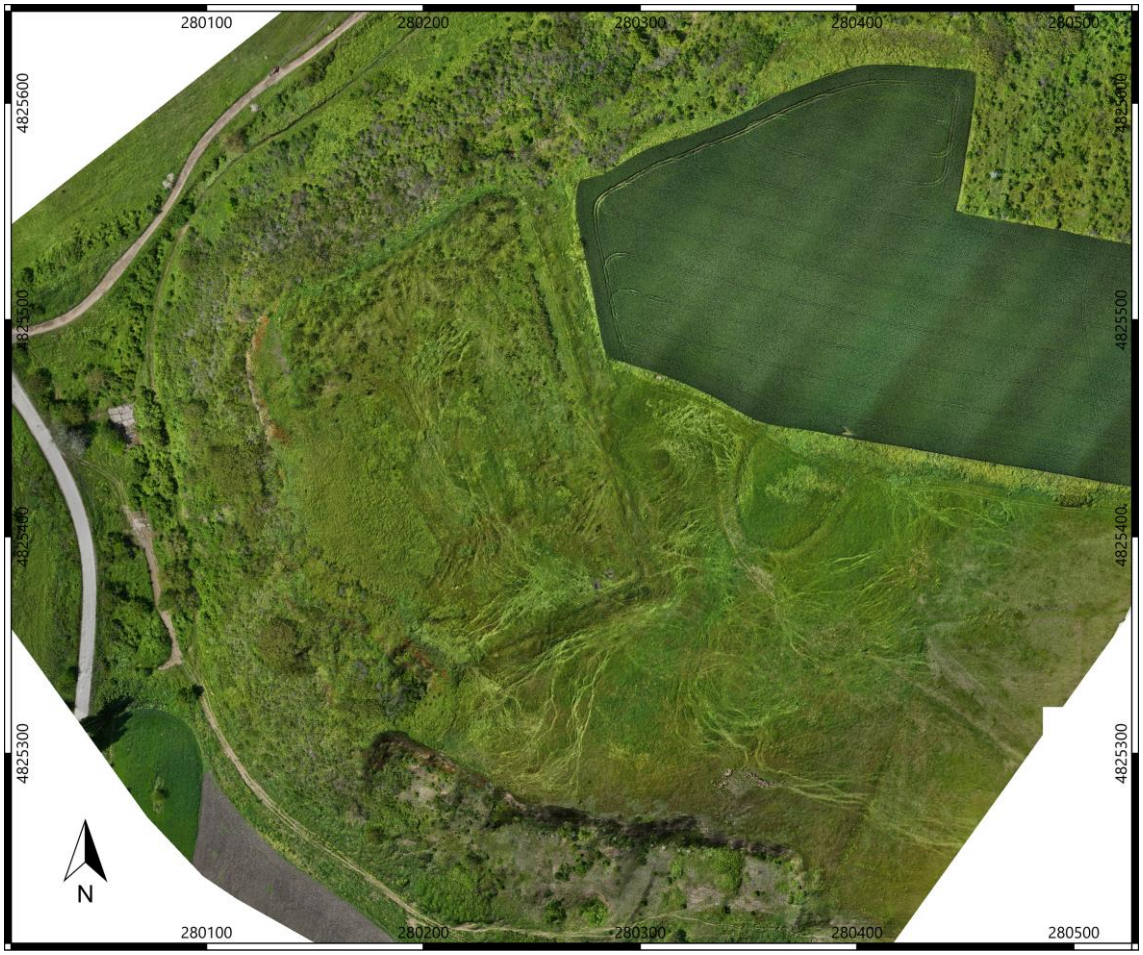


Fig. 1. Orthomosaic with DSM Enhancement of the archaeological site of Staroseltsi-Kaleto (CRS: WGS 84 / UTM zone 35N)

Within the fortress, the UAV-derived datasets reveal the traces of a rectangular structure oriented approximately north–south, which may represent the remains of a building. Its northern and western walls are particularly well defined, while internal partition walls may also be present. The southwestern part of the structure appears to have been severely disturbed or destroyed by modern looting involving the use of heavy machinery, possibly a digger or a bulldozer. Similar traces of relatively recent mechanized disturbance are visible elsewhere within the fortress, particularly in its southeastern and northwestern sectors, indicating that illicit excavation activities have seriously affected the preservation of archaeological features across the site.

Approximately 50 m east of the fortress, a U-shaped earthwork can be identified, consisting of an inner ditch and an outer bank. Examination of historical satellite imagery suggests that this feature originally formed a closed, oval-shaped enclosure. Its northeastern section, however, appears to have undergone alteration or destruction over recent decades. At the present stage of research, the function of this earthwork cannot be determined.

Farther east, a linear earthwork is visible. It follows an approximately north–south alignment, with a slight outward curvature. Its morphology suggests that it may constitute part of an external defensive system, comprising an outer ditch and an inner bank, possibly surmounted by a palisade. The northern section of this earthwork is not discernible in the imagery, as tall wheat crop at the time of the survey obscured the underlying terrain features. The southern section of the earthwork is partially overlain by a network of narrower trenches, which appear to represent a modern drainage system.

Among the four spectral bands recorded by the multispectral sensor, the NIR band provides the clearest representation of the archaeological features. Among the ten vegetation indices evaluated, NDVI, GNDVI, NLI, and SR are the most effective for the identification of archaeological structures.

Figure 2 presents the results of NDVI, which is the most widely employed vegetation index in remote sensing. The map reveals all the archaeological features previously identified in the RGB-derived products. However, certain features are more clearly delineated in the NDVI dataset. These features include the linear earthwork in the eastern part of the site, interpreted as a possible external defensive line, and the network of narrower trenches interpreted as a modern drainage system.

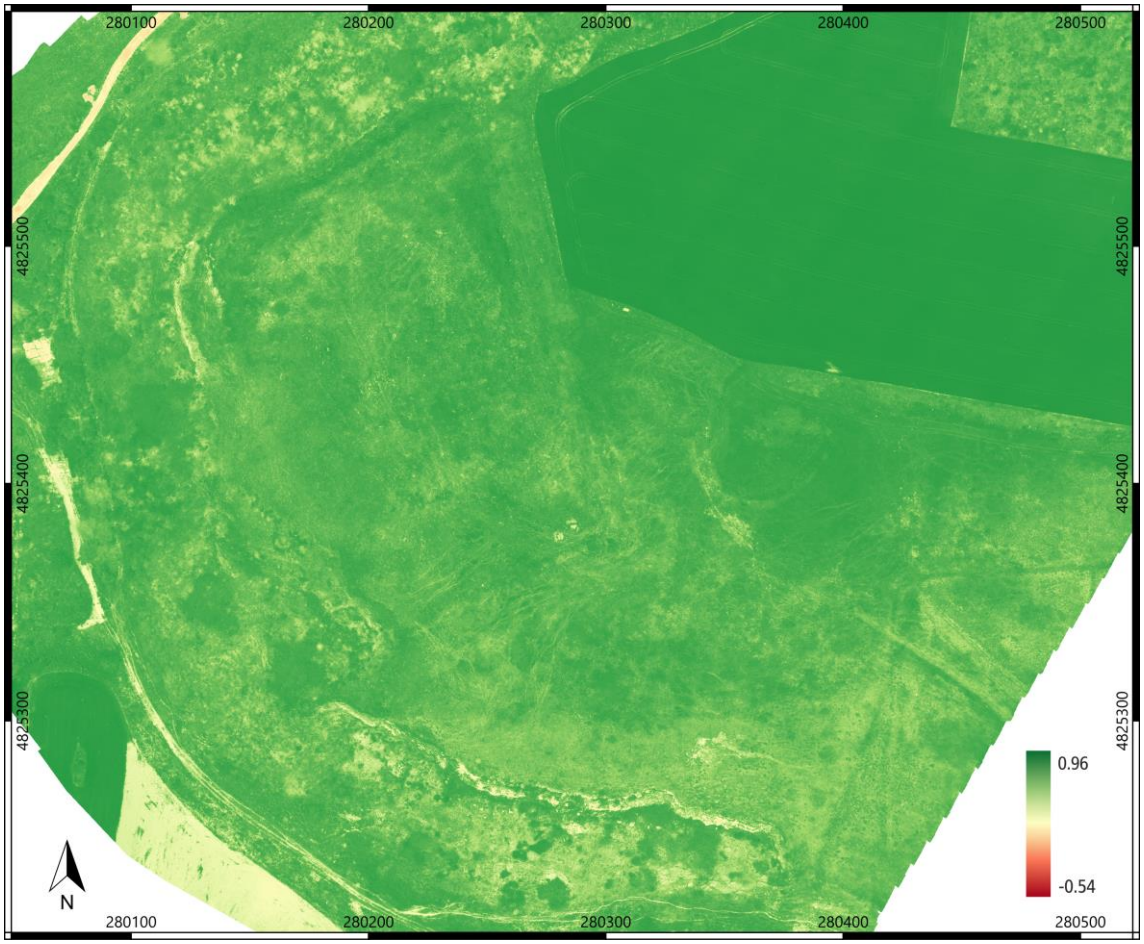


Fig. 2. Normalized Difference Vegetation Index map of the archaeological site of Staroseltsi-Kaleto (CRS: WGS 84 / UTM zone 35N)

The thermal map (Fig. 3) also reveals clearly the fortress and the features associated with it. Moreover, the U-shaped earthwork located approximately 50 m east of the fortress is better distinguishable in the thermal data than in either the RGB-derived products or the NDVI map. One possible explanation is that the ditch associated with this earthwork is deeper and retains more moisture than the ditches running along the fortress walls, which are less clearly visible in the thermal imagery. Greater moisture content may increase the thermal inertia of the soil, causing it to warm more slowly than the surrounding, relatively drier ground. This difference in thermal response could account for the enhanced visibility of the U-shaped earthwork in the thermal map.

The enhanced visibility of certain features in the NDVI and thermal maps highlights the benefits of integrating multispectral and thermal data for archaeological remote prospection, demonstrating their capacity to reveal and delineate features that are less clearly distinguishable in conventional RGB-based photogrammetric products.

Overall, the remote sensing methods employed provide a detailed representation of the fortress and its surrounding landscape. The results enable a preliminary reconstruction of the defensive perimeter, the identification of internal architectural structures, and the recognition of outer earthworks potentially associated with the site's defensive system. Nevertheless, vegetation cover, modern disturbances, and erosion processes limit these investigations. Further investigation is therefore required to explore the site's archaeological potential more comprehensively. In particular, systematic surface archaeological survey, geophysical prospection, and targeted archaeological excavation will be essential to refine the reconstruction of the fortress's original layout, establish its chronology, and clarify the function of the separate features.

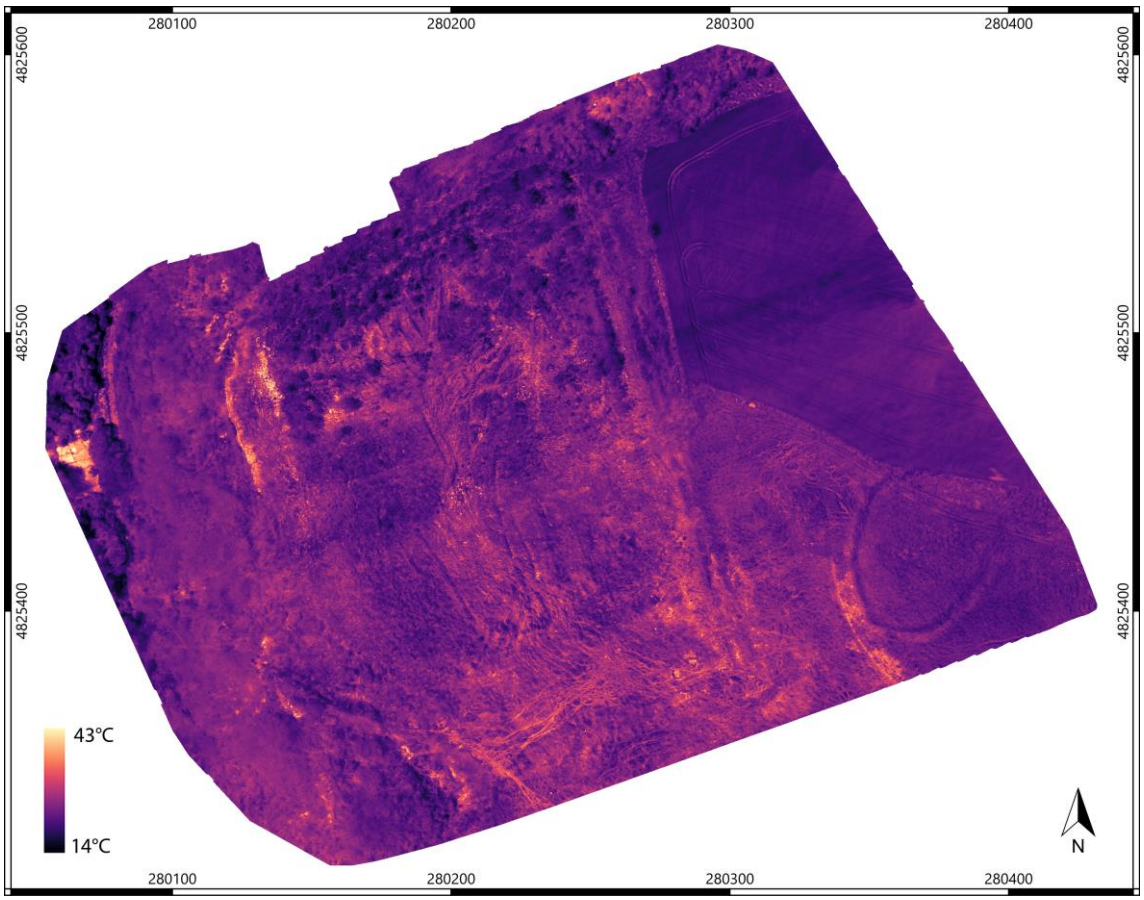


Fig. 3. Thermal map of the archaeological site of Staroseltsi-Kaleto (CRS: WGS 84 / UTM zone 35N)

In addition, our field investigation documented two recent looting pits, indicating ongoing illicit disturbance at the site. These findings highlight the need for the competent authorities to implement appropriate protective measures to prevent further looting and destruction of the site.

Conclusions

The present study shows the potential of multisensor UAV-based photogrammetry for the non-destructive investigation of archaeological sites. Through the integration of RGB, multispectral, and thermal imagery, the main structural elements of the Kaleto fortress near Staroseltsi are identified and delineated in considerable spatial detail. This remote sensing approach provides an initial spatial documentation of the site and establishes a foundation for future monitoring and long-term protection of this vulnerable cultural heritage asset.

The analysis of RGB-derived orthomosaics and terrain models, vegetation index maps derived from multispectral imagery, and thermal maps enables the identification and preliminary interpretation of architectural remains and defensive earthworks. Furthermore, field observations revealed traces of recent looting, indicating that the illicit disturbance of the site, reported about half a century ago, continues to the present day. The integrated datasets reveal the main sections of the fortress perimeter, including the clearly delineated northeastern and southeastern walls, which are flanked by an external ditch and meet at a junction where a tower may have stood. The configuration of the fortress's southwestern perimeter remains largely uncertain owing to vegetation cover, erosion, and modern disturbance; further investigation is therefore required to clarify it. A possible building within the fortress is also identified. In addition, the datasets reveal a U-shaped earthwork east of the fortress and an additional linear earthwork that is interpreted as an external defensive system. Although the features are generally identifiable across the different datasets, their visibility and degree of delineation vary depending on the sensor and data product employed. The RGB-derived products, specifically the DSM, are particularly effective, revealing all the aforementioned features. Yet, the external defensive line and modern drainage trenches in the eastern part of the site are more clearly delineated in the multispectral datasets, while the thermal imagery provides a particularly clear representation of the U-shaped earthwork.

Overall, the present study brings to light a valuable archaeological site that has received limited scholarly attention to date, but holds considerable potential for further research. Its systematic

investigation could make an important contribution to our understanding of ancient fortifications and the history of the region. However, the site has already suffered partial damage and remains at risk of further deterioration, highlighting the urgent need for continued archaeological investigation, systematic monitoring, and the implementation of appropriate protective measures.

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