Potential of Modern Geotechnologies for Analyzing, Monitoring, and Communicating the Sustainable Development of UNESCO Designated Sites

Alexander Siegmund, Maike Petersen, Emmanuel Eze & Johannes Keller

UNESCO Chair on Observation and Education of World Heritage and Biosphere Reserve, Institute of Geography & Geocommunication, Heidelberg University of Education (Germany)

Abstract Preserving UNESCO designated sites amid diverse risks like environmental hazards and human conflicts necessitates sustainable development strategies. This paper examines the diverse challenges faced by these sites (UNESCO World Heritage, Biosphere Reserves, and Geoparks) and underscores the role of modern geotechnologies, including remote sensing, geographic information systems (GIS), and mobile geotools in assessing and mitigating risks. Geotechnologies aid in hazard mapping, disaster risk reduction, and documenting conflicts' impacts in various ways, from analyzing and monitoring to modeling structures, processes, and changes. They also enhance visualization, communication, and education efforts, facilitating professional planning as well as public awareness and engagement in conservation. However, there is a significant knowledge gap among UNESCO site managers on the use of modern geotechnologies, highlighting the need for targeted training programs. Within the scope of a collaborative initiative, the UNESCO Chair at Heidelberg University of Education has designed two pilot training courses and conducted them in Costa Rica and Malawi to convey essential skills in target-driven use of remote sensing, GIS, etc. Closer collaboration between UNESCO entities and stakeholders can enhance capacity development efforts, fostering disaster resilience and sustainable development to safeguard cultural and natural heritage for future generations.

Keywords UNESCO World Heritage and Biosphere Reserves, geotechnologies, sustainable development, capacity development.

1. Sustainable development of UNESCO designated sites

The aim of the UNESCO Program is to contribute to sustainable development and the 2030 Agenda by preserving and promoting UNESCO designated sites at various levels (Jagielska-Burduk, Pszczyński, and Stec 2021). In the face of growing (human-induced)

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environmental risks and hazards as well as threats from human conflict, such international measures have gained importance. UNESCO designated sites are found in diverse landscapes and face a broad variety of challenges (Ashrafi, Kloos, and Neugebauer 2021; KC 2021; Kapsomenakis et al. 2023). Threats to the sites can be as manifold as the sites themselves: Prominent UNESCO designated sites particularly struggle with the massive attention and have to regulate visitor numbers to prevent deterioration (Coccossis 2016). Structures within large cities may face damage due to air pollution or an impairment of their visual integrity through construction projects (Di Turo et al. 2016; Ashrafi, Kloos, and Neugebauer 2021) while others are located within regions subject to geo- or natural hazards such as earthquakes, floodings, or wildfires (Mallinis et al. 2016; Pavlova et al. 2017; Cigna, Tapete, and Lee 2018). Some sites such as the prehistoric pile dwellings around the alps are confronted with even more complex issues: Some of the sites are located under water and are exposed to increased erosion connected to changed shipping routes or due to felling along the shoreline, which destabilize the ground (Ostendorp et al. 2016; Hafner and Schlichtherle 2007). In countries with current violent conflicts, the preservation of UNESCO designated sites is aggravated even further (Levin et al. 2019). Assessing these highly site-specific potential hazards and developing suitable actions for prevention or adaptation is crucial in the management of UNESCO designated sites.

Despite its importance, the focus of international efforts on UNESCO designated sites cannot exclusively lie on the mere protection of them but also needs to include their sustainable development to ensure their preservation for future generations (Xiao et al. 2018). To emphasize this, the sites are also targeted by the UN Sustainable Development Goals (SDGs) which directly focus on their protection (SDG 11.4) and indirectly on their sustainable development (e.g., SDG 8.9) (UN 2015; Xiao et al. 2018). Sustainable development, which includes environmental, social, and economical aspects of the tourism sector, can, for example, create jobs, boost local products, and create incentives to also preserve intangible cultural heritage (Xiao et al. 2018). The sustainability of UNESCO designated sites has also been connected to their resilience and disaster risk reduction (Eze and Siegmund 2024a).

Their managers play a pivotal role, both in the protection as well as the sustainable development of UNESCO designated sites. They have to consider locally diverse conditions and challenges such as tourism, natural disasters, and socio-economic factors. Therefore, site-specific concepts for development and education must be developed for each UNESCO designated site. Detailed information about the status and ongoing processes of the natural and human-made environment in the core and buffer zones, as well as within the wider setting, form the basis for these concepts. Modern geotechnologies such as remote sensing, GIS, and mobile geotools are highly relevant for generating, analyzing, and visualizing such information and thus for the protection and sustainable development of UNESCO designated sites. This relies on UNESCO site managers' capacity to effectively utilize geotechnologies. Current studies, however, indicate significant knowledge gaps and the need for further training in this area (Eze and Siegmund 2024b). The following sections will illustrate the potential

of geotechnologies for protecting UNESCO designated sites, focusing on satellite data and the use of mobile geotools (see Chapter 2). Subsequently, an example will demonstrate how training for UNESCO site managers can be designed to utilize this data effectively (see Chapter 3).

2. Use of modern geotechnologies

The studies of Eze and Siegmund (2024b) as well as Orimoloye et al. (2021a; 2021b) highlight the utility of modern geotechnologies, such as remote sensing, based on satellite images as well as unmanned aerial vehicles (UAV, drones) and GIS for hazard mapping and advancing disaster risk reduction. The availability of different spatial scales and resolutions of earth-observation data offers a range of applications relevant for the protection and sustainable development of UNESCO designated sites. Freely available satellite imagery such as from the Landsat and Sentinel programs can be used to monitor large-scale environmental processes, which may directly or indirectly affect UNESCO designated sites. Higher resolution data, though usually commercialized, can provide detailed information of damage on structures. Satellite imagery, for instance, allows for regular and systematic monitoring of large areas, enabling the detection of changes in land use, vegetation cover, and potential threats. GIS complements this by integrating various data layers, facilitating the visualization and analysis of complex spatial relationships. This helps conservationists and site managers to identify trends, assess the impact of human activities, and implement timely interventions (Siegmund and Prodan 2022).

Comparing satellite or even historical aerial images from earlier decades of the 20th century with those of current time points allows tracking changes in physical and environmental conditions of and around UNESCO designated sites (Elfadaly et al. 2018). Elfadaly et al. (Elfadaly et al. 2018) modeled the effects of uncontrolled urban expansion on the historical temples of west Luxor (Egypt) using a variety of remote sensing data ranging back as far as the 1960s. The high repetition rate of earth observation missions such as Landsat (eight days) or Sentinel (five days) further holds the possibility to track even short-term processes such as the spread of wildfires or flooding to assess threats or damage to protected areas. For instance, Landsat data was used in a study to assess the damage on the Machu Picchu Natural Park (Peru) caused by wildfires (Lasaponara et al. 2022) or to model the burn probability and fire potential for the 20 monasteries on Holy Mount Athos in Greece (Mallinis et al. 2016).

Though destruction of UNESCO designated sites during times of violent conflict cannot be prevented by geotechnologies, they may help in documenting assaults on these sights at times when access on the ground is largely restricted. For instance, the destruction of the Temple of Bel in May 2015 in Palmyra during the war in Syria was confirmed by very high-resolution satellite images (Cerra and Plank 2020). Also, after the destruction of the Kakhovka Dam in Ukraine in June 2023, the Institute of Geography & Geocommunication – Research Group for Earth Observation (^{r}geo) provided

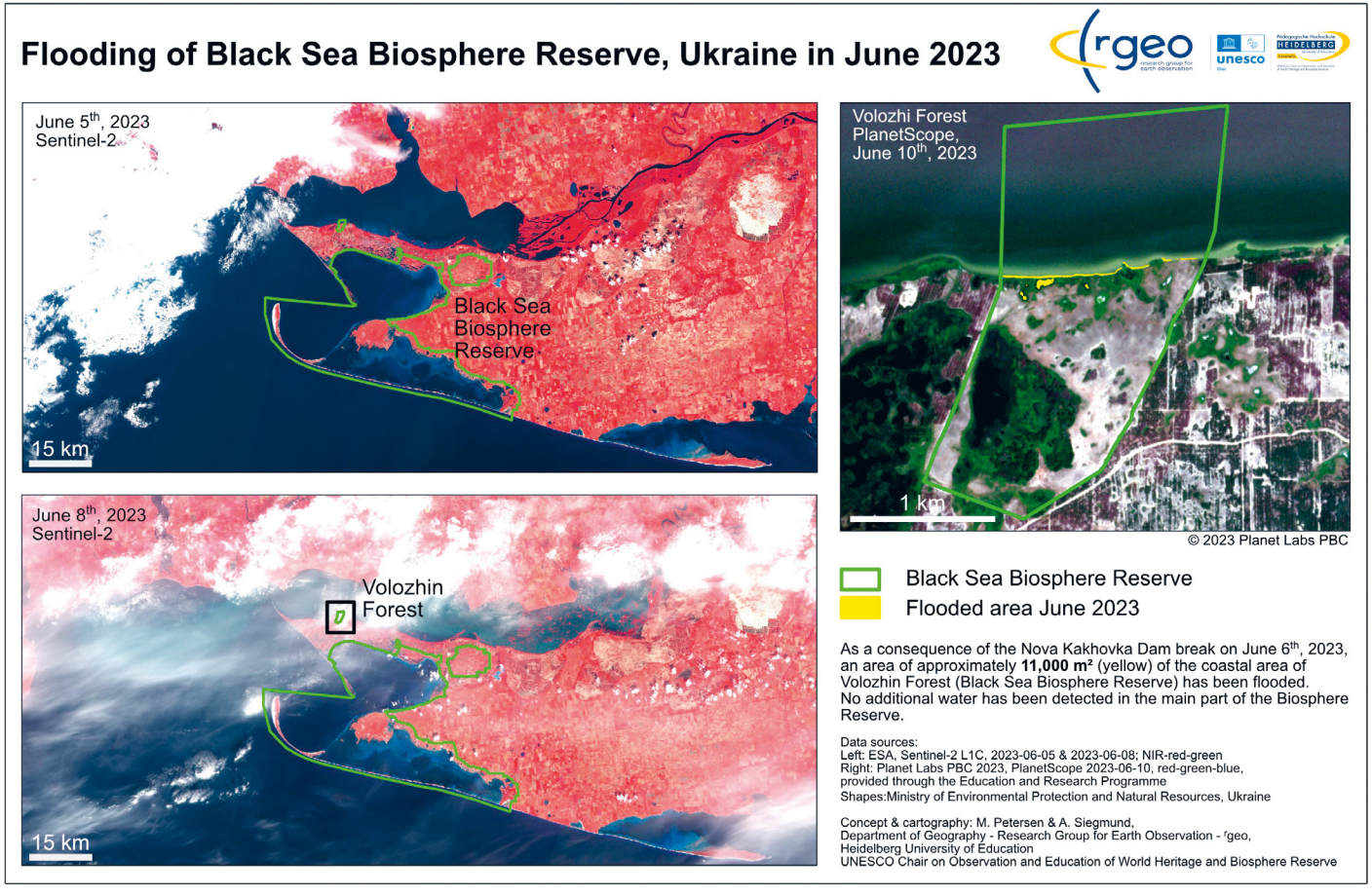

Figure 1 Flood map provided by the Institute of Geography & Geocommunication – ʳgeo after the destruction of the Kakhovka Dam, Ukraine in June 2023 (Heidelberg University of Education).

UNESCO stakeholders with a map of the flooded area within the Black Sea Biosphere Reserve, Ukraine, approximately 150 km downstream of the dam. The analysis was based on a comparison of satellite images of before and after the destruction of the dam (see fig. 1).

Geodata such as digital elevation models together with information on soil conditions, historical data, and climate projections are further used to predict severity and extent of future floods. Resulting hazard zones can be demarcated and, consequently, mitigation measures for UNESCO designated sites within these zones can be planned and prepared (Figueiredo, Romão, and Paupério 2020).

Furthermore, the Institute of Geography & Geocommunication – [r]geo used different sources of geodata to assess potential land-use conflicts in the context of the expansion of renewable energy. The analysis did not only consider where the development of new plants would interfere with existing core- and buffer zones of UNESCO designated sites but also where the wider setting might be affected, e.g., by compromising the visual integrity of the sites.

Modern geotechnologies are already used to develop early warning tools for hazards such as wildfires (e.g., European Forest Fire Information System – EFFIS (Copernicus Emergency Management Service 2024b)), floods (e.g., European Flood Awareness System – EFAS (Copernicus Emergency Management Service 2024a)), or illegal logging (e.g., Global Forest Watch (Global Forest Watch 2024)). These often use a combination of earth observation data, weather forecasts, information on geology, soil, and land cover as well as participatory approaches.

Furthermore, insights gained through modern geotechnologies about the development, threats, and protection strategies of UNESCO designated sites can make a significant contribution to their visualization, communication, and education. On one hand, visualizations and maps can illustrate large-scale processes comprehensibly. These can be integrated into informational/educational materials, social media, or AR and VR applications. On the other hand, mobile geotools like Actionbound or the app BLIF:Explorer, developed by the Institute of Geography & Geocommunication – [r]geo and the related UNESCO Chair of Observation and Education of World Heritage and Biosphere Reserves at the Heidelberg University of Education, offer the possibility to create educational opportunities through digitally supported excursions (Keller et al. 2024), which are especially attractive for younger people. Geotechnologies have also already been used to visualize the unbalanced global distribution of UNESCO designated sites through cartograms (Blersch et al. 2023).

3. Training of UNESCO site managers

The uses of modern geotechnologies for the protection and sustainable development of UNESCO designated sites are manifold, however, using them requires a certain level of training. A prerequisite for this is the availability of free data and easy-to-use applications for processing digital geodata like satellite images, UAV data, etc.

This is made possible by the Landsat and Copernicus programs of NASA and ESA respectively. For the Copernicus program, many free and web-based services and applications have been developed in recent years, allowing even beginners to conduct analyses and visualize the results. New policies such as the Infrastructure for Spatial Information in the European Community (INSPIRE) work towards more open and transnational utilization of geodata. This emphasizes the importance of such geotechnologies while also facilitating the access to geodata. The Institute of Geography & Geocommunication – ʳgeo has developed a web-based application to convey the principles of remote sensing to first-time users. This application, BLIF (www.blif.de), is currently being extended to also cover current technological developments such as UAV data, time series, or hyperspectral data. The adaptive e-learning platform geo:spektiv (www.geospektiv.de), also developed by the Institute of Geography & Geocommunication – ʳgeo, offers e-learning modules for different topics and target groups, including students as well as UNESCO stakeholders (within the project Space2Place). These applications are already used to train different user groups on the principles of modern geotechnologies. Nevertheless, more training concepts tailored to the specific needs of UNESCO site managers are needed. This was also confirmed by a national needs assessment, conducted by the Institute of Geography & Geocommunication – ʳgeo among UNESCO site stakeholders within Germany on their prior knowledge and training needs regarding geotechnologies, which is currently expanded on an international scale. This global needs assessment systematically collects the level of experience regarding modern geotools among global UNESCO site stakeholders. The survey also collects information on the preferred course format, length, and topics of respondents.

Closing the knowledge gap among UNESCO site stakeholders regarding geotechnologies is one of the main goals of the UNESCO Chair in Heidelberg. Therefore, it is currently working on the development of a multi-level training concept for UNESCO site managers in close collaboration with UNESCO. This concept includes several introductory course formats, which could be completed individually or as part of a University Master Program.

As a pilot program, the UNESCO Chair in Heidelberg cooperated with the Malawi National Commission for UNESCO (MNCU) and the UNESCO Chair at the University for International Cooperation, Costa Rica (UCI), to design and conduct two training courses for UNESCO site stakeholders in the respective countries with the help of four young researchers from three countries.

For both partnering countries, Biosphere Reserves were selected as case studies, as these were closest to the needs of the local partners. Site-specific issues such as drops in lake levels or illegal farming and required skills such as use of satellite images and data collection with mobile devices were identified together with local experts.

Participants were UNESCO stakeholders from the Biosphere Reserves and related governmental organizations. Those participants who completed the pre- and post-course survey reported an increase of their perceived level of knowledge on remote sensing, GIS, and mobile geotools. They displayed a high level of interest in and

motivation for the topic and the collaboration partners voiced an interest in repeating such formats. An analysis to assess the long-term effects of these trainings is currently ongoing.

The results from the course evaluation and the needs assessment will help to design training courses on modern geotechnologies designed specifically for the level of knowledge, needs, and preferences of different UNESCO site stakeholders.

4. Conclusion

While this contribution can just cover a few exemplary use cases of modern geotechnologies for visualization, communication, and education of UNESCO designated sites, it highlights their broad potential. At the same time, it indicates the complexity of available data, applications, and opportunities, thus emphasizing the need for suitable training courses. To develop and conduct trainings that aim at the specific needs of UNESCO stakeholders, these needs must be analyzed and centrally evaluated. A closer collaboration between different UNESCO entities would be beneficial for capacity development. Therefore, the valuable work of the UNESCO Chair in Heidelberg could be supported more efficiently by other UNESCO stakeholders to support their research and training endeavors.

Evidently, there is a pressing need for capacity development initiatives focused on enhancing the utilization of geotechnologies for analyzing and monitoring changes at and around UNESCO designated sites to increase disaster preparedness, resilience, and thereby foster sustainable development. By addressing this capacity gap, the UNESCO Chair of Observation and Education of World Heritage and Biosphere Reserves at the Heidelberg University of Education and its partners can empower site managers with the tools and knowledge needed to effectively mitigate disaster risks and safeguard the UNESCO designated sites under their stewardship.

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