Integrating Remote Sensing and GIS for Cultural Heritage Management: Case Studies of Paphos and Ancient Jeddah

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Abstract. Cultural heritage, which has cultural and historical value, is important and plays an important role in human society. In recent years, many challenges have effect the protection pf cultural heritage. New pressures were brought by rapid urban expansion and frequent natural disasters to heritage conservation. Many previous studies mainly target the use of a single technology or individual case studies, and only a small number carry out systematic comparative analysis. The paper studies how remote sensing and GIS can be of help in monitoring cultural heritage. The research is about the effects of natural disasters and city's growth. Two case studies are used by this research. A case in question is the archaeological landscape of Paphos Archaeological Park in Cyprus. Another instance is the historic district of Historic Jeddah in Saudi Arabia. In the Paphos case, those doing research used Synthetic Aperture Radar and Differential Interferometric Synthetic Aperture Radar. These ways helped researchers to find ground movement after earthquakes. For the case of Jeddah, researchers used satellite images that came from Landsat. Researchers also made use of an analysis of Geographic Information System. With these tools, researchers were able to study how city growth affects the historic area. The research results show that every technology has its particular strengths in heritage monitoring. Different tools are able to show various kinds of information. When researchers use several tools side - by - side, they can obtain a clearer view of possible dangers. The study also gives ideas for using remote sensing and GIS to protect heritage. The research may help researchers to plan better protection strategies in the long - run.

Keywords: Remote sensing; Geographic Information Systems; Cultural heritage management

1 Introduction

Cultural heritage has important historical and cultural value. Cultural heritage also affects the economy and the environment of local areas. In recent years, researchers have faced several problems. Fast city growth has changed many historic areas. Tourism has also increased pressure on heritage sites. Natural disasters have also created risks for

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cultural heritage. These problems have produced new pressures on heritage protection. Early studies have shown that weather conditions such as temperature, snowfall and relative humidity promote the decomposition of natural substances in the atmosphere, which can cause desertification and erosion and the continuous dispersal of land life.It is also becoming more complicated to protect internal buildings. In addition, the task of protecting the inside of buildings is more difficult. In lots of historical buildings without air conditioning, unstable environmental conditions could have negative effects on construction time and materials[1]. These problems highlight the need for systematic monitoring and more efficient management of cultural heritage.

As two important digital technologies, remote sensing and GIS are used more often in cultural heritage research and management. Those doing research can use these technologies to observe spatial changes at different levels of scale, study long - term environmental tendencies, and carry out more quantitative appraisals. In the past few decades, remote sensing and GIS have been extensively used in heritage research worldwide. They've aided researchers in discerning archaeological site boundaries, reconstructing historical landscapes, and detecting potential risks early [2]. These days, technologies like satellite imaging, aerial photography, and UAV - based photogrammetry are commonly used for change detection, land - use analysis, and hazard assessment, including the impacts due to earthquakes, landslides, or hydrological dynamics. A significant example is the Angkor archaeological complex in Cambodia. By means of LiDAR, extensive settlement systems previously hidden under thick vegetation were found, which greatly modified the understanding of the site's spatial extent and historical growth[3].

Although these technologies have been widely put to use, there are still limitations in current research work. Initially, a great many studies tend to implement individual technologies rather than integrate different methods. Therefore, the outcomes remain fragmented rather than setting up an all - around policy - support system. Secondly, a good number of research projects still depend on single - case research studies. However, there aren't enough comparative studies among different regions and environmental conditions. At last, a great number of analytical data can be obtained from remote sensing technologies and systematic mapping (SIG). But, it stays a hard task to change this technological knowledge into practical protection measures that match local management systems and meet social and environmental needs.

To look into these problems, this paper selects two World Heritage Sites in non - identical environmental and cultural settings as case studies: the Archaeological Landscape of Paphos in Cyprus and the Historic District of the Old City of Jeddah in Saudi Arabia. The research looks at how the combination of multi - source remote sensing data and GIS - based analysis can be used in heritage monitoring, risk assessment, and conservation planning. Conducting this comparative analysis, the research tries to gain a more in - depth understanding of the role of digital technologies in heritage management and give references for balancing heritage protection against urban development and environmental change.

2 Theoretical and Technical Framework

With the improvement of digital technology, remote sensing and GIS have become common tools in the research and management of cultural heritage. These devices help researchers to study spatial changes at different size - based scales. They render help to researchers to look into long - term environmental trends. As well, they encourage more quantitative analysis. Remote sensing is a technique to get information without direct interaction with an object. Regularly, it makes use of sensors on satellites or airplanes to obtain spatial data. In recent years, researchers in cultural heritage protection have used this technology more often. On a large scale, remote sensing is able to offer up long - term and continuous spatial data. The data allow researchers to keep track of environmental changes near heritage sites. It can also be done by researchers to study high-resolution images. They can watch terrain changes in heritage sites with the help of these pictures. Researchers can also find potential risks from natural disasters earlier on. This work is of help for the conservation of antique buildings and cultural settings. Remote sensing can be used for the purpose of monitoring land use and land cover too. It supports researchers in discovering problems during the city's rapid build - up, say. These difficulties can be made up of encroachment on land and the loss of farm - plots. Research participants have the ability to compare photos of different years. This way of working enables them to trace land - use changes over time. The data enable researchers to design superior, evidence - based protection measures[4]. Remote sensing is able to survey vegetation and ecological conditions close to heritage sites also. Scientists can look at how vegetation changes during a period of time. The data helps them make sense of the environmental variations near heritage - related sites. It also offers data that is of help to ecological protection. On account of these applications, remote sensing has become an important means for heritage monitoring and management. This technology renders practical technical help to protect cultural heritage better.

GIS is a good medium for managing the information of spatial data. A good deal of researchers and planners make use of GIS for urban planning and in areas with ample spatial details[5]. There is wide employment of GIS in cultural heritage protection also. GIS has a number of primary functions. GIS can perform spatial overlay analysis. GIS can make comparisons of data from different chronological periods. GIS can partition areas in relation to risk level. GIS can present spatial data by means of maps and pictorial presentations. These functions help researchers and managers make a more exact and clear - cut investigation of heritage areas. Researchers can make use of GIS to amass different data sorts. The data could be made up of remote sensing images, historical records, heritage site boundary specifications, and social and economic data. GIS makes it possible for researchers to do an aggregate analysis of these data. Through this process, researchers can detect potential risks near heritage sites. This way of doing the work helps researchers find areas that may face more damage risk. Managers may use the results while making strengthened protection and management plans. GIS causes heritage protection to be more orderly in arrangement and more scientific. GIS gives technical help for the undertakings in heritage management. Commonly, GIS is a tool for spatial analysis and, at the same time, takes on the role of a platform for processing research data[6].

Working in good alliance, remote sensing technology and GIS preserve cultural heritage. The two tools support each other in a mutually dependent way. They help achieve more exact and science - based heritage protection. Remote sensing can find environmental and landscape changes around heritage sites. By means of this technology, researchers can observe how the environment nearby changes over time. GIS functions in a different way from others. GIS can gather and put in order different kinds of spatial data. GIS can also make an analysis of these data. This procedure enables researchers to grasp environmental changes more clearly. It helps researchers to develop suitable protection and management plans too. Researchers often make use of remote sensing and GIS together. The efficiency of heritage monitoring and management can be improved by the two tools. In a good number of heritage protection studies, researchers combine these two technologies. For the process that goes from data collection and monitoring to data analysis and final decision - making, researchers use them. This study has also used this combined method. The main technical process of this study is shown in Figure 1. The figure shows the sequence of the workflow from data collection to analysis and decision - making.

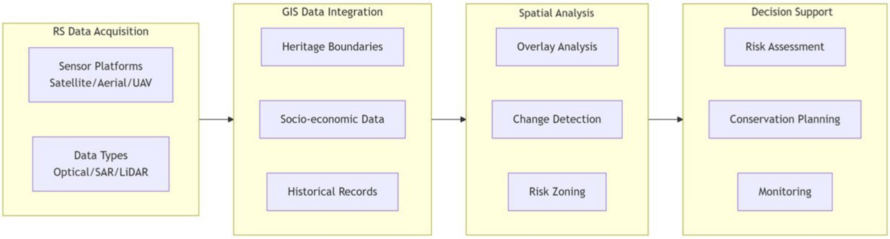

Fig. 1. Technical framework illustrating the synergistic integration of Remote Sensing (RS) and Geographic Information Systems (GIS) for cultural heritage management.

3 Case Studies

3.1 Case Study: Paphos, Cyprus

The Paphos area in Cyprus has special landforms. The area has many archaeological sites and old monuments. One famous site is New Paphos. New Paphos became a UNESCO World Heritage Site in 1980 [7]. Cyprus is located in a place that often happen earthquakes. Many old buildings in this region are fragile and not stable. Because of this, earthquakes have affected the area many times in the past. An earthquake happened on April 15, 2015. The earthquake had a magnitude of 5.6. The earthquake happened about 8 kilometers northwest of Paphos. This type of earthquake can damage nearby archaeological sites and cultural landscapes. So researchers think monitoring heritage sites in this area is very important.

Researchers studied how this earthquake affected the Paphos area by using Sentinel-1 SAR time-series data. These data are free to use. The researchers also used Differential Interferometric Synthetic Aperture Radar (DInSAR) and they processed the data with SNAP open-source software. The study mainly looked for ground changes after the earthquake. The study focused on the area inside and around the heritage zone. The study also examined how ground change relates to the locations of cultural heritage sites. The researchers used this analysis to study possible risks.

The results show several areas of ground change around the Paphos heritage zone. In the study area, vertical movement ranged from −79.43 mm to 102.92 mm . After the researchers removed the parts of the data that were of low quality, the largest uplift was 74 mm. In the 12 - day observing period, the greatest subsidence amount was 31 mm. A number of these deformation areas are overlapping with archaeological sites and landscape features. The result shows possible risks associated with cultural heritage (see Fig. 2). According to what was observed, the combined displacement of the two UNESCO World Heritage Sites, "New Paphos" and "Tombs of the Kings", is very close to zero. This conclusion was verified by means of GNSS data from the PAFO Continuous Operating Reference Station (CORS), part of Cyprus's national CYPOS network. The PAFO station showed only 0. The 5 - mm vertical displacement (statistically insignificant) serves as a "zero reference" for this study's analysis. Slight vertical displacement was only noticed in areas with modern buildings, say, the southern part of "New Paphos" and the eastern side of "Tombs of the Kings". On the contrary, the eastern and northern parts of the Paphos Historical Center were found to have negative vertical displacement (subsidence). Crucially, SAR data had high sensitivity when it came to capturing seismic impacts on heritage environments. Sentinel-1's C-band SAR system detects phase shifts near 2. The line - of - sight displacement is 7 cm per interference fringe, enabling the monitoring of surface deformation at the millimeter level and giving reliable spatial evidence for post - earthquake damage assessment[8].

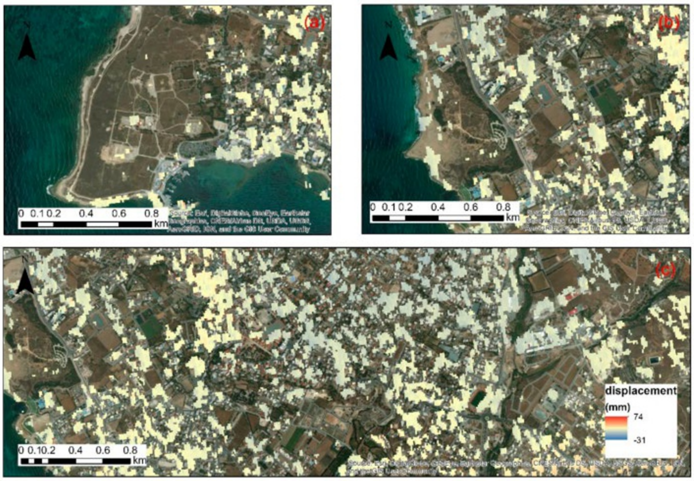

Fig. 2. Final displacement map at (a) Nea Paphos; (b) “Tombs of the Kings”; and (c) historic center of Paphos [8].

What is significant about this study is the provision of a quantitative analytical method for evaluating seismic disaster risks to cultural heritage. Measurable indicators contain displacement magnitude (±mm level) and coherence thresholds (⩾0). 6 for valid analysis and the temporal resolution comes from a 12 - day interval between SAR acquisitions. By making use of open - source software and the free Sentinel - 1 datasets from the Copernicus Programme, the technical and cost thresholds are significantly lowered. So, the methodology can be scaled well in regions with limited funding. This study too has a number of limitations. The Sentinel - 1 Interferometric Wide (IW) mode data used in this piece of research has a spatial resolution of about 2. 7 multiplied by 22 m going as far as 3. 5 × 22 m.Because of the relatively low resolution, detecting very small surface deformation around small cultural heritage relics is difficult. The C - band wavelength is not good at passing through dense vegetation. Thickly - grown plants are capable of reducing the coherence of SAR images. This problem can have an effect on the accuracy of the deformation results. In upcoming studies, researchers may use SAR data of higher resolution. For example, it is possible for researchers to use COSMO - SkyMed data or TerraSAR - X data. These data could play a role in improving monitoring accuracy. Besides, researchers make use of field surveys together with remote sensing analysis. Field surveys make it possible to obtain more direct information. Remote sensing is able to offer data for large areas. Using both methods, researchers are able to get more reliable results. These results can be of help in disaster monitoring and risk assessment in heritage locales. In the D - InSAR data processing, if the vertical baseline is kept within about 200 meters in C - band systems, it can reduce geometric decorrelation and make results more reliable.

3.2 Case Study: Ancient Jeddah, Saudi Arabia

The ancient city Jeddah is of great importance in the Middle East. Many years of Islamic building history can be seen in Historic Jeddah. The buildings reveal a mix of Persian, Mamluk, and Ottoman styles[9]. The main investigative area covers about 67. 14 km^2.The old city covers an area which is about 0. 66 km^2.In 2014, UNESCO designated the ancient city as a World Heritage Site. In recent years, the city has grown fast. Tourism in Jeddah has also increased. These changes have put more pressure on the historic district. At the same time, some environmental problems have appeared in the area. For example, the groundwater level has risen. The groundwater also has high salt content. The groundwater level rose by about 0.12 m each year from 1996 to 2002. These problems make the protection of the historic district more difficult. To examine how urban expansion has influenced cultural heritage conservation in this area, this study used multi-temporal satellite images together with GIS data. The satellite data include Corona imagery from 1966, Spot images from 1986, Landsat images from 1987, Orbview data from 2003, and Sentinel-2A images from 2017, with spatial resolutions ranging from 1.2 m to 30 m. Researchers studied land use and land cover change in Jeddah. The researchers used GIS spatial overlay methods. The researchers also used hot spot analysis with the Getis-Ord Gi* statistic. The study looked at local land use trends in Jeddah. The study also examined how urban growth moved into heritage protection areas and how these areas were managed.

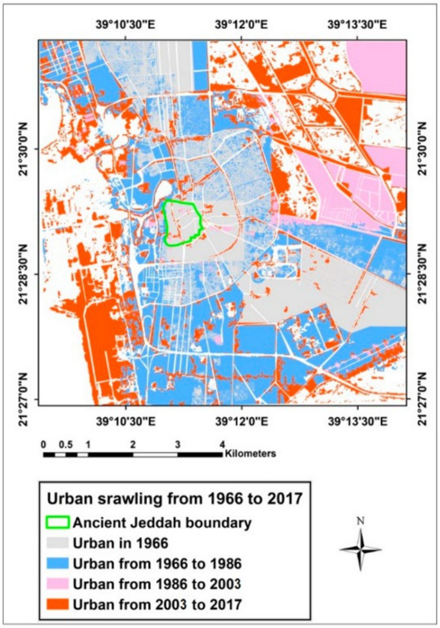

Fig. 3. The total changes in the four studied layers (Barren, Desert, Road, Urban, and Water-bodies) in the study area between 1966, 1986, 2003, and 2017 [10].

The results show that Jeddah had strong urban growth from 1966 to 2017. During this time, the area of urban construction land increased from 12.5 km² to 41.35 km². The total increase was 28.85 km² over 51 years. The speed of growth changed in different periods. From 1966 to 1986, the urban area increased by 15.07 km². From 1986 to 2003, the increase was 4.82 km². From 2003 to 2017, the growth reached 8.96 km². Other land types also changed during this time. The area of barren land changed only a little. The area increased slightly from 14.5 km² to 14.65 km². Desert land decreased a lot. The area fell by 21.07 km², from 25.45 km² to 4.38 km². Water areas also became smaller. The area decreased by 7.93 km², from 11.55 km² to 3.62 km².Some of the city growth moved into the heritage core area. Researchers used GIS overlay analysis and hot spot detection to study this change. The analysis used Z-score and P-value to find important clusters. The results show several high-risk areas that may threaten the heritage zone (see Fig. 3). The map shows that the urban area of Jeddah kept growing from 1966 to 2017. Urban growth formed clear clusters near the old city. The research also suggested some protection plans. The plan includes a 100-meter buffer zone around the boundary of Historic Jeddah. This buffer zone should be a no-construction area. The plan also suggests building three dams to reduce flood risk from nearby streams. The results from remote sensing indices also show that urban areas continued to grow from 1987 to 2017. Areas with higher index values were mainly in built-up zones. Some of these areas slowly expanded toward nearby heritage sites. The finding shows that urban development has put pressure on the historic district. Researchers can use GIS analysis to see the spatial pattern of urban growth. By means of GIS analysis, researchers can understand how this growth affects nearby heritage regions. The analysis is useful in identifying risk areas. The analysis can help in devising buffer zones and development limits around heritage sites. Nevertheless, the study points out a number of limitations. The researchers mainly made use of optical remote - sensing data, for example, satellite images. This kind of data has certain issues. Sometimes, the data is not able to detect very small or local changes. For example, it's not easy for the data to show small - scale structural damage in heritage buildings. Some datasets also come with low spatial resolution. As an example, Landsat TM data has a spatial resolution of around 30 - meter. As a result of this resolution, finding small land use changes is difficult. As a consequence of this limit, researchers are not always capable of getting detailed or continuous information about changes in the study area.

4 Comparative Insights and Implications

The two case studies about World Heritage conservation in Paphos and Jeddah show both common points and dissimilarities. The two cases show obvious differences in data sources, research contexts, and technical approaches. The Paphos study applied SAR data, looking at natural hazards triggered by natural disasters. Using DInSAR technology, it accurately captured the surface deformation triggered by earthquakes. The Jeddah case mainly made use of optical satellite imagery. LUCC analysis and GIS methods were used to investigate the effect of urban expansion on the World Cultural Heritage site.

The study results show a connection between the growth of a city and changes in the nearby heritage milieu. The findings allow people to understand how city development affects heritage sites. Two different research methods were used by the two case studies. Both studies show that remote sensing and GIS can be useful for protecting heritage. These technologies let researchers observe environmental change and possible risks in heritage areas. In the case of Paphos Archaeological Park, researchers made use of Differential Interferometric Synthetic Aperture Radar to study ground vibrations. The method helped researchers to keep track of surface deformation. It also allowed researchers to study possible risks brought on by earthquakes. The Jeddah study carried out a spatial analysis with the help of GIS, offering decision - making support for integrating heritage conservation and urban construction. Both managed to deeply integrate research results with management requirements, like risk zoning and conservation planning.

Regarding methodology, both cases yield significant insights into heritage conservation research. In the study of different kinds of cultural heritage, choosing suitable data sources and research methods is important. At the same time, future research may integrate different data kinds to decrease limitations from using only one technology.

Both give heritage sectors reference protection strategies under different situations. Heritage sites under high natural - disaster risks, say frequent earthquakes, can take the technical approach from Paphos to realize early disaster warning and exact appraisal. For heritage sites under the effect of rapid urban development, the research way from Jeddah can be used to balance urban growth and heritage site preservation measures.

5 Discussion

This cross - case study looks into the comparison of ways to conserve cultural heritage in two different regions. It broadens the application scope of remote sensing and GIS in heritage conservation research. It not only supplements existing studies but also offers insights for future conservation work in various contexts. Actually, the dynamic monitoring skills of remote sensing, in combination with GIS spatial analysis, empower heritage management authorities. The applications are earthquake risk early warning, land use change monitoring and control, and scientifically defined buffer zones, increasing conservation efficiency and rigor. Nevertheless, limitations are present: the small number of case studies cannot stand for all heritage protection types or situations. Second, the resolution and acquisition cycle of remote - sensing data have had an effect on the exactness and timeliness of monitoring to some degree. Specifically speaking, the outcomes of technical analysis still call for verification by means of field investigations to improve the accuracy and reliability of research conclusions. Future studies could enlarge the scope of case - study examples, add more data, and improve the link between technical analysis and fieldwork to advance cultural heritage conservation research.

6 Conclusion

Through a study of the case studies of Paphos and Jeddah, the paper intends to compare the use of cultural heritage detection in two different circumstances. The Paphos case proves the worth of SAR in monitoring disaster - related risks. At the same time, the Jeddah case shows the role of optical imagery combined with GIS in urban change. Both cases make known the complementary characteristic of remote sensing and GIS. Academically, this research extends comparative perspectives among case studies. Practically, this study can offer valuable references for heritage management authorities when facing challenges like natural disasters and urban expansion. Future investigations can make use of more than one kind of remote sensing data. Researchers are able to combine SAR data, optical images, and UAV images. This method is able to improve monitoring results. Researchers can use new digital tools also in the future period. As an example, AI and deep learning can help make sense of large amounts of data. These tools might also contribute to the rise of the level of automatic data analysis. Researchers are able to build a larger and more complete database for the purpose of global heritage monitoring. This type of database has the means to store different kinds of data on heritage sites. The database is useful for researchers to track long - term changes. The database will also be able to support the protection and management of cultural heritage later on.

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