Resilience of Cultural Heritage in Extreme Weather Conditions: The Case of the UNESCO Villa Romana del Casale Archaeological Site's Response to the Apollo Medicane in October 2021

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Abstract. The conservation strategies of cultural heritage (whether it is movable or immovable), in response to damage resulting from the natural phenomena of aging and decay but also from the occurrence of disasters (earthquakes, floods, fires, etc.), inevitably require a methodological approach aimed at planned conservation and preparedness for the risk event of the cultural site. In this perspective, between 2007 and 2012, the intervention of recovery and conservation of the archaeological site of Villa Romana del Casale in Piazza Armerina (Sicily, Italy), since 1997 inscribed in the list of UNESCO World Heritage Site, was planned and realized. The project, directed by the Centro Regionale per la Progettazione e il Restauro, Regione Siciliana, was aimed not only at carrying out the conservative intervention of the monumental site and its decorative apparatus, but also at drawing up a protocol for preventive maintenance. This protocol concerned the new covering system of the archaeological site, its protection and fruition, as well as the hydrogeological asset of the territory on which it rises. Concerning this last aspect, in fact, since the early Middle Ages the fonts document serious floods that interested the area on which the Villa del Casale is located. These floods inevitably interacted with its conservation history, even influencing its existence. The damages caused by the flood of October 1991 are documented, when the archaeological area was already excavated thanks to the archaeological campaign directed by the archaeologist Gino Vinicio Gentili. These excavations were themselves influenced by the flood of 1951 that covered the area still partially explored. This study, considering the previous impact on the UNESCO site of the weather event of October 1991, analyses the occurrence of October 2021

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and the construction's positive response to the stress caused by the meteorological phenomenon. The investigation was performed using ground-based and satellite-based measurements, to provide a detailed overview of the extreme event that occurred, to identify the pressures that insisted on the studied site. The analysis highlights the effectiveness of recovery and conservation project carried out on the monumental complex and completed in 2012.

Keywords: Meteorology · Cultural Heritage · Archaeological Site · Flooding · Resilience

1 Introduction

At about 5 km south-west from the city of Piazza Armerina, in the province of Enna in the heart of Sicily, Italy (coordinates: latitude 37°21'53", longitude 14°20'04.39"), at the western slopes of Mount Mangone, near the exit of a side vallecula in the valley of the Torrent Nocciara, is located the archaeological area of the Villa Romana del Casale (Fig. 1). Since 1997 the site is included in the list of UNESCO World Heritage Sites as a "sublime example of a luxurious Roman Villa" for the exceptional nature of its mosaics. Residential building of late antiquity (IV sec. AD), built on a previous rustic Villa of the I–III sec. AD, the site was, with alternating events and transformations, inhabited continuously until around the 12th century AD, due to a powerful flood a thick layer of mud has covered and delivered to oblivion [1–3].



Fig. 1. View of the Villa Romana del Casale after 2012 intervention (photo by Guido Meli ©)

In the 15th century there is evidence of a Village called "Casale", risen above the Roman ruins and the early medieval Arab settlement then inhabited by the Normans. Also this rustic Village is destroyed by successive floods. The repeated

burials that occurred over time have meant that the late antique structure was preserved below the superstructures of the Byzantine and Arab-Norman periods. It is only at the end of the 18th century that the emerging ruins of the "Contrada Casale" begin to attract the interest of scholars and foreign travellers as well as antiquities dealers and clandestine diggers. Another flood in the first years of the 19th century does not allow to evaluate the entity of the damages due to the robberies perpetrated at the end of the 18th century. The first official archaeological excavations, which brought to light most of the ruins and mosaic floors, began in the first decade of the 19th century and then again in the first decades of the 20th century. However, after the Second World War, from 1949 to 1956, the archaeologist Gino Vinicio Gentili led the most complete work of discovery of the Villa del Casale site (Fig. 2) [4].

After the announcement of the competition for the design of a covering system of the monumental complex, the choice fell on the project signed by the architect Franco Minissi who carried out the work between 1957 and 1967, giving rise to an innovative architectural solution for that time that closes the perimeter wall returning the ancient volumes to the Roman Villa (Fig. 3) [5].

This solution, although valid in its design idea, will reveal itself soon disastrous from the point of view of conservation for the mosaic floors and wall paintings because of the materials used, their progressive deterioration over the years and microclimatic conditions absolutely unsuitable not only for the preservation of artefacts but also for the well-being of visitors [6]. The site, unearthed, suffers considerable damage in the 90s of the last century, in particular a flood in 1991 (Fig. 4) that again covers the rooms of the Villa with mud; in that period are

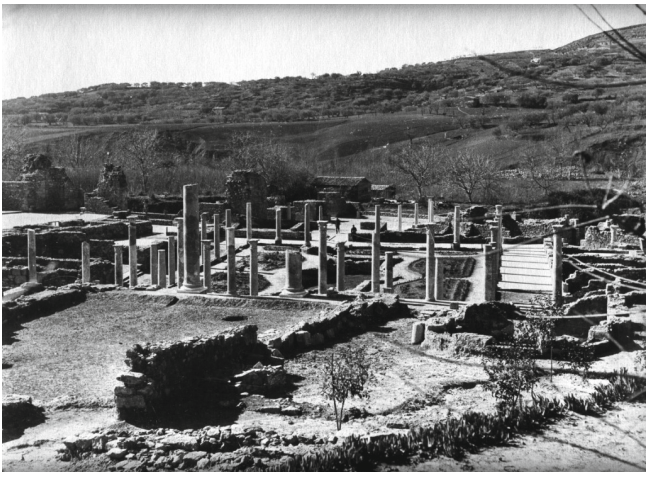

Fig. 2. Villa Romana del Casale: detail of Peristilium, during the G.V. Gentili's excavations in 50s of last century (source: Archive of Soprintendenza dei Beni Culturali ed Ambientali di Enna [7])



Fig. 3. View of the Villa Romana del Casale with F. Minissi's covering system before 2012 intervention [7]

also documented repeated acts of vandalism on the mosaics, occurred between 1995 and '98.

The progressive decay of the covering system, highlighted with more attention, activates the Centro Regionale per la Progettazione e il Restauro (C.R.P.R.), Assessorato dei Beni Culturali ed Ambientali e della Pubblica Istruzione of Regione Siciliana to start an articulated activity of study and research on the conservative issues, which characterize the archaeological site and its decorative apparatus. After a first project phase stopped in 2004, in 2005 the "Project for the recovery and conservation of the Villa Romana del Casale of Piazza Armerina" is presented by the C.R.P.R., under the direction of architect Guido Meli, then director of the C.R.P.R., and in accordance with the guidelines dictated by the newly appointed High Commissioner for the Villa Romana del Casale, Vittorio Sgarbi, whose work finally started in 2007 by the Consortium O.B.C. of Florence [7].

The complex recovery project, concluded after five years with the inauguration on July 4th, 2012 of the new musealization of the site (during this long period the archaeological area has never been closed to the public), involved not only the restoration of over 3,500 m^2 of mosaic floors and opus sectile but also the restoration of wall paintings that decorate about 50% of the walls of the rooms. The intervention included the replacement of the obsolete covering system, the design of new suspended walkways, less invasive for the visit path, as well as a new lighting system, also provided for the evening openings, and the reorganization, from the hydrogeological and naturalistic point of view, of the area on which stands the entire archaeological site. The intervention of recovery, in fact, started with the restoration of the mosaic floors, has also involved the work of drainage and regulation of the waters that cross the Villa, by means

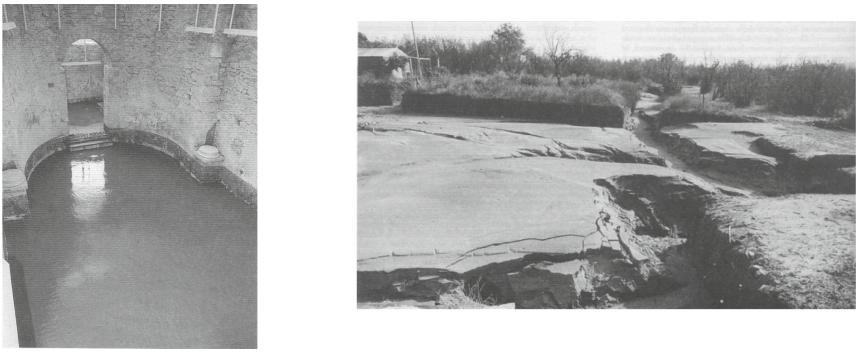

Fig. 4. Villa Romana del Casale after flooding of 1991, details: inside on the left; outside on the right (source: Archive of Soprintendenza dei Beni Culturali ed Ambientali di Enna [7])

of canals, and those that soak the perimeter walls. The existing original system of small canals inside the Villa has been recovered and re-functionalized as well as an excavation has been made along the perimeter of the walls of the Villa, in order to create a barrier to water infiltration with a draining and breathing system for the masonry. Water has always played a major role in the existence of the site, not only as water brought into it with a sophisticated hydraulic system of canals to meet the needs of daily life, but also for the conservation history of the archaeological area, related to decay phenomena due to the presence of groundwater, surface water and rainwater. Above all, the part of the Villa exposed to the north-east was the one most at risk for the runoff of the latter because of a marked variation in the altitude of the ground that in its direction made them convey. For this reason, interventions were also made on the structure of the surrounding areas, mitigating the risk of hydrogeological instability and flooding.

A fruitful occasion for the assessment of the resilience of the Villa downstream of the safety works, was certainly the event occurred in October 2021, during which a medicane called Apollo hit central-eastern Sicily. The event was monitored and followed in its different phases, using both conventional meteorological analysis tools (i.e. rain gauges, radar, NWP models) and more recent techniques (i.e. satellite products).

In recent years, the frequent occurrence of intense meteorological events has driven the scientific community to employ more and more data sources (e.g. rain gauges [8], radar [9], radiometers [10], NWP models [11,12], satellite products [13–16], GNSS [17], lightning [18]) that, properly integrated and analysed, provide effective support in the description of these phenomena [19].

In this paper, after an overview on site features and performed structures, a focus on the Apollo event is provided employing both ground-based and satellite-based techniques. A spotlight on the area's resilience precedes the final conclusions.

2 Site and Performed Structures Overview

The entire site of Villa Romana del Casale of Piazza Armerina is located, as previously described, in an area with hydrogeological problems related to frequent flooding events, thus giving rise to numerous issues of physical-chemical and biological nature. In fact, over time, several geological movements have been registered that have created instabilities in the structures, with the formation of cracks, lesions, detachments and especially significant deformations of the mosaic surface, consisting of depressions and lifts. These consequences were more evident in the rooms where the mosaic was still lying on the original laying surface. The water coming from the foundations and from the layers of alluvial soil leaning against the external walls caused the capillary transmission of humidity on the surface and the loss of the chemical-physical characteristics of the mortars and therefore the disaggregation of the different layers of the substrate. It also contributed, in a predominant way, to the process of alteration of the different constituent materials [7]. The issue regarding the hydrogeological situation of the sites was known since a long time [4]. From the information acquired during archaeological excavations, we know that the archaeological site of the Villa del Casale has shown, since its discovery, a sensitive vulnerability to natural events such as landslides and floods. In particular, despite the absence of maps of the survey points, the investigation conducted by engineer Luigi Pappalardo in 1881 is of significance [20].

Gentili, at the conclusion of the 1956 excavations, based his thesis of a hydrogeological disaster on the objects found and on stratigraphic examination: "The Platia then moves, giving life to the current Piazza Armerina, while in the site of the Roman monument, will arise a few decades later still a rural Village of poor hovels, destined to succumb under the earthy burden of a flood that, for the changed conditions of the environment now devoid of ancient forests, came down by landslide from the hills above" [4].

The most recent and significant flooding events which have affected Sicily and which have had relevant impacts on the territory of Enna are, in particular, the one recorded on October 15th, 1951, the one of December 31st, 1972 and the most recent one of October 1991. On the October 12th, 1991 in fact, the province of Enna was affected by strong perturbations that caused the covering of vast areas of the Villa Romana del Casale (from a few centimetres up to a meter thick). The alluvial lime came from the overflow of one of the tributary channels of the Torrent Nocciara (Fig. 4), tributary of the River Gela at the highest altitudes of Mount Mangone. The formulation of a geological model of the subsoil of the Villa appeared as necessary as ever in consideration of the particular location of the same in a conoid of alluvial origin, with lithological horizons characterized by a complex lay, seat moreover of phreatic water table close to the ground level.

It was possible to delineate the geomorphologic and hydrogeological conditions of the area, to characterize the present soils from a geotechnical and geoseismic point of view. The issues addressed concerned, first of all, the effects of damming of surface waters caused by the presence of backfill materials accu-



Fig. 5. Geomorphological and hydrogeological interventions in the Villa Romana del Casale area (2007–2012): a) north western thermae area contact earths and b) related earthworks; c) and d) works for the realization of the drainage canal downstream of the Villa for the convoying of water to the river; e) works for the cleaning of the original drainage canal, realized upstream the Villa; f), g), h) execution of works to safeguard the masonry: perimeter excavation under foundation and placement of sheets and drainage pipes (photo by Guido Meli ©)

mulated downstream of the Villa (dam effect), for which it was necessary to remove a large section of these materials, in order to allow the rapid flow of water. Another issue was related to the presence of the phreatic water table close to the topographic surface. For this one, rather than assuming an artificial depression of the piezometric through forced drainage, probably harmful to the statics of the archaeological complex, it was thought to a rational exploitation in terms of balance between the quantities taken and those of natural water recharge. Finally, the conditions of morphological balance of the area close to the riverbed of the Torrent Nocciara have been improved, through the creation of a green area in the tract between the new access road to the Villa and the torrent itself, with consequent water regulation. The intervention has also planned the recovery of existing sections of the original water system of the Villa, related to networks of adduction, latrines, fountains, sheet of water, baths, aqueduct, and network of capture and disposal of water. The work carried out has allowed, in this way, to recover a correct reading of the original system of canalization of rainwater and water adduction, used inside the building of the Villa and for the operation of the thermal building, while avoiding the dispersion of water, due to clogging of the pipes, never before inspected and cleaned. The works of improvement of the water canals regulation system concerned the whole perimeter of the Villa, excavated on the back of the walls, until reaching a level lower than the sea floor. In this section of the ground, in the bottom and in contact with the masonry, a double membrane sheet was placed, breathable to the outside but, at the same time, preventing the entry of water from the outside. On the bottom of the main canal, thus created drainage pipes were placed in order to convey all the water canals to the lower part of the Villa, outside its perimeter, and then flow into the vast area (residual of the Gentili excavation) downstream of the baths (Praefurnia). In this area a drainage pipe was placed of adequate size that has allowed removing the water from the area and conveying the flow downstream to the torrent below (Fig. 5) [7].

3 Case Study: Apollo Medicane, October 2021

During the last ten days of October 2021 a Mediterranean cyclone, named Apollo, develops over the sea south of Sicily. Throughout the event analysis, the study of the atmospheric high layers clearly revealed that a split of the polar jet stream forced the development of Apollo over North Africa and Sicily; this resulted in a direct exposure of the mentioned territories and consequently of the UNESCO archaeological site discussed in this paper.

3.1 Weather Event Description

The event of interest was monitored continuously through both ground and satellite data; this allowed a detailed description of the occurrence of which here, for the sake of brevity, we provide the main outputs.

Ground Data Analysis. In Fig. 6 the product of merging between DPC radar and rain gauges , which shows the accumulated rainfall over the whole period from October 22nd, 2021 at 00:00 UTC to October 29th, 2021 at 23:55 UTC, points out the large amount of precipitation occurred on Sicily, southern Italy, during the pinpointed event.

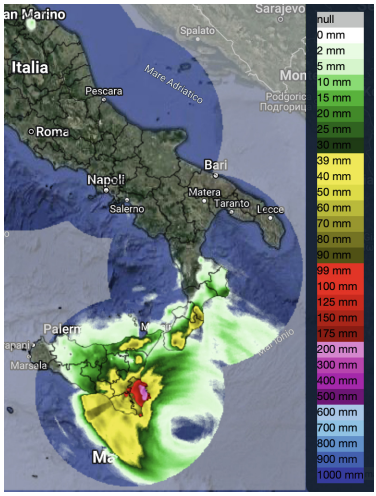

Fig. 6. Merging DPC radar and rain gauges - accumulated rainfall over the whole period from October 22nd, 2021 at 00:00 UTC to October 29th, 2021 at 23:55 UTC [21]

It is interesting to remark that throughout the analysed period the rain gauge of the Municipality of Piazza Armerina (Fig. 7) registered a total precipitation of almost 180 mm (94.2 mm only on October 22nd, 2021) [22].

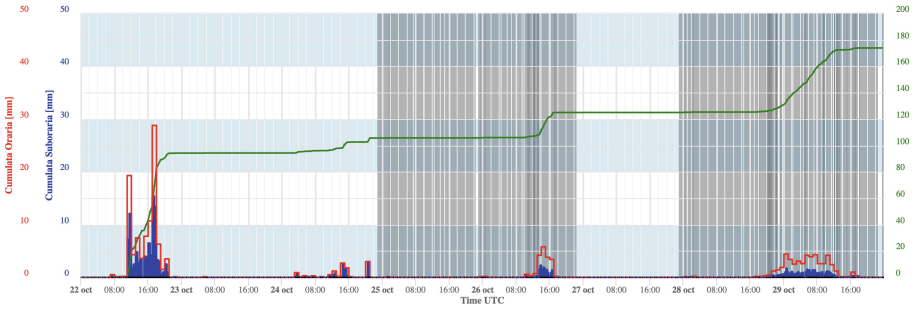

Fig. 7. Piazza Armerina rain gauge output [21] - Time period from October 22nd, 2021 at 00:00 UTC to October 29th, 2021 at 23:55 UTC

In Fig. 7 sub-hourly (blue), hourly (red) and total (green) cumulative rainfall are given; the grey areas represent the real-time data lack. Although the intense rainfall caused flooded areas and landslides in the surroundings [22], the archaeological site investigated in this study made it through the event without significant damage.

Satellite Data Analysis. A continuous monitoring of the Apollo event was carried out by satellite acquisitions, using different kind of products and data (i.e. precipitation, cloud properties, soil moisture, flooded area). In this frame, Meteosat satellite is particularly useful for observing and monitoring weather events. Using the IR channels, it is possible to follow the evolution and trajectory of the structure every 15 min. Figure 8 shows for each of the 9 days ranging from 22nd to October 30th an acquisition of the IR channel at 10.8 microns. In the afternoon of October 22nd (a), about 94 mm of rainfall were registered by the Piazza Armerina rain gauge. The phenomenon evolution is given in panels (b) and (c). In the early hours of October 25th (d), the cyclone formed close to the coasts of North Africa and continued its trajectory (e) towards the east/south-east until October 27th (f). On October 28th (g) it strengthened and moved closer to Sicily, reaching its closest point to Italy on October 29th (h). Finally, from October 30th (i) it has definitively moved south-east towards the coasts of Libya.

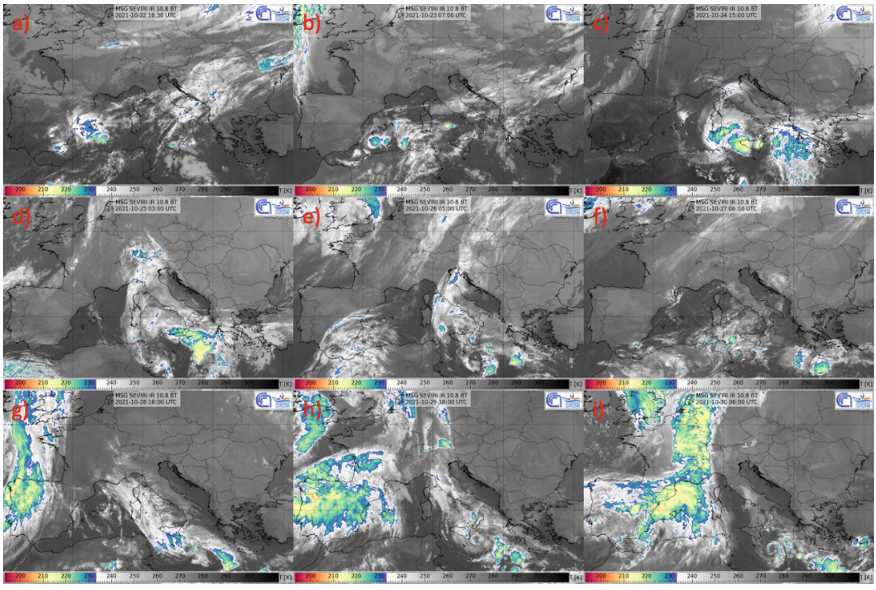

Fig. 8. MSG IR 10.8 micron acquisitions from 25th to October 30th, 2021. Red circle highlights the centre of the Cyclone for each day.

In this context, data from H SAF consortium (supported by EUMETSAT), which provides satellite-based products for hydrology purposes, are particularly useful to better analyse the phenomenon. In particular, the estimation of surface precipitation is one of the objectives pursued by this project and for sure it includes interesting products for our study.

Instantaneous precipitation rate as well as temporally accumulated (hourly up to 24-hourly) precipitation is estimated both from passive microwave (PMW) measurements from Low Earth Orbit (LEO) satellites and from IR data from geostationary (GEO) satellites [13]. So, the products that more than others allowed us to follow the evolution of the event are those based on the SEVIRI sensor on board the MSG, named respectively P-IN-SEVIRI-PMW (H60) (instantaneous) and P-AC-SEVIRI-PMW (accumulated) (H61).

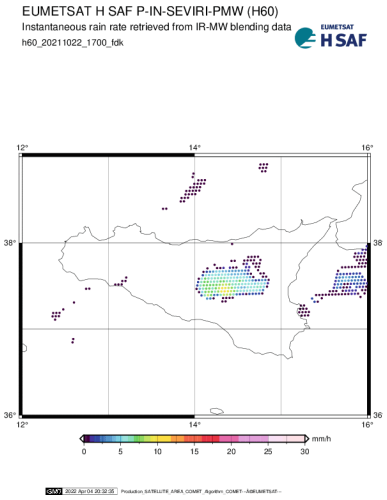

Fig. 9. Instantaneous precipitation rate (H60) - October 22nd, 2021, 17:00 UTC

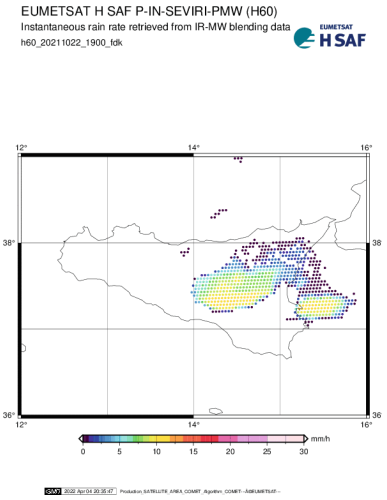

Fig. 10. Instantaneous precipitation rate (H60) - October 22nd, 2021, 19:00 UTC

Both exploit the precipitation rate estimates derived from PMW sensors and the MW/IR blended rapid-update technique, and provide the instantaneous precipitation rate every 15 min (H60) and the hourly and daily accumulated precipitation (H61). Figures 9 and 10 are two images of Instantaneous precipitation rate (H60 product), whereas Figs. 11 and 12 are two pictures of Hourly accumulated precipitation (H61 product). Both products are given for October 22nd, 2021, at 5:00 p.m. and 7:00 p.m., respectively, and clearly show the magnitude of the event that hit the area. Considering the exceptional nature of the event, highlighted by the above observations, the response of the UNESCO Villa Romana del Casale site to these stresses is of particular importance and interest.

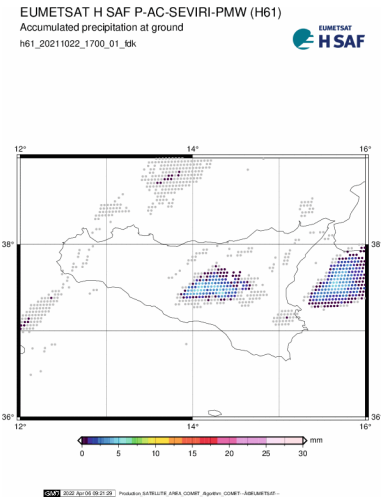

Fig. 11. Hourly accumulated precipitation (H61) - October 22nd, 2021, 17:00 UTC

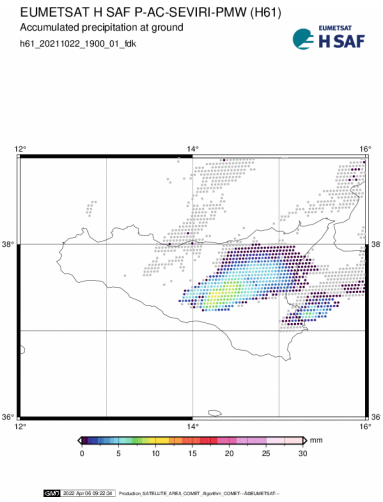

Fig. 12. Hourly accumulated precipitation (H61) - October 22nd, 2021, 19:00 UTC

3.2 Archaeological Site Resilience

It can be affirmed, today, that the Villa Romana del Casale has been well protected from the recent meteoric events, of medium intensity but, also, from the exceptional meteoric event occurred at the end of October 2021, exactly three decades after the last episode (October 12th, 1991). In fact, the eaves canals built in concrete, after the flood of 1991, to collect water from the slope of Mount Mangone upstream of the site, as well as the functional recovery of the system of canals that convey water, inside the monumental building, realized under the Project of recovery and conservation of the Villa Romana del Casale managed by the C.R.P.R. and concluded in 2012, have fulfilled their task. The project, directed by architect Guido Meli, also included a plan for the preventive maintenance of the site over time. In fact, it is now well known that the policy of prevention is at the basis of planned conservation in order to avoid the recurring to restoration, considered as an exceptional event, traumatic and therefore expensive. The definition of specific protocols for planned conservation must be preceded by a careful evaluation of the phenomena and dynamics that characterize the hazards present in the area and the vulnerabilities of the cultural site in its entirety [7].

The phase of study and research preliminary to the planning of the restoration, as mentioned above, has allowed to analyse in depth all the aspects related to the geological and structural characterization of the archaeological site, as well as the knowledge from the chemical, physical and biological point of view of its decorative apparatus, being able to verify the causes of the damages detected. The overall state of conservation, after the interventions of the last thirty years,

can be defined as satisfactory, but the characteristics of the site require a continuity of maintenance and care of all its constituent elements, almost continuous, able to effectively counteract the causes of the processes of decay and alteration. With regard to the risk arising from increasingly frequent extreme weather events, at the international level in general, the measures and strategies that are included in the plans for risk reduction and management are still sporadic. UNESCO, for example, is only requiring since 2019 for the inclusion of a site in the World Heritage List, the definition of the plan of risk management of the site, highlighting how important it is to develop strategies that are in line with the United Nations Sendai Framework for Disasters Risks Reduction 2015–2030 [23]. Mainly, attention was paid to "Priority 4 -Enhancing disaster preparedness for effective response", in which the European Commission is committed, also through a specific study [24], concerning the safeguarding of cultural heritage against natural and anthropogenic disasters. In the recommendations provided, for the safeguard, it is indicated the promotion of the use and application of earth observation data (satellite data), the development of dedicated alert systems and the realization of local risk maps with a high spatial resolution.

The frequency and magnitude of extreme climate events such as heavy precipitation, flooding and drought, due to climate change, produces disasters and significant damage to cultural heritage increasingly. These phenomena, defined Rapid Onset Disasters (ROD) are in addition to the natural aging processes of cultural heritage and decay due to the Slow Onset Disasters (SOD), increasing its exposure over long term risks. For this reason, there is an urgent need for analytical methodologies and technological tools for multi-risk assessment that truly enables cultural heritage managers, policy and decision makers to be able to cope with emergencies promptly and appropriately basing decisions and actions on the principles of knowledge and preparedness [23,24]. In fact, research in this area is developing new methodologies and applications [25–27].

The "Parco Archeologico della Villa Romana del Casale e delle aree archeologiche di Piazza Armerina e dei Comuni limitrofi" has drawn up its first Management Plan in 2012 [28] and since 2020 it is being updated, also comparing the current situation with the one of 2012, corresponding to the restoration work, carried out by the C.R.P.R. For this aspect, therefore, the management of this UNESCO site is at avant-garde both in the national and international context.

4 Conclusion

The definition of the Protocol for the planned conservation of the archaeological site and its decorative apparatus allowed to mitigate and, in part, to eliminate the intrinsic vulnerabilities and prevent further restoration interventions. The writing of the Villa Romana del Casale Management Plan, which is being updated since 2020 compared to the post-restoration edition of 2012, turns out to be a fundamental tool for the response of the archaeological site to possible damage from environmental and anthropogenic causes. This action is perfectly in line with what is established in Priority 4 of the United Nations Sendai Framework

for Disasters Risks Reduction 2015–2030. Specifically, a proof of the effectiveness of such a management policy was provided by the occurrence of the late October 2021 flood. The exceptional meteorological event, whose evolution was presented in this work, affected, with its exceptional power, the central-eastern Sicily involving, therefore, also the area on which is located the Villa Romana del Casale. For the first time, in the history of its existence, the archaeological site did not suffer any damage because of this umpteenth flood that, instead, proved disastrous for the city of Piazza Armerina and the surrounding areas, as documented by local testimonies and reported by the main sources of information [29–31].

Acknowledgements. Agreement between CNR-ISAC and Parco Archeologico di Morgantina e della Villa Romana del Casale di Piazza Armerina (Protocol number 289, signed on 3 February 2020). Part of this work belongs to the H SAF Project. The authors would like to thank Antonio Oriente (National Civil Protection Department) for his expertise and helpfulness.

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