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THE DATES OF ABANDONMENT AND DESTRUCTION OF MORGANTINA AND THE TREND OF AVERAGE RAINFALL IN THE LAST TWO MILLENNIA ESTIMATED BY THE BURIAL OF THE *AGORA* WITH THE RUSLE METHOD♦

Il metodo RUSLE, pur presentando criticità concettuali, è ampiamente utilizzato e validato negli studi di geomorfologia e idrogeologia ma trova scarsa applicazione in campi di ricerca come la geoarcheologia. In questo studio si è cercato di utilizzare le potenzialità di questo metodo nell'area archeologica di Morgantina, dove la grande quantità di dati storici, archeologici e geologici disponibili ha permesso di minimizzare queste criticità e soprattutto di avere un controllo sull'affidabilità dei valori assunti per i vari fattori di calcolo e sui risultati ottenuti. Lo studio si è basato sul confronto tra il volume di terreno scavato durante le varie campagne archeologiche per portare alla luce le rovine dell'agora di Morgantina e il volume di detriti che ne ha determinato l'interramento a partire dalla data di abbandono e/o distruzione della città. I risultati ottenuti hanno permesso di confermare l'ipotesi del 50 d.C. come data di abbandono definitivo della città greco-romana e di convalidare l'andamento delle precipitazioni medie degli ultimi 2000 anni, desunto in precedenza mediante studi paleoclimatici. Inoltre, è stato possibile formulare l'ipotesi che il sistema idrico-fognario della città abbia potuto continuare a funzionare, anche se in modo ridotto, fino al 365 d.C., quando fu irrimediabilmente messo fuori uso da un violento terremoto che distrusse anche la maggior parte degli edifici della città. In conclusione si ritiene, anche se con le dovute cautele, che l'uso del metodo RUSLE possa essere accreditato anche nel campo della geoarcheologia, auspicandone la sua applicazione in altri casi di studio.

Introduction

This study is part of the ongoing geoarchaeological research on the archaeological site of Morgantina (central Sicily) since 1993. The large amount of data acquired and the many multidisciplinary issues addressed, the results of which have recently been published in the series of Geoarchaeological Guides of Italy[1], have made it possible to unravel many of the mysteries that have characterized this site since the first archaeological excavation campaigns. In fact, having overcome the "impasse" of the identity of the site and the name to be attributed to the city by archaeologists, numerous questions have remained unresolved for several decades, first of all the motivation and the date of depopulation and abandonment of the city. The first

♦ We would like to acknowledge the Arch. Flavio Alessandro Bruno for the expertise shown in the realization of *fig*. 3.

1) Bruno 2017.

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hypotheses about the reasons why the city, starting from the second century B.C., gradually began to depopulate and was definitively abandoned in the first century A.D. were put forward at the end of the 90s of the last century[2] and subsequently confirmed after in-depth studies and hydrogeological balances[3]. While it seems now well established that the depopulation and abandonment of Morgantina is due to a strong depletion of the hydro-potable resource of the area due to a climate change, the date of definitive abandonment of the site remains doubtful. The objectives of this research, therefore, are to estimate this date and, at the same time, to try to validate the climatic trend of rainfall in the last 2000 years, proposed in previous paleoclimatic studies[4]. The methodology used to achieve these objectives, unconventional and indirect, is based on a comparison between the volume of soil that archaeologists had to excavate to bring out the archaeological remains of the *agora* and the volume of debris eroded from the slopes and accumulated in the area of the *agora* (upper and lower) of Morgantina, in the period of time between the year 50 A.D. (assumed date of abandonment of the city) or 365 A.D. (date of destruction of the buildings due to an earthquake) and the year 1955 (date of the beginning of the annual archaeological excavation campaigns). In detail, it was necessary to calculate the volume of soil excavated, using topographic mapping of the area at a scale of 1:10,000 and expeditious analytical formulas (Torricelli's formula), then, to implement in the QGIS environment and in the catchment area underlying the *agora* the RUSLE equation (Revised Universal Soil Loss Equation) widely used to assess the annual volume of debris produced on the slopes of a given catchment area due to meteoric erosion[5] and recently also in geoarchaeological studies[6].

The burial volume of the archaeological remains present in the *agora*

The first step of the research consisted in estimating the volume of debris that, during the various excavation campaigns, archaeologists had to excavate to bring out the remains of the building as we can see them today in the area of the upper and lower *agora* (*fig.* 1).

The estimate does not derive from the calculation of the volumes effectively excavated, deduced from the excavation reports, but from an *a posteriori* calculation, based on the available cartography and excavation news and the use of Torricelli's expeditious formula, widely used in topography for the calculation of volumes (*fig.* 2).

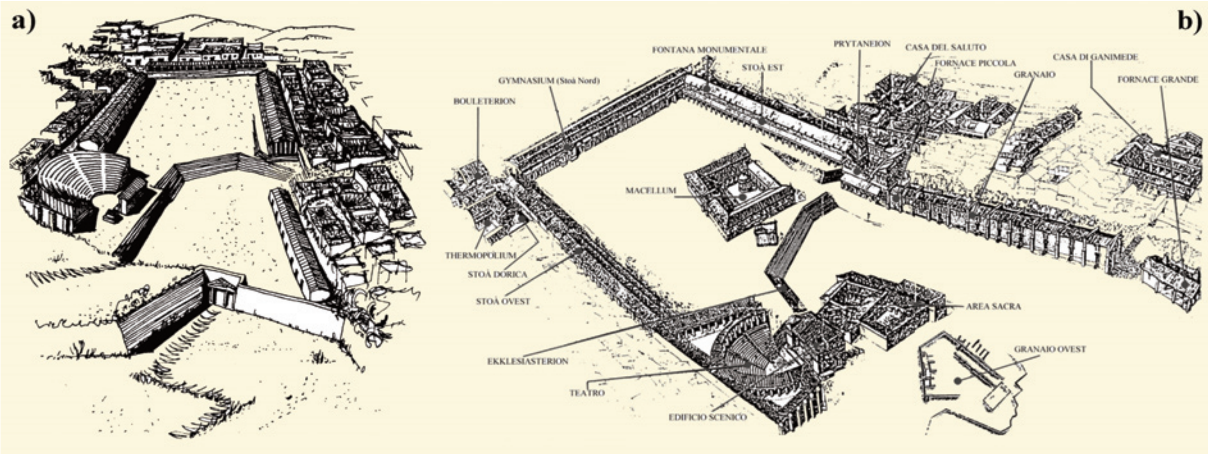
Before summarising the results of the calculations performed, it is necessary to make the following remarks:

a. The cartography used is the contour-line restitution of an aerophotogrammetric survey of 1960 after which came over 50 years of excavations, altering the morphology of the area;

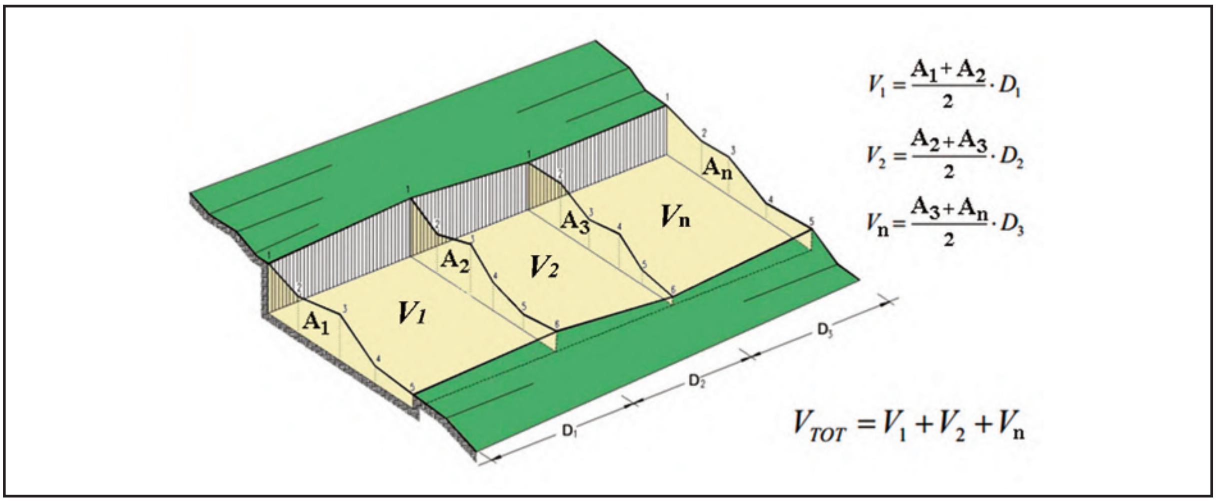
b. Since the start of the annual archaeological excavation campaigns (year 1955) the pathway of the rainwater flooding the site has been regulated in order to protect the archaeological heritage;

c. The archaeological reports of the excavations show that between March and June 1957, the third season of excavations by Princeton University, the area of the *ekklesiasterion* (lower *agora*) was buried under a thickness of cm 450 of debris-alluvial sediments[7]; in

2) Bruno, Nicosia 1998; Schilirò *et al.* 2000; Bruno, Renna 2000.
3) Bruno 2015; Bruno *et al.* 2015a; Bruno 2017.
4) Sadori *et al.* 2013.
5) Wischmeier, Smith 1965; Wischmeier, Smith 1978; Renard *et al.*1991; Renard *et al.*1997; Stone, Hilborne 2012.
6) Vaccaro *et al.* 2013.
7) Sjöqvist 1958.



1. RECONSTRUCTION OF THE BUILDINGS PRESENT IN THE MORGANTINA *AGORA*: A) BEFORE THE EXCAVATION OF THE *MACELLUM* (UPPER *AGORA*) AND THE SACRED AREA OF THE CTHONIAN SANCTUARY (LOWER *AGORA*); B) AFTER THESE EXCAVATIONS (modified from: KYLLINGSTAD 2018; http://sgi.isprambiente.it/geositiweb/files/dis/2931/nuova%20immagine.png; last accessed 4 October 2021)



2. CALCULATION SCHEME OF THE EXCAVATION VOLUMES WITH TORRICELLI'S FORMULA (Bruno G.)

2013, also the area of the *macellum* (upper *agora*), in correspondence with the trench I.150[8], had a sediment thickness of cm 317;

d. The buildings, of which only the foundations and the basal part of the walls in elevation remain today, certainly had to be completely above ground in order to fulfil their functions at the time of their frequentation and/or abandonment of the city;

e. From the date of abandonment of the city until that of the excavations of the archaeological remains, it is assumed that there have been no significant changes in the area's morphology, except for those changes brought on by nature, as it has been verified and documented in specific studies on the apparent different average sedimentation rates between the upper and lower *agora* and on the landslides of the slopes overlooking it[9];

8) WALTHALL *et al.* 2014.

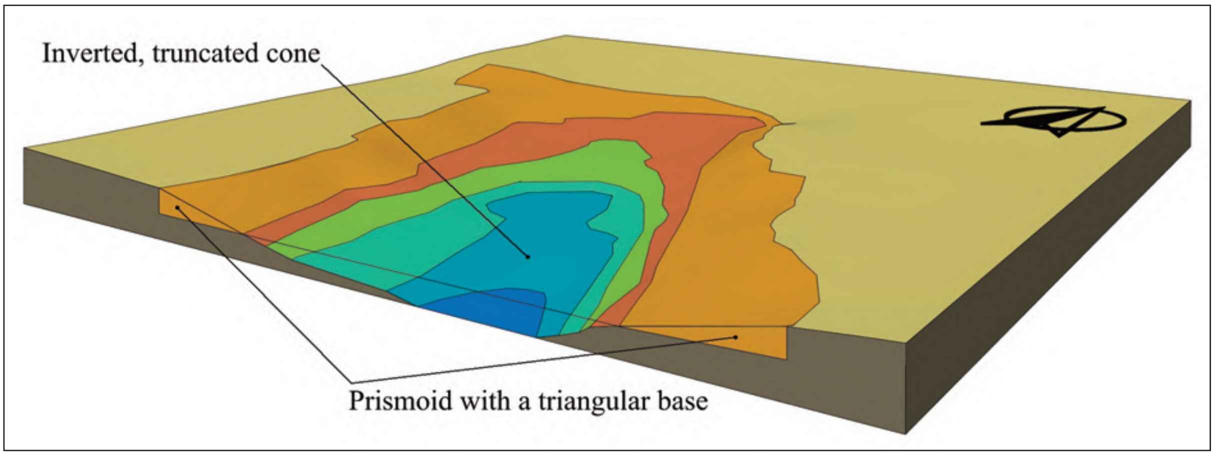
9) BRUNO 2017.

f. The top and basal elevations of the excavated volume, obtained by means of averages weighted on the number of occurrences of the data, have been assumed, respectively, equal to Qmax = m 564 asl (north-west corner of the *bouleuterion*) and Qmin = m 545 asl (south gate - monumental entrance to the city).

Preliminary to the calculation of the excavated volume, the horizontal surfaces corresponding to the contour lines were delimited and measured using the QGIS software at an equidistance of m 2 in the 4 intervals between the base elevation Q_{min} = m 545 asl and the elevation Q = m 553 asl. Therefore, the volume, in the shape of an elongated prismoid with triangular base, has been delimited, which starting from the outer edge of the horizontal surface of the contour line Q = m 553 asl is connected with the slopes that delimit the *agora* (*fig.* 3).

In order to carry out this last operation, it was ensured that the top edge of the prismoid entirely covered the archaeological remains existing in these areas and, at the same time, for the stability of the slopes, that the shoe angle of the silty-sandy soil, which covered the remains before the excavations, did not exceed that of friction or natural slope which for this lithotype was assumed to be $\varphi \leq 30°$. Figure 3 shows that the excavated volume has, roughly speaking, the shape of an inverted truncated cone, with an elliptical off-centre base, on the perimeter edge of which three sections of a prismoid with a triangular base develop without interruption. As regards the data used and the volume of excavation obtained (*tab*. 1), we can say that the value obtained is certainly an estimate by default.

In fact, it does not take into account the volumes of land that, due to the repeated landslides documented in the area (*fig*. 4), sliding along the slopes have been brought outside the catchment area underlying the *agora*. The presence of instability phenomena is of fundamental importance for the correct evaluation of the volumes of debris produced and accumulated within a catchment area. In fact, the volumes of soil moved by gravitational phenomena along the slopes of a water basin are not explicitly covered by the RUSLE method. As a consequence, in the presence of landslide phenomena, the RUSLE method provides estimates in default or in excess, respectively, when the landslide bodies are or are not included within the area of the river basin considered.



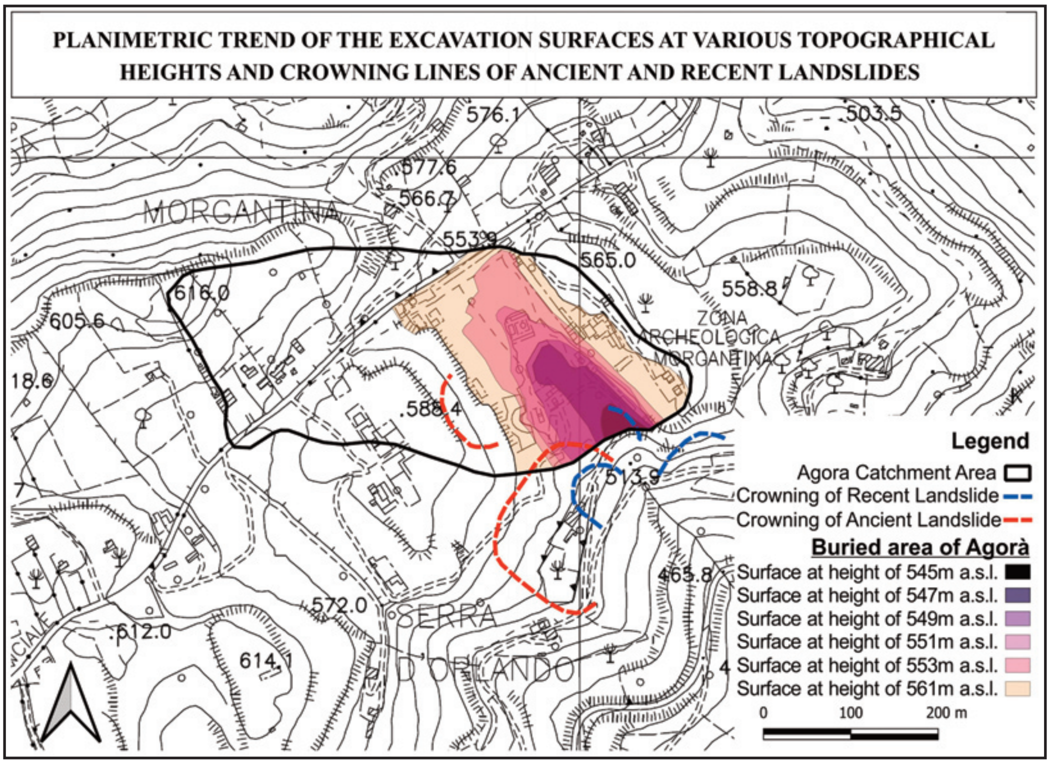
3. SCHEMATIC REPRESENTATION OF THE BURIAL VOLUME EXCAVATED TO BRING OUT THE ARCHAEOLOGICAL REMAINS IN THE UPPER AND LOWER *AGORA* OF MORGANTINA (Bruno A.F. & Bruno G.)

Level curve or weighted average height (m)	Level curve Area (m^2)	Height difference between two contiguous level curves (m)	Volume between two contiguous contour lines (m^3)
$Q_1 = 545$	$A_1 = 1119$	-	-
$Q_2 = 547$	$A_2 = 5647$	$(Q_2 - Q_1) = 2$	$V = (A_1 + A_2)/2 \cdot (Q_2 - Q_1) = 6766$
$Q_3 = 549$	$A_3 = 10102$	$(Q_3 - Q_2) = 2$	$V = (A_2 + A_3)/2 \cdot (Q_3 - Q_2) = 15749$
$Q_4 = 551$	$A_4 = 15380$	$(Q_4 - Q_3) = 2$	$V = (A_3 + A_4)/2 \cdot (Q_4 - Q_3) = 25482$
$Q_5 = 553$	$A_5 = 24644$	$(Q_5 - Q_4) = 2$	$V = (A_4 + A_5)/2 \cdot (Q_5 - Q_4) = 40024$
Integration volume between level curves			**$V_1 = m^3$ 88021**

Base width of prismoid stretch (m)	Average height of the prismoid stretch (m)	Length of prismoid stretch (m)	Volume between two contiguous stretches of prismoids (m^3)	Shoe angle of the prismoid stretch (degrees)
$B_1 = 26.22$	$H_1 = 8$	$L_1 = 232.44$	24378	13
$B_2 = 19.72$	$H_2 = 6$	$L_2 = 148.63$	10258	27
$B_3 = 29.53$	$H_3 = 6.5$	$L_3 = 266.26$	25554	8
Integration volume of the three prismoid traits			**$V_2 = m^3$ 60190**	

Total excavation volume $V_{tot} = (V_1 + V_2)$	**$V_{tot} = m^3$ 148211**

Tab. 1 - DATA USED TO CALCULATE THE VOLUME OF EXCAVATED SOIL AND RESULTS OBTAINED (Bruno G.)



4. PLANIMETRIC TREND OF THE EXCAVATION SURFACES AT VARIOUS TOPOGRAPHICAL HEIGHTS AND CROWNING LINES OF ANCIENT AND RECENT LANDSLIDES (Bruno G.)

The date of abandonment of the city and the trend of the average rain for the RUSLE calculation

Two fundamental aspects for the purposes of this research concern the average rainfall parameters ($\overline{P}$) and the duration of the calculation period (T) which contribute, more or less explicitly, to the calculation of the volume of burial of the *agora* with the RUSLE formula. The formula in question, in fact, has been conceived to calculate the rate of erosion of the slopes caused by the erosive action of meteoric precipitation in a time interval of one year (tonne·years^{-1}·hectare^{-1}). Considering that the reference time interval of the formula is annual (t), it follows that the value of rain used in the formula is the average annual one (p). In our case study, the time span considered (T) is the one between the year 50 A.D. (the assumed date of abandonment of the city) and the year 1955 A.D. (the starting date of the annual archaeological excavation campaigns).

For the purposes of the RUSLE this time span has been divided into calculation steps of 100 years, for each of which the average rainfall value has been estimated ($\overline{P}$) which is necessary for the calculation of the rain erosivity factor "R". The date of 50 A.D., as the year of complete depopulation and abandonment of the city of Morgantina, is a hypothesis supported by a series of historical sources, archaeological evidence and hydrogeological studies that can be summarized as follows:

Historical sources

We have no historical or archaeological evidence, dating to the period between 36 B.C. and 50 A.D., that make think of Morgantina as a vital city and/or as a city of some significant interest for the nascent Roman Empire. According to the historian and geographer Strabo (60 B.C. - 24 A.D.), at the beginning of the 1st century A.D., Morgantina was a city that was once but no longer exists «*πόλις δ'ἦν αύτη, νῦν δ'ούκ ἐστιν*»[10]. These circumstances leave room for speculation on the causes, modalities and time of abandonment of the city. The most frequently credited hypothesis is that of the destruction of the city and deportation of its inhabitants in nearby towns. As reported by Diodorus Siculus «*τῶν τε πόλεων αἱ μὲν ἑκούσιαί οί προσχωρήσασαι συγγνώμης ἔτυχον, αἵ δ'ἀντάρασαι ἐδικαιώθησαν*»[11], Octavian Augustus, having defeated Sextus Pompey in the naval battle of Nauloco on September 3, 36 B.C., according to the custom of the time, took action against the Sicilian cities which adhered to Pompey's cause.

The new geo-political setting that arose in Sicily during the Roman imperial period provides evidence of the depopulation of this area in the form of reorganization of the road network. The new road network[12] Catania-Agrigento and *mutatio Gelasium* moved south at the beginning of the fourth century A.D., whereas in the previous road network[13] *mutatio Gelasium* is supposed to be located in Contrada Belmontino Sottano of the original *Chora* of Morgantina[14].

Archaeological evidence

Evidences of a residual occupation of the city are found in the most recent indications provided by archaeological remains. These concerns only the areas of the Trigona Hill, where the "House of the Arched Cistern", "House of the Tuscan Capitals", "House of the Double

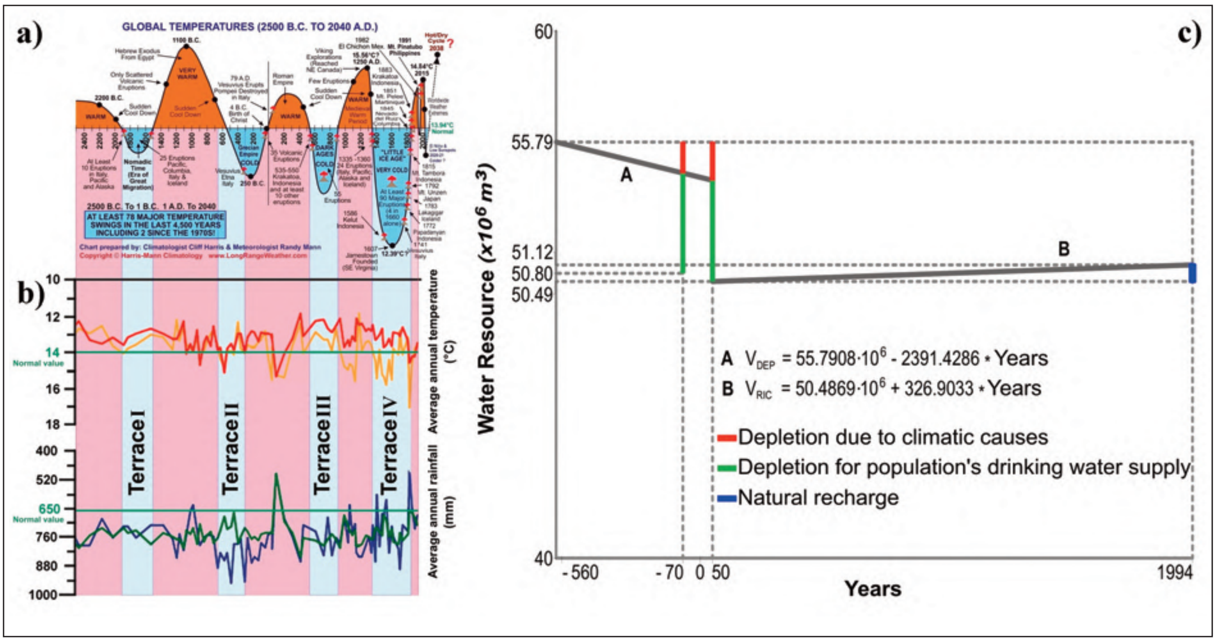
10) Str.VI, 2, 4.
11) D.S. 49, 12, 5; Stone 1983, p. 13.
12) Itin. *Anton. Aug.* 94.
13) Itin. *Anton. Aug.* 88.
14) Bruno *et al.* 2021.

Cistern", "House of the Palmento" and "House of the Gold Hoard", were built in the third century B.C., then damaged or destroyed by fire in 35 B.C. and finally repaired and reused until their final abandonment in 30-40 A.D.[15]. Such evidence consists of pottery dating back to the emperors Octavian Augustus (63 B.C. - 14 A.D.) and Tiberius (42 B.C. - 37 A.D.) and coins of which the most recent finds concern a coin of the emperor Caligula (12 B.C. - 41 A.D.)[16].

Hydrogeological studies and the hydro-potable needs of the inhabitants

In a recent study based on the hydrogeological balance of the area and the hydro-potable needs of the inhabitants[17], it was investigated whether the area's hydro-potable resources had been depleted for a long time due to climate warming as a possible reason for abandoning the archaeological site (*fig.* 5, a-b). The comparison between the hydro-potable needs of the inhabitants and the hydrogeological balance of the area identified the year 50 A.D. as the possible date of abandonment of the city. (*fig.* 5, c). Ultimately, the joint reading of historical sources, the most recent archaeological finds in the area and the studies on the population's hydro-potable needs and the reconstructions of the hydrogeological balance seems to support the hypothesis of the year 50 A.D. as the reference date for the abandonment of the site.

With regard to the rainfall regime, necessary for the calculation of the rainfall erosivity factor "*R*" of RUSLE, considering the wide extension of the total time interval under consideration (*T* = 1906 years) and the available rain data (*fig.* 5, b), it was decided to estimate



5. CLIMATIC VARIATIONS IN THE MORGANTINA AREA OVER THE LAST 4500 YEARS (BLUE BANDS - COLD AND RAINY CLIMATE; RED BANDS - HOT AND DRY CLIMATE): a) TEMPERATURE TRENDS ON A GLOBAL SCALE; b) TEMPERATURE TRENDS AND PRECIPITATION ON A REGIONAL SCALE - ORANGE AND BLUE CURVES - HAVE BEEN OBTAINED WITH THE "MODERN ANALOGUES TECHNIQUE - MAT" METHOD AND RED AND GREEN CURVES HAVE BEEN OBTAINED WITH "WEIGHTED AVERAGE PARTIAL LEAST SQUARES REGRESSION - WAPLS" METHOD; c) WATER TABLE DEPLETION/RECHARGE LINES: STRAIGHT-A FOR THE PERIOD OF 610 YEARS BETWEEN THE FOUNDATION (560 A.C.) AND THE SUPPOSED YEAR OF ABANDONMENT OF THE CITY (50 A.D.); STRAIGHT-B FOR THE PERIOD OF 1944 YEARS BETWEEN THE YEAR OF ABANDONMENT OF THE CITY (50 A.D.) AND THE YEAR 1994 (modified from: Harris, Mann 2015; Sadori *et al.* 2013; Bruno 2017)

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15) Trümper 2019, pp. 106-108; Pfunter 2013, p. 920.

16) Stone 2015, p. 63; Tsakirgis 1984, p. 149; Tsakirgis 1995, p. 143.

17) Bruno 2015.

the value of the average rain ($\overline{P}$) from the curve obtained with the "Modern Analogues Technique - MAT" method[18].

In detail, time steps of T_n = 100 years have been considered, with the exception of the first and last step which have a duration of 51 and 55 years respectively. For each temporal step, the average rainfall value ($\overline{P}$) was obtained by integrating and mediating the corresponding stretch of the rainfall curve (*tab*. 2).

Historical period (years)	**Time interval (T_n)**	**Average rain $\overline{P}$ (mm)**
50÷100	51	653
101÷200	100	590
201÷300	100	713
301÷400	100	797
401÷500	100	756
501÷600	100	715
601÷700	100	770
701÷800	100	759
801÷900	100	780
901÷1000	100	743
1001÷1100	100	714
1101÷1200	100	787
1201÷1300	100	804
1301÷1400	100	782
1401÷1500	100	698
1501÷1600	100	705
1601÷1700	100	778
1701÷1800	100	746
1801÷1900	100	620
1901÷1955	55	686

Tab. 2 - AVERAGE RAIN VALUES OF EACH TIME STEPS CONSIDERED FOR THE CALCULATION OF THE "R" FACTOR IN RUSLE (Bruno G.)

Volume of accumulated silt obtained by RUSLE and QGIS software for the *agora* area

Erosion is the stage of the natural process of lithogenesis of sedimentary debris rocks responsible also for the remodelling of the earth's surface through the removal of soil/debris, produced by meteoric degradation, from the steep slopes of hydrographic basins. One of the most critical and effective forms of erosion is that caused by water; it depends on various factors such as the intensity of rainfall, the erodibility characteristics of the lithotypes outcropping, the morphology of the slopes, the type of vegetation cover, the cultivation techniques and the so-called hydraulic-forestry arrangement interventions carried out by man to combat the phenomenon. In the literature there are several models of soil erosion estimation that can be traced back to the following two categories[19]: "erosion limited models" (limited detachment) and "transport limited models" *(*limited transport capacity); there are also more general models (SIMWE and WEPP) that are able to simulate both the erosion and deposition process[20].

18) Sadori *et al.* 2013.
19) Cencetti *et al.* 2005.
20) Mitasova, Mitas 1998.

The first category of models (e.g. RUSLE) are based on the assumption that the water flow can carry an infinite amount of sediments and that the amount of soil eroded, therefore, is only a function of the erosive capacity of rainwater to break up the outcropping rock (by impact and runoff). The second category of models (e.g. USPED), on the other hand, assumes that the quantity of sediment transported by the water flow is only a function of the transport capacity of the water flow and is always equal to the maximum transport capacity of the same regardless of whether or not there are previously detached sediments to be transported.

Among the above-mentioned models one of the best known and widely applied is certainly the USLE (Universal Soil Loss Equation) model[21], developed by Wischmeier and Smith in 1965 and revised by the same authors after about a decade[22].

The initial USLE model was developed to estimate the annual average value of soil loss on a slope, caused by laminar erosion and runoff, under specific conditions of rainfall, land use, soil and morphological characteristics of the slope. This model was subsequently modified and refined giving rise to the RUSLE (Revised Universal Soil Loss Equation) equation[23] which, compared to the USLE model, allows a better adaptation to morphologically complex territories and the possibility to estimate the annual erosion at the scale not of the single slope but of the catchment area. The general form of the equation underlying the RUSLE model takes the following form:

$$A = R \cdot K \cdot LS \cdot C \cdot Pr \qquad [1]$$

where:

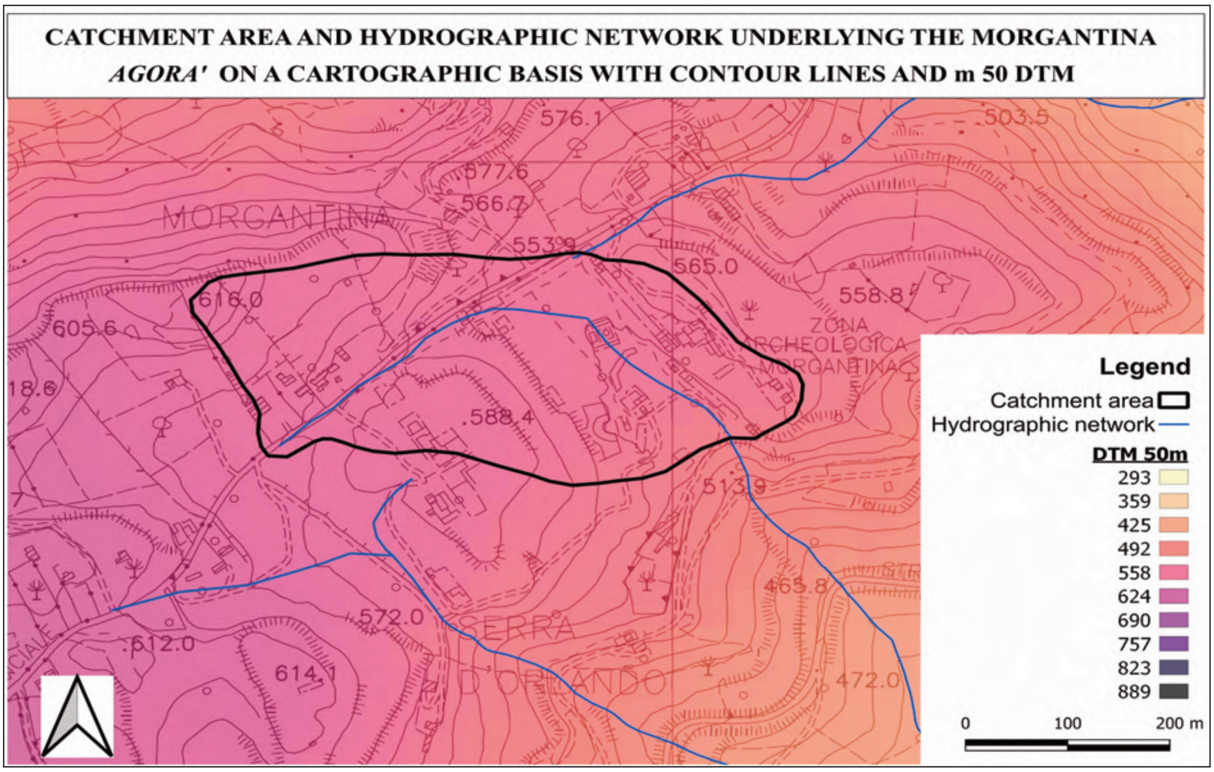
A = *average annual soil loss* (t/ha·years);
R = *precipitation erosivity factor* (MJ·mm/ h·ha·year);
K = *soil erodibility factor* (t·h/ MJ·mm);
LS = *topographic factor* also known as *Slope Length Factor* (dimensionless);
C = *ground cover factor* (dimensionless);
Pr = *hydraulic-forestry erosion control practices* (dimensionless).

In our case study, the RUSLE model was applied in a QGIS environment starting from the m 50 DTM of the catchment area underlying the *agora* of the Morgantina archaeological site (*fig*. 6).

In each of the cells of the relative rasters all the factors of the equation [1] have been calculated and the values obtained/adapted, for each calculation time step, are shown in *Tab*. 3.

Specifically, for the calculation of the rainfall erosivity factor, the equation proposed by Ferrari and other scholars[24] has been adopted, while for the topographic factor *LS*, among the different options proposed by QGIS software, Desmet & Govers[25] has chosen the one based on the concept of the specific contributor area. Finally, for the land cover, factor *C,* and the hydraulic-forestry erosion control practices *Pr* (those more sensitive to anthropic activities), considering that after the abandonment and up to our times the archaeological area has not undergone anthropogenic modifications relevant to the calculation, constant values, congruent with those used in the literature have been adopted. In particular, with regard to the values of

21) Wischmeier, Smith 1965.
22) Wischmeier, Smith 1978.
23) Renard *et al.* 1991; Renard *et al.* 1997; Stone, Hilborne 2012.
24) Ferrari *et al.* 2007.
25) Desmet, Govers 1996.



6. CATCHMENT AREA AND HYDROGRAPHIC NETWORK UNDERLYING THE MORGANTINA *AGORA* ON A CARTOGRAPHIC BASIS WITH CONTOUR LINES AND m 50 DTM (Bruno G.)

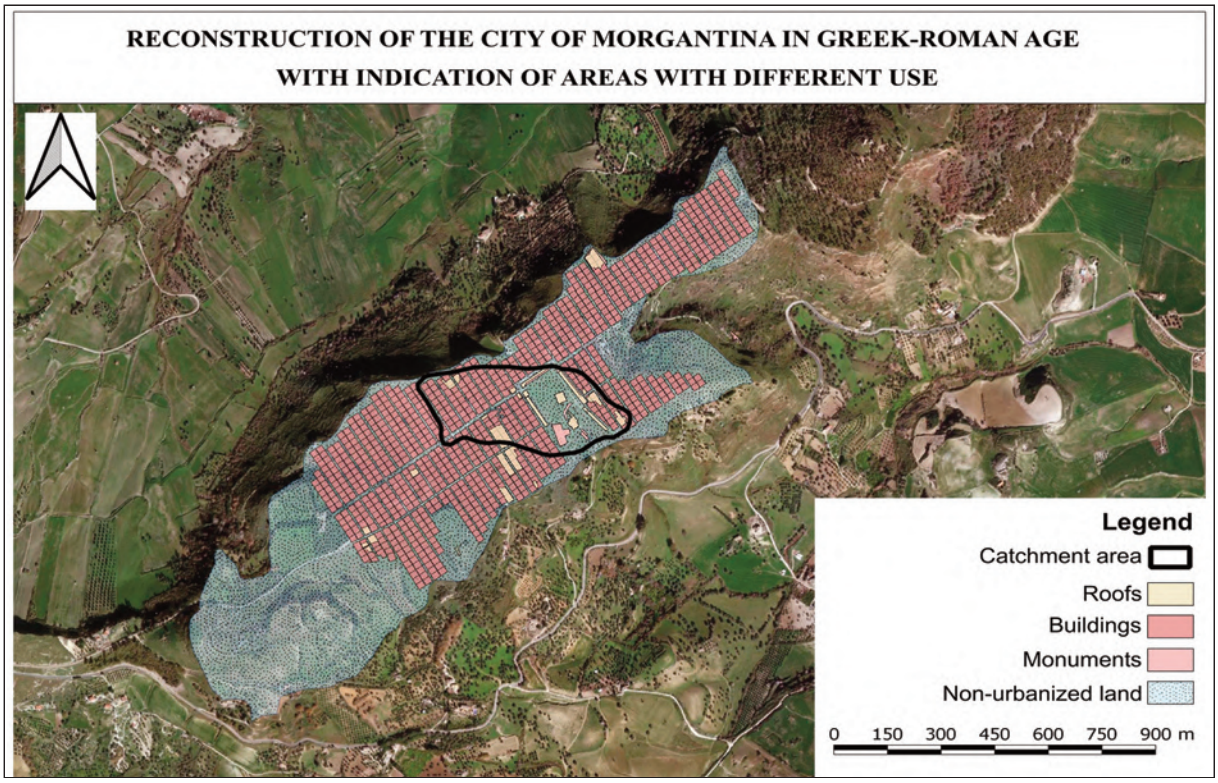
Factor *R*	Factor *K*	Factor *LS*	Factor *C*	Factor *Pr*
1675÷1808	0.04 (sandstone) 0.05 (clay) 0.07 (sand)	0.30÷5.21	0.15 (sparse vegetation)	0.8 (discontinuous residential areas) 1.0 (no anti-erosive practices)

Tab. 3 - VALUES ADOPTED FOR RUSLE FACTORS IN RELATION TO RAINFALL EROSIVENESS (R), ROCK ERODIBILITY (K), SLOPE MORPHOLOGY (LS), VEGETATION COVER (C) AND ANTI-EROSIVE PRACTICES (PR) (Bruno G.)

the *Pr* factor and the related mitigation capacity of the erosion caused by the presence of the urban fabric, a recent archaeological study[26] has been taken into account, in which a reconstruction of the city in the Greco-Roman era is proposed (*fig.* 7), from which it can be deduced that in the catchment area in question, the only non-urbanised area without vegetation cover is that of the *agora*.

Assumed a volume weight γ = t/m^3 1.90 for loam-clay soil, from the product of the *rasters* of the factors of the formula [1] we obtained the areal distribution of the total solid detritus (A) produced by each cell of m 50 of side in the time interval of 1906 years, elapsed between the abandonment of the site and the beginning of the systematic archaeological excavations in the area of the *agora* (*fig.* 8). By integrating the values obtained for the surface area of all the cells, the value of the total debris produced by the entire catchment area was obtained, which was equal to $\boldsymbol{A_{tot}}$ **= m^3 201725.33**.

26) Walthall *et al.* 2020.



7. RECONSTRUCTION OF MORGANTINA IN THE GREEK-ROMAN PERIOD INDICATING THE DIFFERENT LAND USES (modified from: Walthall *et al.* 2020)

Discussion

Previous studies[27] have shown that the city of Morgantina was equipped with hydraulic devices for the disposal of rainwater and the sediments transported by it, such as: canals and drainage pipes for the regulation of rainwater and/or for the abatement of interstitial pressure on the back of the walls against the ground and bridle (*ekklesiasterion*) to control the flooding of the *agora* (*fig.* 9). The latter phenomenon must have been intense, as has already been hypothesized in a previous study[28] based on the raising of three steps of the central-western wing of the *ekklesiasterion*[29], the one overlooking the slope of the Trigona hill to the west of the *agora*. It is obvious that during the period of the city's habitation the correct sizing and maintenance of these hydraulic devices will have prevented the *agora* from being buried. However, after the depopulation and abandonment of the city, the lack of maintenance and the damage/destruction of the water disposal network, as well as all the other buildings (e.g. the theatre, the west *stoa*, the south gate and its defensive walls), by the violent seismic event of 365 A.D. as well as the reiterated landslides (*fig*. 4) caused the entire area of the *agora* to be buried under a blanket of debris.

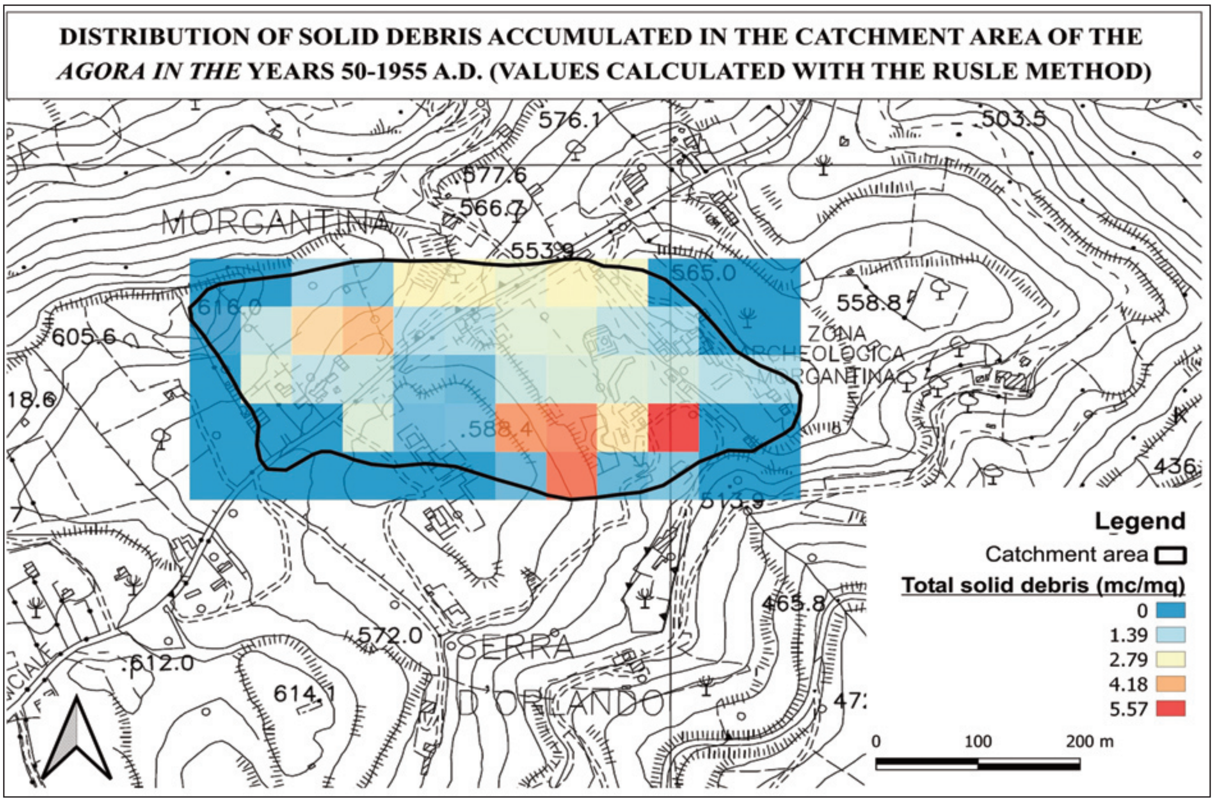
A comparison of the results obtained for the volume of excavated soil V_{tot} **= m^3 148211** and the volume of solid debris produced by erosion $A_{50÷1955}$ **= m^3 201725.33** shows that there is a *surplus* of solid debris:

$$\Delta V_{50\div1955} = A_{50\div1955} - V_{tot} = \mathrm{m}^3\ 53514.33$$

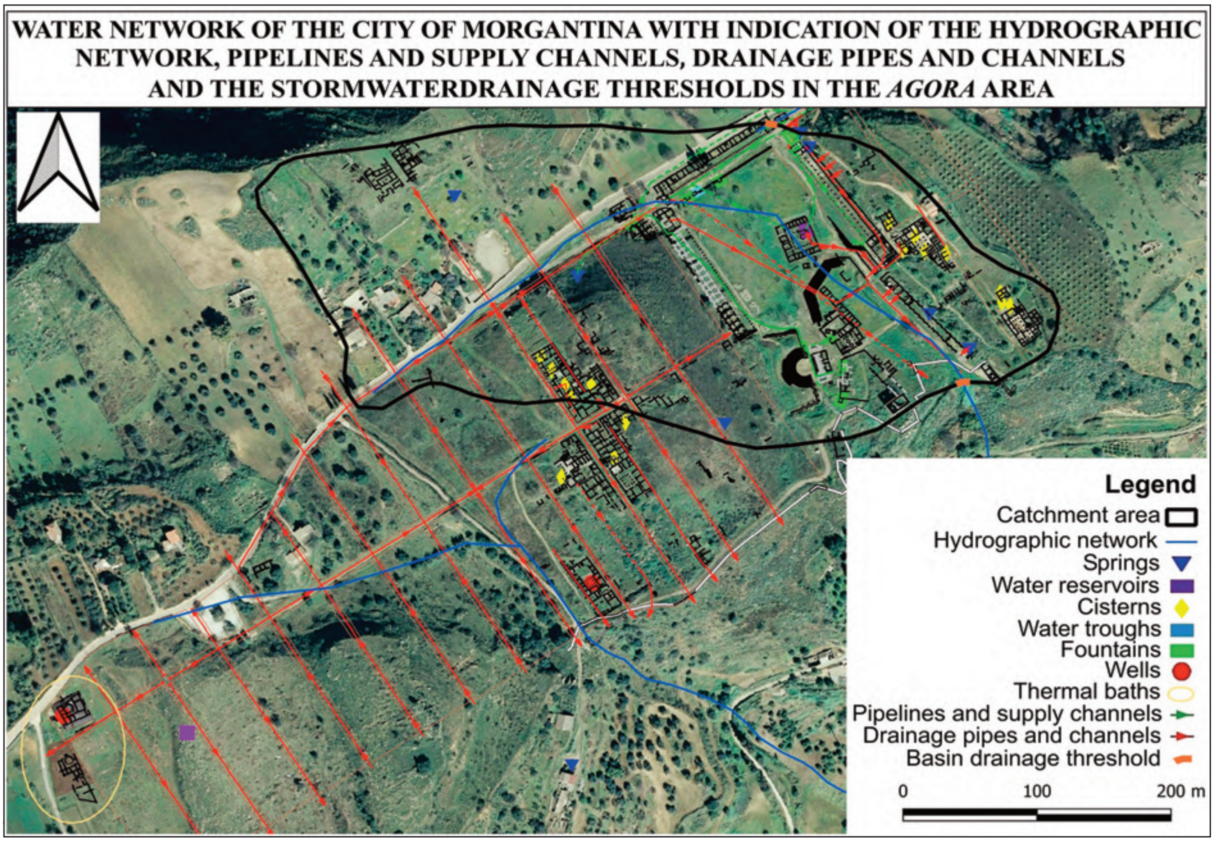
27) Bruno *et al.* 2015a; Bruno *et al.* 2015b.

28) Bruno 2017.

29) Stillwell, Sjöqvist 1957.



8. DISTRIBUTION OF SOLID DEBRIS ACCUMULATED IN THE CATCHMENT AREA OF THE *AGORA* IN THE YEARS 50-1955 A.D. (VALUES CALCULATED WITH THE RUSLE METHOD) (Bruno G.)



9. WATER NETWORK OF THE CITY OF MORGANTINA WITH INDICATION OF THE HYDROGRAPHIC NETWORK, PIPELINES AND SUPPLY CHANNELS, DRAINAGE PIPES AND CHANNELS AND THE STORMWATER DRAINAGE THRESHOLDS IN THE *AGORA* AREA (Bruno G.)

This discrepancy, however, is only apparent as it can be explained by the concomitant action of the following facts:

a. A portion, although difficult to quantify, of the debris produced in the period of time considered has been removed from the area both by the continuing operation of the rainwater disposal network, at least until its destruction in 365 A.D., and by the repeated events of instability on the slopes whose landslide bodies have protruded beyond the catchment area of the *agora* (*fig*. 4);
b. The RUSLE model, used to calculate the solid debris produced by erosion, is of the "erosion limited" type and based on the assumption that the water flow can carry an infinite amount of sediment and that the amount of debris produced by the slopes is only a function of the erosive capacity of the rainwater, is not able to take into account the actual possibility of the catchment area to retain the same or not; Based on the assumptions, the RUSLE model determines the amount of debris produced in a basin, without taking into account whether the sediments accumulate in or outside of the basin;
c. The edge of the catchment area has two altimetrically depressed thresholds capable of draining the runoff water, located in the north-east and south-east corners of the *agora* at m 553 and m 545 asl respectively (*fig*. 9), but no morphological or anthropic barrage that can determine the accumulation of sediments beyond these altitudes.

Considering the amount of the surplus volume $\Delta V_{50 \div 1955}$ obtained and in an attempt to reduce from the calculation of the total volume $A_{50 \div 1955}$ the amount of solid debris disposed of during the period of operation of the drainage network (50÷365 A.D.), the RUSLE calculation was carried out, all other conditions being equal, only for the time interval from 365 to 1955 (*fig*. 10).

The new calculation has provided a volume of solid debris produced by erosion, although greater than the volume of excavated soil V_{tot} which is considerably lower, $\boldsymbol{A_{365 \div 1955}}$ **= m³ 178629.92** to which corresponds a *surplus* value:

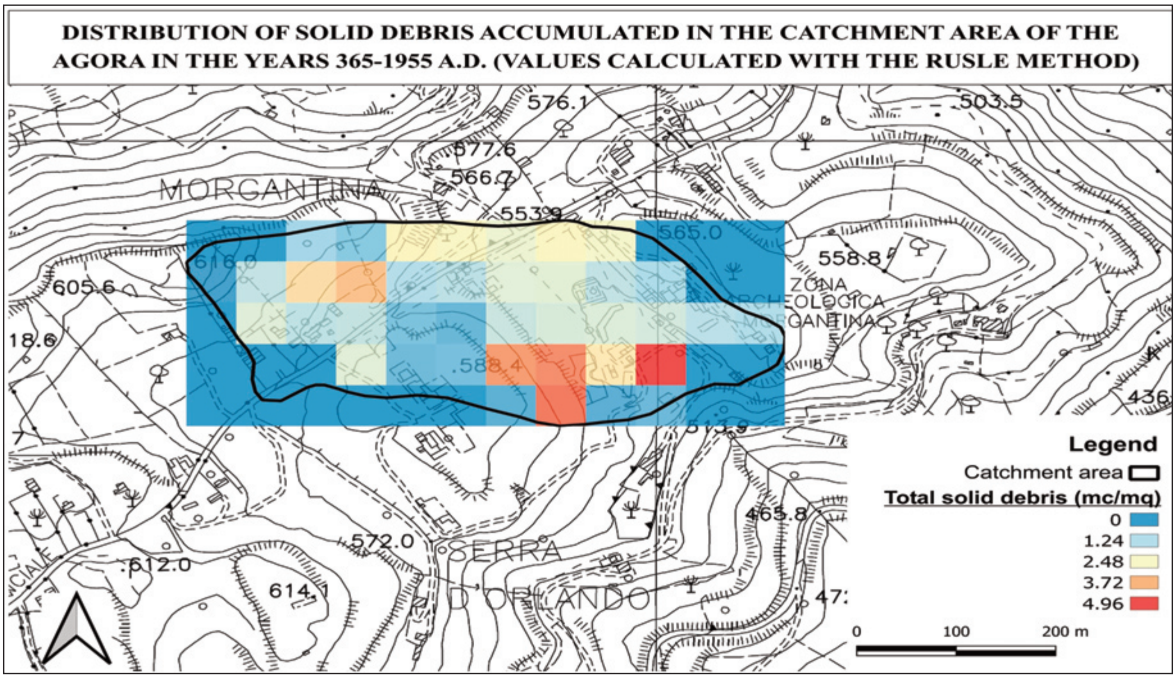
$$\Delta V_{365 \div 1955} = A_{356 \div 1955} - V_{tot} = \mathbf{m^3\ 30418.92}$$

Ultimately, the *surplus* of solid debris produced in the catchment area $\Delta V_{365 \div 1955}$, if not entirely virtual, can certainly be traced back to the reasons given in points a) and c) of the list.

Concluding remarks

The set of results obtained and their congruence with the previous historical and archaeological knowledge on the area, allow us to affirm that the RUSLE method, implemented in the GIS environment, even if it has conceptual limits, can be effectively used also for geoarchaeological studies. These limits are linked to the impossibility of establishing how much of the sediment eroded by the slopes of a catchment basin is actually retained within it and to the fact that the method does not take into account the surplus or deficit of debris that the landslide phenomena are able to mobilise along the slopes of the catchment basins.

In the specific case study analysed, net of the above considerations, the balance sheet carried out returned a fair surplus between the volume of debris eroded by the slopes in the interval of 1906 years, between the abandonment of the site and the beginning of systematic excavations in the archaeological area, and the volume of soil excavated by archaeologists to uncover the ruins of the agora of Morgantina. This surplus, however, is reduced by 57% if we accept the probable hypothesis that after the depopulation of the city the sewage water system,



10. DISTRIBUTION OF SOLID DEBRIS ACCUMULATED IN THE CATCHMENT AREA OF THE *AGORA* IN THE YEARS 365-1955 A.D. (VALUES CALCULATED WITH THE RUSLE METHOD) (Bruno G.)

although reduced due to the lack of maintenance, continued to function at least until the date of 365 A.D. when a violent earthquake, which caused devastation throughout the central-eastern Mediterranean area, struck the city.

The singular circumstance that the Morgantina area after the depopulation did not undergo significant modifications able to influence the variability of the LS, C and Pr factors (those more sensitive to anthropic activities) of the RUSLE model, meant that the only factor able to influence the result of the calculation was the one linked to the erosiveness of the rainfall (*R*) which, as it is known, is a function of the rainfall trend in the considered time interval. This allowed, indirectly, to confirm the hypotheses of 50 A.D. as the date of definitive abandonment of the city and 365 A.D. as the date of general destruction of the building, as well as the trend of average rainfall in the last 2000 years hypothesised in previous studies of the paleobotanical type.

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References

Bruno 2015: G. Bruno, "La drastica riduzione della risorsa idrica a Morgantina nel periodo greco-romano", in L. Maniscalco (a cura di), *Morgantina duemilaequindici*. *La ricerca archeologica a sessant'anni dall'avvio degli scavi*, Palermo, pp. 195-203.

Bruno 2017: G. Bruno, *Morgantina: Geoarcheologia della città in epoca greco-romana* (Guide Geoarcheologiche d'Italia, 1), Tivoli.

Bruno, Nicosia 1998: G. Bruno, S. Nicosia, "Caratteri geologici e idrogeologici dell'area archeologica di Morgantina (Sicilia centrale)", in C. Albore Livadie, F. Ortolani (a cura di), *Il sistema uomo – ambiente tra passato e presente*, Bari, pp. 185-196.

Bruno, Renna 2000: G. Bruno, E. Renna, "La rete idrica di Morgantina: tentativo di definizione del livello dell'acqua all'interno delle condotte in terracotta", in G.C.M. Jansen (a cura di), Cura Aquarum *in Sicilia* (Proceedings of the Tenth International Congress on the History of Water Management and Hydraulic Engineering in the Mediterranean Region; Syracuse 1998), Leiden, pp. 69-78.

Bruno *et al.* 2015a: G. Bruno, L. Bobbo, A.F. Bruno, "Evidenze di cambiamento climatico desunte da dati idrogeologici e dagli schemi di funzionamento della fontana monumentale di Morgantina (Sicilia)", in G. Bruno (a cura di), *La geoarcheologia come chiave di lettura per uno sviluppo sostenibile del territorio* (Atti del Convegno Nazionale SIGEA; Aidone 2014) (*Geologia dell'Ambiente*, suppl. 2), pp. 7-18.

Bruno *et al*. 2015b: G. Bruno, A.F. Bruno, L. Bobbo, "Aspetti urbanistici, materiali e tecniche costruttive utilizzati a Morgantina nel periodo greco-romano", in *Scienze e Ricerche* 7, pp. 34-53.

Bruno *et al*. 2021: G. Bruno, G. Barone, G. De Guidi, R. Maniscalco, P. Mazzoleni, D. Messina, A.G. Pellegrino, "Risultati preliminari sulla possibile individuazione della *Mutatio Gelasium* lungo la via romana Catania-Agrigento (*It. Provinciarum Antonini Augusti* n. 88)", in E. Di Loreto, G. Gisotti, G. Lena, C. Rosa (a cura di), *Le vie di comunicazione nell'antichità* (Atti del Convegno Nazionale SIGEA; Roma 2019) (*Geologia dell'Ambiente*, suppl. 1), pp. 39-45.

Cencetti *et al*. 2005: C. Cencetti, P. De Rosa, A. Fredduzzi, I. Marchesini, "Erosione dei suoli applicazioni tramite il software GRASS GIS", in *Giornale di Geologia Applicata* 2, pp. 196-202.

Desmet, Govers. 1996: P.J.J. Desmet, G. Govers, "A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units", in *Journal of soil and water conservation* 51, pp. 427-433.

Ferrari *et al*. 2007: R. Ferrari, L. Bottai, R. Costantini, L. Angeli, L. Innocenti, G. Maracchi, "Confronto fra metodi di stima dell'EI30 ai fini del calcolo dell'erosione", in B. Carli, G. Cavarretta, M. Colacino, S. Fuzzi (a cura di), *Clima e cambiamenti climatici. Le attività di ricerca del CNR*, Firenze, pp. 129-132.

Harris, Mann 2015: C. Harris, R. Mann, *Global temperature trends from 2500 B.C. to 2040 A.D.*, http://www.longrangeweather.com/global_temperatures.htm (last accessed 4 October 2021), http://sgi.isprambiente.it/GeositiWeb/files/DIS/2931/Nuova%20immagine.png (last accessed 4 October 2021).

Kyllingstad 2018: R. Kyllingstad, "Memories fron the Excavations of Morgantina (Sicily) – 1961", in *Clara Chronicle* 1, pp. 6-43.

Mitasova, Mitas 1998: H. Mitasova, L. Mitas, "Distribuited soil erosion simulation for effective erosion prevention", in *Water Resources Research* 34, 3, pp. 505-516.

Pfunter 2013: L. Pfunter, "The Vanishing Sicilian City: Identity, Connectivity and Urban Abandonment in a Roman Province", in L. Bombardieri, A. D'Agostino, G. Guarducci, V. Orsi, S. Valentini (a cura di), *SOMA 2012. Identity and Connectivity* (Proceedings of the 16th Symposium on Mediterranean Archaeology; Florence 2012), vol. II (BARIntSer 2581), Oxford, pp. 919-926.

Renard *et al*. 1991: K.G. Renard, G.R. Foster, G.A. Weesies, J.P. Porter, "RUSLE: Revised Universal Soil Loss Equation", in *Journal of Soil and Water Conservation* 46, 1, pp. 30-33.

Renard *et al.* 1997: K.G. Renard, G.R. Foster, G.A. Weesies, D.K. McCool, D.C. Yoder, *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)* (Agriculture Handbook, 703), Washington, D.C.

Sadori *et al.* 2013: L. Sadori, E. Ortu, O. Peyron, G. Zanchetta, B. Vannière, M. Desmet, M. Magny, "The last 7 millennia of vegetation and climate changes at Lago di Pergusa (central Sicily, Italy)", in *Climate of the Past* 9, pp. 1969-1984.

Schilirò *et al*. 2000: F. Schilirò, G. Bruno, A. Cannata, C.E. Renna, "La sinclinale di Morgantina quale sito archeologico ellenistico", in G. Gisotti, F. Zarlenga (a cura di), *The Second International Symposium on the Conservation of our Geological Heritage/World Heritage: Geotope Conservation World-wide, European and Italian Experiences* (Proceedings of Workshop; Roma 1996) (Memorie Descrittive della Carta Geologica d'Italia, 54), Roma, pp. 143-148.

Sjöqvist 1958: E. Sjöqvist, "Excavations at Serra Orlando (Morgantina): Preliminary Report II", in *AJA* 62, pp. 155-162.

Stillwell, Sjöqvist 1957: R. Stillwell, E. Sjöqvist, "Excavations at Serra Orlando: Preliminary Report", in *AJA* 61, pp. 151-159.

Stone 1983: S.C. Stone III, "Sextus Pompey, Octavian and Sicily", in *AJA* 87, pp. 11-22.

Stone 2015: S.C. Stone, *The Hellenistic and Roman Fine Pottery* (Morgantina Studies, 6), Princeton.

Stone, Hilborne 2012: R.P. Stone, D. Hilborne, "Universal Soil Loss Equation", in *Factsheet* 10, http://www.omafra.gov.on.ca/english/engineer/facts/12-051.htm (last accessed 4 October 2021).

Trümper 2019: M. Trümper, "Crisis and decline in Morgantina under Roman rule", in E. Perego, R. Scopacasa,S. Amicone (a cura di), *Collapse or Survival. Micro-dynamics of crisis and endurance in the ancient central Mediterranean*, Oxford, pp. 98-138.

Tsakirgis 1984: B. Tsakirgis, *The domestic architecture of Morgantina in the Hellenistic and Roman periods*, Princeton.

Tsakirgis 1995: B. Tsakirgis, "Morgantina: A Greek town in central Sicily", in *Ancient Sicily* (*Acta Hyp* 6), pp. 123-147.

Vaccaro *et al*. 2013: E. Vaccaro, M. Ghisleni, A. Arnoldus-Huyzendveld, C. Grey, K. Bowes, M. MacKinnon, A.M. Mercuri, A. Pecci, M.A. Cau Ontiveros, E. Rattigheri, R. Rinaldi, "Excavating the Roman peasant II: excavations at Case Nuove, Cinigiano (GR)", in *BSR* 81, pp 129-179.

Walthall *et al*. 2014: A. Walthall, R. Souza, J. Benton, J. F. Huemoeller, "Preliminary Report on the 2013 Field Season of the American Excavations at Morgantina: Contrada Agnese Project (CAP)", in *Fasti On Line Documents & Research* 322, pp. 1-14, http://www.fastionline.org/docs/FOLDER-it-2014-322.pdf (last accessed 4 October 2021).

Walthall *et al*. 2020: D.A. Walthall, K. Buhagiar, J. Flood, "Hydrologic Resources and Management at Hellenistic Morgantina (Sicily)", in S. Bouffier, I. Fumadó Ortega (a cura di), *L'eau dans tous ses états. Perceptions antiques* (Archéologies Méditerranéennes), Aix-en-Provence, pp. 45-62.

Wischmeier, Smith 1965: W.H. Wischmeier, D.D. Smith, *Predicting rainfall erosion losses from cropland east of the Rocky Mountains* (Agriculture Handbook, 282), Washington, D.C.

Wischmeier, Smith 1978: W.H. Wischmeier, D.D. Smith, *Predicting rainfall erosion losses. A guide for conservation planning* (Agriculture Handbook, 537), Washington, D.C.