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Cover image

The view of Mt. Fuji from the street of 'Meiji Shrine Gaien', in front of the Meiji Memorial Picture Gallery in 2016.
Credit: Research Group of the Vista of Fuji-mi-zaka (Fujimizaka Chobou Kenkyukai).

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GEOLOGY

Current affairs are important for a scientific journal too. Last November, 15,372 scientists in all the disciplines, including numerous Nobel prize winners, signed the appeal published on BioScience entitled *World Scientists' Warning to Humanity: A Second Notice*. The document, probably the longest ever signed by scientists, emphasises the fact that the future of humanity is hanging by a thread.

This is the second version of the document published in 1992 and signed by 1,700 scientists who, even then, were forecasting the impacts of climate change, deforestation, an unfair distribution of access to drinking water and of demographic growth on health and wellbeing, putting "hopes for the future of human society at severe risk".

According to the figures disclosed by the scientists who have signed the new appeal, since 1992, emissions of CO_2 have increased by 62%, while global temperature has risen by 29%; vertebrate life forms have diminished by 29%; the amount of drinking water per capita has fallen by 26%; the "dead areas" of our oceans have increased by 75%; over 121.46 million hectares of forest have been lost.

Plants, animals, insects, fish and other natural species produce oxygen, clean the water and pollinate. It has been calculated, perhaps a little haphazardly, that these "natural services" have a value of between 125 and 145 trillion dollars a year; but they are subject to constant pressure due to the increase in population (two billion people since 1992, equating to 35%).

The way things stand, the only positive trends are those related to the replenishment of the ozone layer, which protects us from ultraviolet rays. This is thanks to the Montreal Protocol signed in 1987, and the growing use of renewable energies.

The 1992 document indicated the need to eliminate the use of fossil fuels, the main cause of emissions of CO_2. But the emissions of the United States are scheduled to increase 2.2% in 2018, partly due to the cold winds that are expected to hit the country; China's and India's emissions continue to grow, albeit to a lesser extent than years ago.

It has been calculated that, to avoid irreversible damage, emissions have to be near zero by 2050. According to the European Commission, we have to reduce our emissions of greenhouse gases by 80% compared to the levels recorded in 1990, but exclusively through internal reductions, without resorting to international credits. A first 40% abatement (32% of the total) should be achieved by 2030, with a second 60% abatement (48% of the total) by 2040. As long as the reduction regards every sector that produces emissions (energy production, industry, transport, buildings, construction and farming) and the transition towards an economy with low emissions of carbon is feasible and economically affordable.

The *Warning to Humanity* implicitly confirms the need for the institutions to cooperate and for interdisciplinary integration, as stated in editorial no. 1 of CSE; but the convergence between the governments and the economies of the world's biggest countries, which produce most of the emissions into the atmosphere alone, is just as important, and unfortunately still a long way from being achieved.

This issue of CSE contains, for the topic Planning and Land Safety, the paper *The Stava catastrophic failure of 19th July 1985 (Italy): technical-scientific data and socioeconomic aspects* (G. Tosatti), which looks at a significant example of the risks ensuing from the insufficient safety of the hydraulic works in areas subject to extensive intervention by man.

On the 19th of July 1985 at Stava near Tesero (Trento Region, northern Italy), two impoundments collapsed, causing the death of people and the destruction of buildings. The two adjacent basins were constructed for the decantation and storage of fine-grained waste material (tailings), which was pumped from a nearby fluorite mine. The consequence of the failure was a vast mudflow that found its way downstream along the Stava valley. The failure occurred as a result of the collapse of the upper basin, which overwhelmed the lower basin. The paper examines the technical errors, shortcomings, responsibilities and consequences of this disaster.

For the topic of Environmental Design,

the paper *Methodologies for the View Protection Areas and Challenges of Landscape Planning in Japan* (M. Miyawaki) focuses on the methodologies of landscape planning in Japan, where View protection areas were officially adopted in landscape plans at local authority level after the first Japanese landscape law (no.110/2004) was passed. The author studied the recent challenges for view protection from central Tokyo to Mt. Fuji. Through case studies, the influences of the earth's curve and light refraction over a distance of 100 km are estimated, also giving information on regulation methods and the effects on view protection areas.

The paper *Aesthetic Vs. functional restoration of urban and peri-urban rivers: the Manzanares River in Madrid* (F. Magdaleno) concerns the Manzanares River (Madrid, Spain) as a paradigmatic case study of the current debate about the most suitable restoration approaches to urban and peri-urban rivers, also allowing some insights which can be transferred to other urban and peri-urban rivers, both in Mediterranean and non-Mediterranean areas. A multi-functional approach to urban rivers is proposed, considering the importance of providing self-sustaining actions, which can rehabilitate essential river processes inside the city, and which offer relevant ecosystem services to city dwellers.

For the topic of Energy Efficiency,

the paper *Estimating Naples' urban heat island effect using the March 20, 2015 partial solar eclipse* (A. Mazzarella and N. Scalfetta) takes an original look at the emissivity estimates during the solar eclipse that occurred on March 20, 2015, the surface air temperature and the solar radiance records, to characterize the urban heat island of Naples as due to an additional source of heat of about 90 W/m^2 with respect to Casamicciola, on the island of Ischia.

For the first time, we are presenting matters which concern ancient times. The first regards the construction technique used by the Romans (*Roman buildings: mortar, hydraulic mortar and pozzolanic concrete in the Gulf of Naples, Campania – Italy*, R. Esposito), which we can still learn a lot from today.

The aim of the article is to summarise the information published with regard to research carried out into mortar and concrete materials in relation to roman buildings in the gulf of Naples, Italy, as an area implicated in multidisciplinary studies on the raw materials and Roman construction technologies with a view to restoring the archaeological heritage. Two case studies are presented: the Phlegrean Fields (Puteoli, Baia, Misenum) and the Vesuvius area (Pompeii, Herculaneum, Stabia, Surrentum). The results indicated that monuments of importance are built using a variable – in time – composition of mortars and conglomerates. Futhermore results confirmed that Roman engineers extensively used local geomaterials such as volcanic and sedimentary aggregates mixed with hydrated lime.

The second looks at a case of geoarchaeology (*Evaluation of recent vertical motions along the Island of Capri: geoarchaeological evidences and implications at the Roman villa of Palazzo a Mare*, C. Stanislao) which proves the utility and effectiveness of survey methods on the morphological evolution of the territory and the landscape. The paper presents geoarchaeological and geomorphological results along the northern and central coasts of the island of Capri, where the submerged ruins enabled the ancient position of both the sea level and the coastline to be reconstructed, as well as making it possible to evaluate the type, entity and rate of vertical ground movements. The surveys covered a maritime villa attributed in its first phase to Augustus, Palazzo a Mare. A rapid displacement due to aseismic and microseismic phenomena occurred during post-Roman age, which caused the coast to drop with consequent shoreline adjustments. An integrated approach linking the morpho-evolution of the landscape to proper management of exposed cultural heritage and the resolution of coastal hazard, is essential, particularly if we consider the population concentration in coastal zones.

Loreto Colombo

EDITORIAL

Experimenting criteria for risk mitigation in fluvial-coastal environment

Carlo Donadio

Vanishing beaches and hungry water[1] originated by different human pressure are a worldwide issue, with significant and sometimes unpredictable socio-economic and environmental impacts (Kondolf, 1997). The United States Environmental Protection Agency estimates that between 80% and 90% of America's sandy beaches have been eroding (EPA, 1994). In most cases, single beaches may be losing only a few centimeters per year, but in some cases the problem is much worse: the coast of Louisiana is losing about 15 m of shoreline per year (NOAA, 2003).

In Europe about 40% of the shoreline is eroding, in some countries an erosion range between 50% and 70% was registered (Beachmed, 2008).

These problems should be tackled on a large scale and with a different approach. Rivers and coasts, *i.e.* the border between land and water, represent transition environments which are extremely sensitive to perturbations, both natural or anthropogenic. Each environmental component, whether a physical, biotical or anthropic element, mutually influences the adjacent one and thus triggers interactions. These complex processes do not follow the linear physics of cause-effect, but are dominated by a non-linear or chaotic physics. Therefore, small modifications in the catchment due to a forcing could cause significant variations of shoreline, out of phase and also far from the river mouth, often with amplified feedback.

Historically, in planning and managing, rivers and coasts are considered as separated domains with very different dynamics. The river mouth represents the common point where waters and sediments coming both from land and sea interchange.

A modern approach should be based on the criterium of *flumen unicum*, whereby the river basin and the facing littoral are considered as a single indissoluble and continuous space-time system. Actually, both these environments are strictly linked to each other, from the farthest end of the watershed to the seabed down to 15 m depth, where the main geomorphic and sedimentary processes take place.

For the same reason, the facing littoral does not end at the river mouth, but extends to the entire coastal physiographic unit, that is the bay delimited at the margins by promontories in which the river discharges the sediments drifted by waves and marine currents. This approach does not consider the river and the shoreline as bi-dimensional elements, but tridimensional ones, that include the whole waterscape with its drainage network, littoral prism and sea bottom.

Global warming, for which human activities partly contribute, and the accelerated subsidence of urban areas promote sea-level rise and consequent coastal erosion. The alternation of hot-arid and cold-humid climatic crises, ranging from a 150-200 to a 10-40 year duration, at medium latitude where megalopolises and large industrial plants are present activate floods and landslides in catchments, following severe rainfall.

Moreover, starting from 1900, and especially since the 1950's due to socio-economic policies linked to the postwar period, the demand for land rapidly increased and its availability gradually decreased. Urbanization developed particularly in Mediterranean climate areas *sensu* Koppen (1936) and James (1966), including non-European regions such as California, China, South Africa and Australia. Consequently, certain river valleys and coastal zones became the most anthropized areas thanks to their less complex morphology, abundance of freshwater and geomaterials such as sand and clay which fostered the rapid development of settlements and infrastructures.

At the same time, the demand for energy increased over the last century, and its production required the construction of hydroelectric power plants, with reservoirs barred by a series of large dams along major rivers. Dams regulate watercourse flows, but change their environmental and hydrogeomorphological features, by trapping sediments and starving the river mouth and beach and thus triggering coastal erosion processes.

Mitigation consisted in the construction of various coastal defenses over time, to protect settlements and reduce risks. However, some defenses often proved to be ineffective, or activated other focuses of erosion in the coastal physiographic unit. From this point of view, the dam-river-coast system is characterized by a higher complexity compared to the anthropized fluvial-coastal environment.

The crucial questions nowadays are firstly how to properly intervene in the river basin without irreparably affecting the

1. According to Kondolf (1997), if the continuity of sediment transport is interrupted by dams or removal of sediment from the channel by gravel mining, the flow may become sediment-starved (hungry water) and prone to erode the channel bed and banks, producing channel incision (downcutting), coarsening of bed material, and loss of spawning gravels for fish (as smaller gravels are transported without replacement from upstream).

coast and secondly how to intervene along the coast without substantially altering the river mouth or the low valley.
There are a few suitable solutions for each case, which are effective for a given time interval in relation to the variability of the environmental versus the anthropogenic system, and to the available technique selected to mitigate the risk. Multidisciplinary research, based on surveys of the long-term period and the monitoring of the short-term one, could help to improve the planning and management of interventions in anthropized transition environments.

Hydrogeological imbalance

Landslides and floods cause substantial economic losses and thousands of casualties in the world each year, especially in tropical and Mediterranean climate areas. Several factor combinations trigger these phenomena: persistent rainfall or strong rainstorms, non-vegetated permeable soils, slope gradient, deforestation, fires, incorrect plowing of agricultural fields and earthquakes.
Manmade interventions along the basin slopes and river over time, such as the engineering of river banks and riverbeds, dam construction, change in the river flow (Kondolf and Matthews, 1993) could cause flash floods with high sediment load. These are dangerous and harmful especially along urban streams, reaches of a watercourse crossing a town, usually engineered or tunneled, and with a reduced section compared to the natural one (Magdaleno and Fernández, 2011).
When a watercourse is transformed in a culvert and hidden from sight, the population loses memory of the existence of the urban river. Tragically, the memory suddenly resurfaces turbulent during a flash flood.
In Europe and the United States, in the last 20 years floods have increased, especially in urban areas (Jongman et al., 2012; Kundzewicz et al., 2013). Since the 1990's, the basin authorities and local government agencies have laid down the rules for hydrogeological and coastal defense. These are based on research and mathematical models that have not always taken in due consideration the close relationship between river basin and coastal-marine environment, and their degree of anthropization.

Dams

The dams, as well as the vegetation, behead the river floods and regulate river flow. However, dams represent a sediment trapping, causing a lack of deposits downstream and a starvation of sediments to the coast (Willis and Griggs, 2003; Slagel and Griggs, 2008), especially if the reservoir is sufficiently close to the river mouth (less than 50 km). The sand and gravel supply is dramatically reduced, but the silt and clay in suspension can partly bypass the barrier, gradually turn the beach sediment grain size and composition into finer and more easily erodible deposits. Moreover, these barriers reduce hydrological connectivity, which is essential to the ecological integrity of the landscape. Reduction or enhancement of this property by humans may have major negative environmental effects, contributing to dramatic losses in global aquatic biodiversity and associated ecosystem integrity (Pringle, 2003). Dams and other manmade structures in rivers have also altered thermal and sedimentary regimes as well as energy and material flows, and consequently, the extent and distribution of available habitat for many river species (Ward and Stanford, 1995).
Floods have relevant effects on the ecogeomorphic integrity of rivers altered by flow regulation (Magdaleno, 2017), especially along those rivers barred by several dams.
Particularly, the riparian ecosystems downstream of the dam suffer significant alterations and the river banks may be affected by landslides, due to the lack of sediments and the reduction of river flow and floods.
Dam reservoirs emit greenhouse gases such as methane and therefore represent a significant source of climate pollution. Large dams reduce water quality and quantity, dry up forests and wetlands, flood productive land, and deplete fisheries.
In California 70 out of more than 500 dams, over 50 years old, are responsible for 90% of the sediment reductions to the coast and make any sediment management efforts far more localized in southern areas, where threatened beaches reach 70% (Willis and Griggs, 2003). About 18% of the main dams in Italy have an average age of 50 years, 1.5% are full of sediment, 4.5% show a reduced capacity of 50%, 17.5% of 20% and 76.5% of 4% (Molino et al., 2007a,b), which makes them partially ineffective and hazardous. More extreme rainfall will increase the siltation of dams, reducing their life cycle, and also increase the risk of failures and catastrophic flood releases.

Coastal hazard

Coastal hazard is due to several interrelated factors, by descending order of influence: man-made structures, shoreline erosion, landslides, storm waves, river flooding and local seismicity and volcanism (De Pippo et al., 2008, 2009; Valente et al., 2014). In Mediterranean climate areas, global warming and the consequent increase of sea storm frequency as well as sea-level rise have accelerated beach erosion in the last 50 years. In particular, wind direction change and the absence of wind calm have triggered new erosion focuses since the mid-1970's, especially along densely urbanized river mouths.
Erosion processes change morphology, reduce width, increase the gradient and grain size of beaches, and end up dismantling the coastal dune with changes in vegetation assemblage, like in the Mediterranean maquis. This results in a huge loss of sand, as well as environmental and cultural

heritage. The sand eroded by sea is mobilized along the seabed by littoral drift and secondary cell circulation and confined in the coastal physiographic unit . The inshore depth is thus reduced and the siltation of harbor down-drift is initiated.

Mitigations

The high degree of complexity and variability inherent to dam-river-coast systems hinders the selection of universally-valid mechanisms to protect both the natural and the anthropized environment. Mitigation measures are numerous and diverse, but in certain regions a few types are recurrent. Different national management approaches to coastal protection exist. They depend on the large variability of physical, political and economic attributes as well as the cultural heritage of the regions affected by floods and coastal erosion.

Frequently, the measures address only the emergency situation and/or are implemented in limited areas. Sometimes obsolete techniques are adopted and the problem is simply shifted elsewhere allowing maladaptive strategies to prevail over adaptive ones.

Both in Europe and extra-Mediterranean areas floods are rarely mitigated through interventions at basin scale but more commonly along the channel bed and banks. Frequently, only specific reaches of the mainstem or some tributaries are regulated and engineered, especially in the case of urban rivers (Kondolf et al., 2003).

Future attempts to release artificial floods should also focus on solid flow transport from the dam, and on the most adequate procedures to couple flow and sediment releases (Magdaleno, 2017). Sediment routing, flushing and hydrosuction are some of the adopted solutions, and sand bypass systems seem to aim in the same direction (Wang and Kondolf, 2013): they are designed for new dams, but the problem for old dams filled with river sediments remains.

In this case it might be possible to turn a liability into an asset by dredging deposits from the reservoir, separating the gravel and sand from the silt and clay. The mixed sand-gravel can be reused for the artificial replenishment of rivers and the sand for the nourishment of beaches, while the silt and clay for soil amendment in agriculture and light aggregates production for building construction, depending on their mineralogical composition (Ock et al., 2013). These solutions have an additional economic cost, but a greater final benefit compared to common defense systems or the coastal retreat itself with irremediable loss of valuable transition environment, structures and infrastructures.

When a reservoir is almost ineffective and potentially really dangerous, dam removal followed by river restoration and beach nourishment could be the appropriate solution, as attested to by the intervention on the 1921 San Clemente dam (Capelli, 2007) on Carmel River in California, which was initiated in 2014. Dam removal has become an increasingly widespread management choice in the United States (Maclin and Sicchio, 1999), where more than 450 barrages have been removed.

Several techniques are used to mitigate coastal erosion: groins, jetties, sea walls, breakwaters both emerged and submerged, artificial sand nourishment, dewatering system (Donadio and Valente, 2007). All of them show different impacts, even on shorelines that are far from the intervention sites. The main effects are indentation of the shoreline due to a focused retreat (cove) or progradation (salient, tombolo); eutrophication of sea water segregated in small basins at the back of breakwaters; proliferation of allochtonous species of marine organisms (algae, polychaetes, molluscs) on the secondary rock substratum represented by breakwaters emplaced on the sandy seabed; change of color, composition and grain size of beach deposit by allochtonous bioclasts and gravel coming from the artificial barriers. These effects of environmental alteration cause unpleasant use of littorals, therefore produce a negative impact on tourism.

Beach nourishment is a common solution to replace the lost sand, by pumping on the littoral the marine sediments dredged offshore, but this intervention is time consuming and expensive and needs to be repeated every few years to preserve the beach. Beach dewatering systems show a lower impact compared to many others, but their efficiency depends on local environmental conditions, *e.g*. river sediment supply even when it is not abundant.

The European Union (EU) supported several research projects on coastal erosion and flooding hazard, protection strategies, technical expertise, legal-institutional instruments, Integrated Coastal Zone Management (ICZM), taking also into account extra-Mediterranean experiences: Eurosion (2004), Conscience (2007), Beachmed (2008), OurCoast (2008), Pegaso (2008), Coastance (2009), Theseus (2009), Maremed (2010), Shape (2011), FaceCoast (2012), Ritmare (2012), CoastGap (2013), Mare Nostrum (2013), Medsandcoast (2014), and many others.

Recently, an EU Directive (2014), based upon a previous Directive (MSP 2008), introduced a common framework for European Maritime Spatial Planning (MSP), urging public authorities and stakeholders to produce a coordinated, integrated and trans-boundary approach to coastal issues for when and where anthropic activities take place at sea (Pranzini et al., 2015).

Considerations

Within the dam-river-coast system, conflicting priorities exists between the populations living far from the coastland, who need protection from river flooding and landslides, and those living along the flood prone coasts, for whom the river sediment, supplied to the coastline by floods, is indispensable to counteract erosion processes. This conflict could be resolved only within a wider approach, even wider than a single Integrated Coastal Management (ICM) and MSP. A possible solution could be found by merging together ICM and River Basin Management (RBM).

With reference to the size and the current state of this wide-ranging problem, international research policy should be pursued or established. This could be implemented by developing multidisciplinary research aimed at river restoration, preservation of fluvial connectivity, rehabilitation of dam efficiency and desilting or at its removal, beach sand nourishment and coastal dune renaturation.

Human interaction in coastal and fluvial environments needs modern approaches to management, such as engineering solutions and soft techniques which take in due consideration habitat protection as well (Charlton and Oxford, 2002).

Morphodynamics and morpho-evolutionary trends of river basins and coasts are usually carried out by analysis of historical cartography, aerial photos and satellite image interpretation, littoral drift detection, monitoring of morphosedimentary and vegetation aspects of sand dunes as sensitive environments. Along the coastland, accelerated erosion rates represent the main issue and are, sometime incorrectly, considered as a consequence of anthropogenic impact (Pranzini et al., 2017). In this perspective, sea-level rise is a result of global warming while decrease of river sediment input is due to river damming, overmining of sediments by the river bed, land use changes in catchment, construction of ports and coastal defenses.

To date coastal defenses have been constructed along relatively short segments of littorals, with limits coinciding to administrative boundaries. This approach definitely failed, considering the impact along adjacent shorelines, frequently resulting in downdrift erosion processes and floods.

These changes make it difficult for people and ecosystems to adapt to a changing climate.

Therefore, new tools are required for the study of the dam-river-coast systems. They should aim at defining in the medium-short term: (i) river longitudinal zoning, (ii) concentration time evaluation and return time, (iii) catchment erosion rate, (iv) quantification of silting of reservoir, (v) littoral drift and morho-evolutionary trend of littoral prism.

Each of these items is related to others, and is quite complex in term of stages and implications. In particular, longitudinal zoning allows to highlight the relationships between natural and engineered reaches of a mainstem and its tributaries and to measure their lengths, to describe the interventions and morphography of an urban river compared to the buildings over time. Concentration time permits to assess if a flash flood could occur: the probability is high especially when the value is lower than one hour. The catchment erosion rate, through surveys and modelization, may point out the main criticalities of slopes and relationships with sediment load and silting of reservoir. Sand trapped by dam, together with other meteomarine and anthropic factors, may drive the morho-evolutionary trend of littoral prism.

According to the methodological approach change, these tools can work in two ways: on one hand they are a *reflection* of the approach, on the other hand they are an *instrument* of the approach. Actually, this systemic approach aims to select adaptive rather than maladaptive strategies, following a policy of forecast, prevention and protection.

Ecological engineering techniques and environmental design are fundamental to recover and remediate endangered transition environments, considering integrated interventions in dam-river-coast system based on resilience rather than resistance.

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Planning and Land Safety

The Stava catastrophic failure of July 19, 1985 (Italy): technical-scientific data and socioeconomic aspects

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Abstract

On July 19, 1985 at Stava near Tesero (Trento Region, northern Italy), two impoundments collapsed, causing the death of 268 people and the destruction of many buildings. The two adjacent basins were constructed for the decantation and storage of fine-grained waste material (tailings), which was pumped from a nearby fluorite mine. The consequences of the failure was a vast mudflow that found its way downstream along the Stava valley. The failure occurred as a result of the collapse of the upper basin, which overwhelmed the lower basin. The mudflow continued down the valley destroying many houses in the village of Stava, eventually reaching Tesero, where more property was destroyed or severely damaged. The disaster in the Stava valley was one of the most tragic of its kind. With its high toll of lives lost and over 133 million euros in damage, it was one of the worst industrial catastrophes anywhere in the world. This paper examines the technical errors, shortcomings, responsibilities and consequences of this disaster.

Introduction

Mining activities require the use of ore washing plants for separating concentrated mineral ore from the waste rock or *gangue* that will not be used. This is generally attained by means of froth flotation, a process relying upon the capability of finely ground minerals to aggregate with water.

The processed waste – or tailings – is a liquid mixture of sand and silt that is discharged through a pipe into a purpose-built basin, named a tailings dam. A tailings dam can grow progressively to a considerable height (up to over 60 m). Therefore, proper construction and management are of paramount importance in order to guarantee long-term stability. Unfortunately, there is no economic interest in the construction of tailings dams, since no revenue can result from the waste material, so many mining companies tend to spend as little as possible for these geotechnical structures to the detriment of their stability.

The catastrophic failure of the Stava valley and other similar disasters can teach us an important lesson concerning the long-term stability and safety of tailings dams.

History of the Stava tailings dams

Stava is a hamlet in the municipality of Tesero, in the province of Trento (Fig. 1). Since the 16th century, a mine was active on Mt. Prestavèl for the extraction of small amounts of fluorite and, to a lesser extent, silver galena (Giordani, Lucchi, Salghetti Drioli, and Tosatti 2003). In 1961, a new plant was constructed adopting the froth flotation system in order to obtain high-grade fluorite suitable for use in the chemical industry. At the same time, a first basin was constructed for storing and decanting the tailings thus produced (Fig. 2). Once a small starter dam was constructed of locally available material, the lower dam was raised by the use of two moveable hydrocyclones. Sands deposited by the hydrocyclones formed the shell of the dam, with finer particles carried further onto the beach areas (Lucchi 2005). The sand shell was never compacted. Supernatant water collected in a pond at a distance from the dam and was decanted and recycled. The downstream slope of the lower dam was raised with an angle of about 32° to an ultimate height of about 25 m.

The beginning of new mining activities at an industrial level (early 1960s) brought about some urban development of the Stava valley, with the construction in Tesero of accommodation facilities for the Montecatini mineworkers (Fig. 3). These miners and technicians came from other Italian areas, in particular Tuscany and Belluno province, where mining was thriving and had a long tradition (Morra, and Vighi 1964). In 1980, Fluormine gave back its mining concession and sold the accommodation facilities to a building society, which later turned them into tourist residences.

In 1969, in order to deal with increased mining production, it was necessary to construct a second basin just upstream of the first one. The dam of this second basin was raised without any provision either for anchoring it to the ground or for draining. As the dam grew higher, the base of its embank-

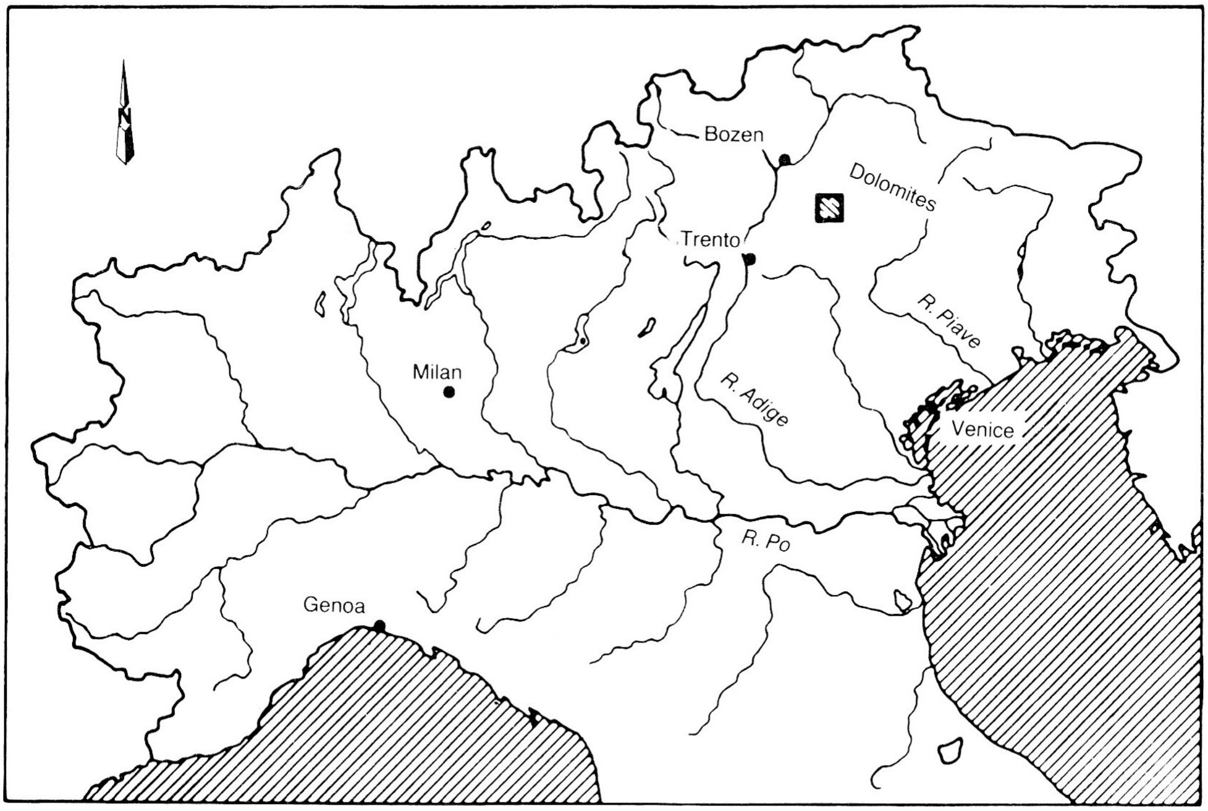

Figure 1 – Location of Stava, northern Italy (shaded box indicates area of disaster).

ment grew wider until eventually it rested partly on the silt of the lower basin. The decant pipes were placed inside the basins and discharged outside by passing through the dams. For a period (1978 to 1982), the basins were not in use. Activity resumed in 1983 and continued until the collapse of the structures in July 1985 (Lucchi 2005).

Proper urban planning was completely lacking at Stava, since the mining plant and the tailings dams had been built in a valley highly appealing to tourists, considering the scenic beauty of the area. Therefore, two incompatible activities

Figure 2 – The lower Stava basin in April 1985.

were sharing the same territory: on the one hand, the traditional mountain buildings and hotels in a charming Alpine valley and on the other, an industrial activity with heavy environmental impact. Technically, this means that together with tourist development also exposure to potentially hazardous events increased but was totally ignored.

Dynamics of the catastrophic failure

When failure occurred, the lower dam was 25 m high and the upper dam was over 34 m high. Together, they made up an earth structure nearly 60 m high. The upper dam had a berm at about 2/3 from its base, which partially rested on the silt of the lower dam. The upper dam's slope was 38°÷39° below the berm and about 32° above the berm (Fig. 4).

At 12 hours 22′ 55″ of July 19, 1985, the upper dam collapsed, causing also the failure of the lower dam.

Failure occurred suddenly without any warning. A loud rumble and the raising of a thick cloud of whitish dust accompanied the collapse of the two dams. It was followed by the quick propagation of a 180,000 m^3 flow slide of semi-fluid slime, which shortly attained a velocity of 90 km/h, running a distance of 4.2 km, as far as the riverbed of the River Avisio in Fiemme valley, where eventually it depleted its devastating energy (Alexander 1986, Takahashi 1991, Govi, and Luino

Figure 3 – The accommodation facilities for the mineworkers in Tesero (early 1960s).

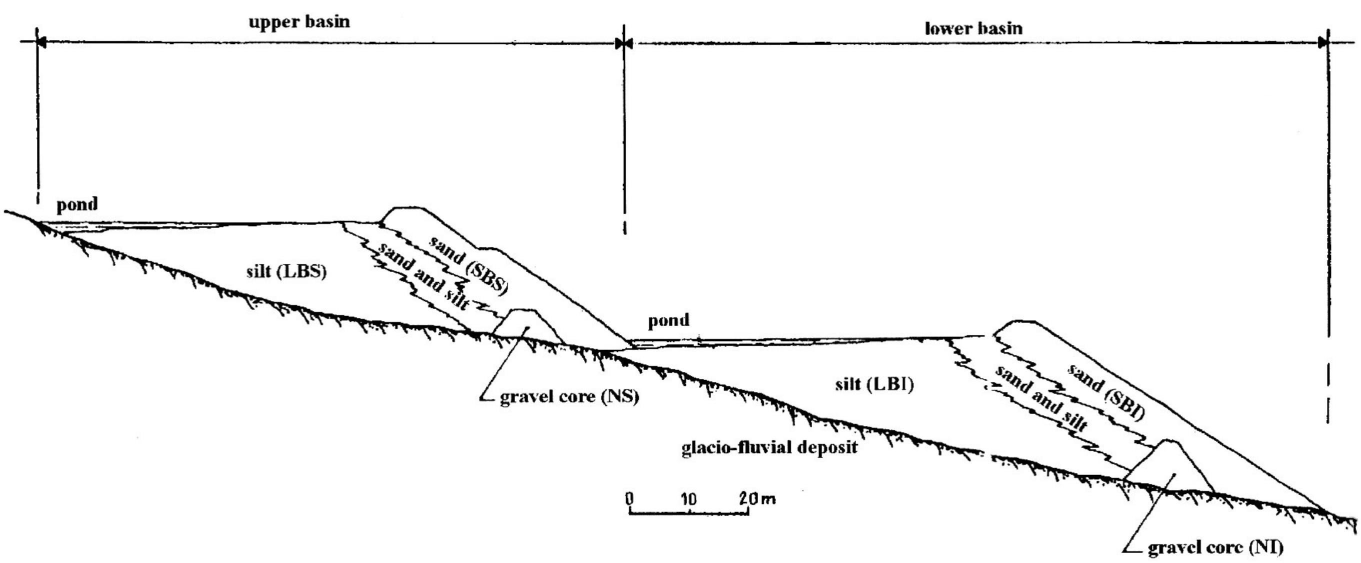

Figure 4 – Section sketch of the Stava tailings dams (after Colombo, and Colleselli 2003).

2003). Hundreds of trees were broken or uprooted because of the air blast that preceded the flowslide (Fig. 5).
Along its route, the flowslide caused the death of 268 people, the complete destruction of 53 houses, three hotels, six industrial buildings and eight bridges, seriously damaging several other buildings. Of the two bridges of Tesero, the first was overflowed and damaged by the flowslide, although it stood 16 m high over the valley floor. Total damage amounted to over 133 million euros (Lucchi 2011).

Geotechnical aspects of the collapse

The size of a tailings dam depends on the quantity of tailings to be disposed of and, in turn, this quantity depends on the estimated amount of waste material that fluctuates continuously as mining development progresses. Accordingly, the final size and design of tailings impoundments can differ substantially from the initial project and may often reach tens of meters in height and cover several square kilometers. Costs are often directly related to the amount of fill material used in the dam or embankment (i.e., its size) built to contain the slurry. Therefore, major savings can be obtained by minimizing the size of the dam (for example by constructing the impoundment against natural slopes) and by maximizing the use of local materials, particularly the coarse part of the tailings that can be obtained by separation with a hydrocyclone. The use of raised embankments is therefore much more common than the use of retention dams (designed and constructed at full height from the beginning of disposal activities), and, therefore, the stability of tailings dams should be a major concern for designers. At the same time, the phased nature of raised embankments makes it possible to attempt to address problems that may arise during the life of a tailings dam and accomplish engineering solutions without taking the impoundment out of service.
As an example, the Żelazny Most tailings storage facility in southwestern Poland, which is one of the largest tailings dams in Europe, at the end of 2013 stored $527x10^6$ m^3 of tailings, consistent with an average storing rate of $17x10^6$ m^3/year. At that time, a maximum dam height approaching 63 m and a covered area of 12.4 km^2 were attained. In 1972, at the beginning of mining activities, the disposal was planned to be in service for an overall period of over 70 years and, since 1992, a four-member international board of experts, in cooperation with a Polish geotechnical engineer, was assigned the task of overseeing the safe development of the tailings dam by applying the observational method.
The application of the observational method, as conceived by the board of experts, consists of the following stages (Jamiolkowsky 2014):

Figure 5 – The devastating effects of the flowslide on the Stava valley (July 1985)

a) Continuous enhancement of the monitoring network and of the communication system between the monitoring groups and the end users of the results of monitoring.
b) Geotechnical analyses of the observed displacements of the dams to predict their further evolution with the increase of dam height with time.
c) Modification of the plans for design and construction in

the light of the monitoring results and stability analyses.

Raised embankments can be constructed using upstream, downstream, or centerline methods (Fig. 6). With the upstream method, the embankment axis moves backwards and the beach that develops during the deposition of the tailings becomes the foundation of the next dam. With the centerline method, the coarse part of the tailings is placed on both the beach and the downstream face.

The upstream method was used in Stava to raise the embankments of both the lower and the upper basins. For the lower basin (built from 1961 to 1971), it was used alternately to the centerline method, while for the upper basin (built from 1969 to 1985) the upstream method was adopted after an initial construction stage using the centerline method (Colombo, and Colleselli 2003). It follows that initially the upper basin was partially founded on the inner, and then finer, part of the tailings of the lower basin (Fig. 4).

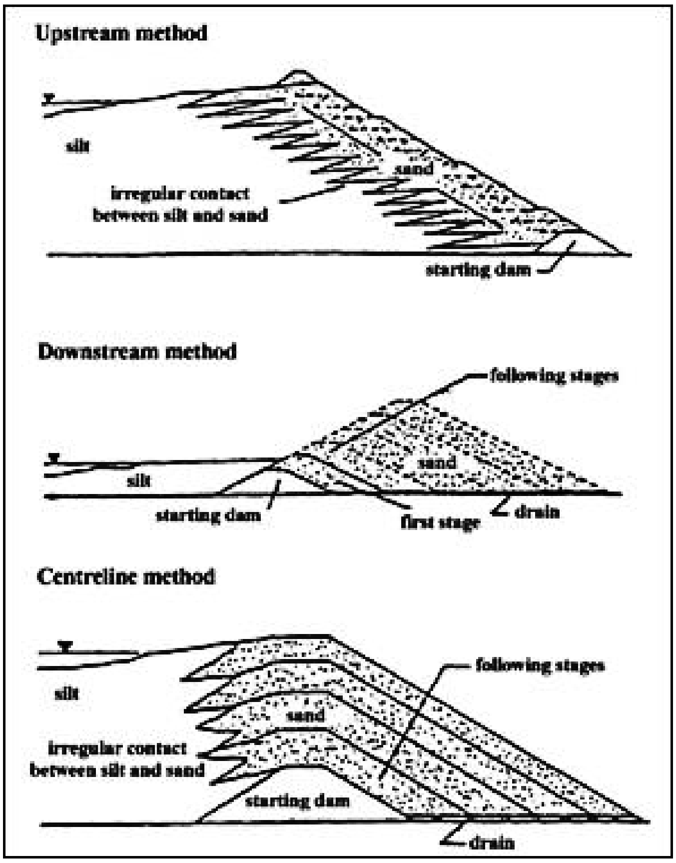

Figure 6 – Construction methods of tailings dams (after Colombo, and Colleselli 2003).

Geotechnical site investigations were not carried out either before the construction or during the management of both the lower and the upper basins. Furthermore, there was no calculation for the stability conditions of the embankments (Chandler, and Tosatti 1995) except for the dam of the upper basin when in 1975 it was decided to increase its height from 19 m to 34 m. An angle of shear strength of 35° was estimated in the laboratory for the sandy part of the tailings, while an angle of 30° was assessed for the silt. Two slope stability analyses by using the Fellenius method and supposing two different potential sliding surfaces gave factors of safety slightly higher than 1 (1.14 for a circular sliding surface, mainly developing in the sand of the embankment, and 1.26 for a circular sliding surface, mainly involving silt). Although the factor of safety was not significantly greater than one, the embankment was raised up, and in July 1985 it attained a height of 34 m.

At least two limitations affected those slope stability analyses: 1) pore-water pressure was assumed to be null everywhere in the embankment and below it; 2) the most critical sliding surface was not identified.

The two impoundments were built on a natural slope made of heterogeneous glaciofluvial soil, 60 to 70 m thick, made of boulders, cobbles and gravel set in a finer matrix. The bedrock directly underlay this deposit. The water table and seepage were affected by rainfall and snow melt. Before the construction of the lower basin, water ponds were identified in the area and a 9 m high starter dam was built with locally won soil, i.e. cobbles, gravel, sand and silt, probably with the purpose of improving drainage through the growing embankment and therefore its stability. In fact, in order to reduce the probability of occurrence of failure due to rotational slide or piping through the embankment, it is of primary importance to maintain a low water table near the embankment face. This task may be achieved by increasing the relative hydraulic conductivity of the embankment in the direction of flow (Vick 1983), but for the embankment of the upper basin the starter dam was built with no regard to the role of relative hydraulic conductivity. As a consequence, occasionally, overtopping had occurred causing the water table to rise. The most serious limitation, however, was the lack of the critical sliding surface identification. For the embankment of the upper basin, Ricceri (2001) obtained an unsatisfactory factor of safety of 0.95 with a circular sliding surface passing through the toe, demonstrating that the embankment built until 1975 was not in safety conditions.

The geological setting and the geotechnical properties of the tailings and of the foundation soil were investigated after the disaster by means of laboratory and field tests (Colombo, and Colleselli 2003). It should be pointed out that results refer to the material that was not directly involved in the failure because, for safety reasons, investigations were carried out away from the unstable area, such as the central part and the toe of the upper basin.

The embankments were made of cycloned fine sand and, behind them, cycloning resulted in the deposit of silty sand and sandy or clayey silt and further inside the impoundment in clayey silt and silty clay. Numerous laboratory (drained triaxial tests, shear box tests and torsional shear tests) and penetrometer (SPT and CPT) tests were carried out to calculate the shear strength of soils. For the sand of the embankments, the angle of shear strength was estimated in the interval of 32°-38°, quite close to the value of the slope of the downstream banks, which was between 34° and 39°. As regards the shear strength of the clayey silt, undrained shear strength resulted different for the lower and the upper basins. For the lower basin vane tests gave c_u=5 to 60 kPa, with values predominantly in the 20 kPa to 40 kPa range. For the upper basin, vane tests gave generally smaller values, ranging between 3 and 30 kPa. Finally, the estimation of the volumetric compressibility m_v versus the vertical effective stress σ′ made it possible to estimate an average degree of consolidation of 50%, with minimum values of 20-22% (Colombo et al. 1986, ISMES 1986). These values were found consistent with the theory proposed by Gibson (1958).

Consolidation of tailings can be improved by providing adequate internal drainage. At Stava, water drain pipes were used for the two impoundments (Fig. 7), but they proved to be inadequate and dangerous for stability. In fact, early in 1985, two failures were caused by the malfunctioning of the decant pipes at the toe of the right bank of the upper basin (January 1985) and in the left bank of the lower basin (May 1985). Moreover, pore-water pressure measurements carried out in the foundation deposit after the disaster indicated that pressure increased in the rainy period. Therefore, it is likely that in some periods, especially in spring and the beginning of summer (when precipitation is maximum, cf. Fig. 8), the foundation soil was not able to drain but, on the contrary, water was seeping upward in the tailings and in the embankments reducing their safety.

The increment of pore-water pressure distribution in the foundation soil played a major role in the failure of the Aznalcóllar tailings dam (Gens, and Alonso 2006) occurring in 1998 in Spain. In this case, pore-water pressure increased for the undrained behavior of the foundation high-plasticity clay and, in addition to its brittle behavior, a progressive failure in the embankment foundation took place.

Foundation failures are not uncommon among earthfill structures. For example, in August 2014, the Mount Polley tailings dam in Canada failed because of a weak layer of soil at shallow depth in the foundation below the structure (Morgenstern, Vick, and Van Zyl 2015). Given that dam failures are not rare, the Independent Engineering Review Board for the Mount Polley disaster recommended promoting unsaturated conditions in the tailings in order to reduce the potential of their failure due to liquefaction. For the same reason, at the Żelazny Most tailings storage facility many efforts were made to identify and control the location and trend of the water table (Jamiolkowsky 2014).

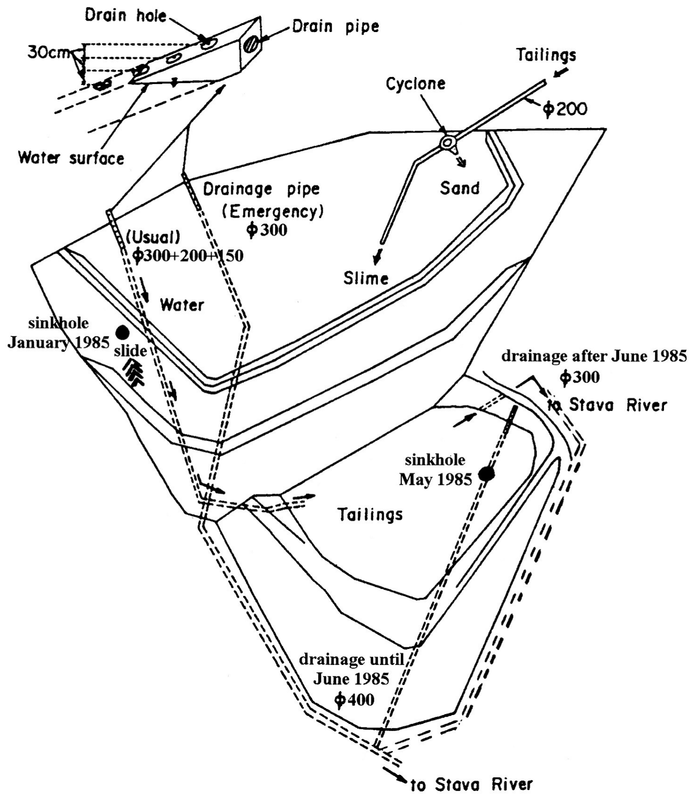

Figure 7 – Location of the decant pipes through the Stava dams (Colombo, and Colleselli 2003).

As for the Stava valley disaster, the fast flowslide of semifluid slime, which followed the collapse of the two impoundments, can be explained by considering a well-known phenomenon in soil mechanics: soil liquefaction due to static loading. The soils susceptible to liquefaction are those in which shear strength is mobilized only by particle friction, i.e., cohesionless soils (sand and silt) such as those which made up the Stava tailings dams. In the case examined, liquefaction is ascribable to water fluctuations that eventually led to a high piezometric surface. Although several scientific papers had already been published on the potential liquefaction of silty-sandy tailings that make up earth dams (Rossi 1973, Vick 1983), this hazardous tendency was completely ignored at Stava.

Among other factors predisposing the Stava tailings dams to instability and, eventually, failure, the first substantial error was the mistaken belief that the silt deposited in the dams could consolidate soon after deposition (Genevois, and Tecca 1993). This optimistic assessment influenced the construction operations of the embankments, which were inadequate, and their location upstream of the villages of Stava and Tesero, without ever considering the risks due to their persisting instability. Based on the data collected on the upper basin after failure, it resulted that its soil composition was rather inhomogeneous, with negative feedback on the

shear strength parameters and horizontal and vertical hydraulic conductivity (Carrera, Coop, and Lancellotta 2011).
In addition, the area where the basins stood was marshy and poorly drained and, as such, unstable and unsuitable for supporting these geotechnical constructions.
Finally, the overflow and decant pipes had been wrongly placed inside the basins and they sagged under the increasing weight of the silt deposits. This caused significant leaks inside the ponds in two different circumstances, early in 1985, when substandard repairs were carried out. This last mismanagement of the drainage system inside the upper basin is considered to be the triggering cause of its eventual failure (Chandler, and Tosatti 1995).
In conclusion, the geotechnical processes that were recognized to have caused the failure and collapse at the tailings impoundments at Stava may be summarized as follows (Colombo, and Colleselli 2003):
1) Local slope failure at the downstream face of the upper basin embankment caused by a temporary rising of the water table; 2) failure-induced liquefaction of the sandy and sandy-silty soil of which the raised embankment was made and 3) undrained failure of the silt deposited behind the embankment.
The collapsed part of the upper basin was about 100 m long and its downward movement caused the collapse of the lower embankment with the result that a volume of about 180,000 m^3 of tailings flowed downstream causing the complete destruction of the Stava valley.

Meteorological characteristics

From a meteorological point of view, the mean annual precipitation in the area studied is 820 mm. This value corresponds to the 1921-1987 observation period and was measured at the Cavalese weather gage, located at about 4 km SW of Stava at an altitude of 990 m. Fig. 8 shows the trend of the mean monthly precipitation and points out that the maximum rainfall is concentrated between May and August. Since the annual mean temperature is about 7 °C, the real evapotranspiration according to Turc should correspond to 52% of the year total precipitation in the period considered. With reference to the precipitation of the year 1985 (Fig. 8), when the dams' failure occurred, it can be noticed that the precipitation in the first six months was 465 mm, compared with the general mean value of 365 mm. In particular, in June of the same year the rainfall was 115 mm, compared with a mean value of 98 mm.

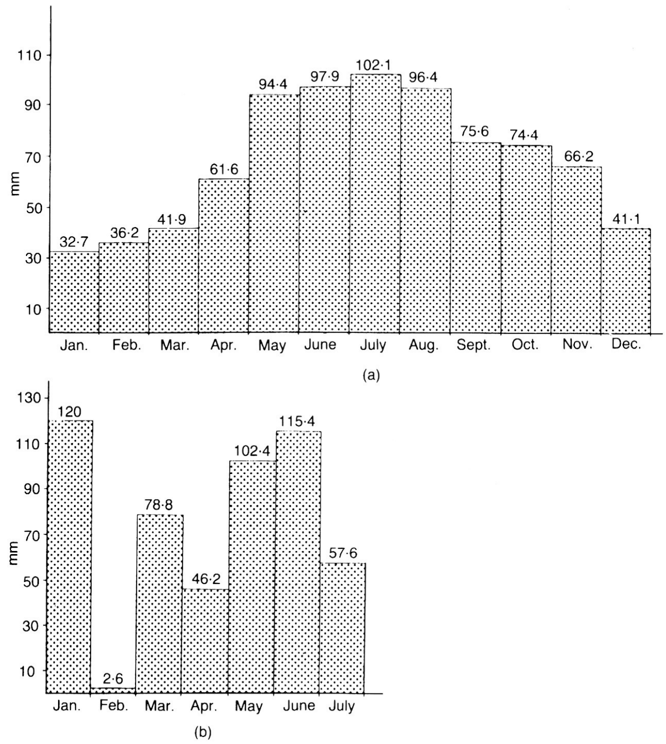

Figure 8 – (a) Mean monthly precipitation at Cavalese gage, near Stava, 1921-1987; (b) precipitation from January 1985 to July 19, 1985.

Geological setting and hydrogeological characteristics

The Stava valley ranges in height between 835 m a.s.l., at the bottom of the valley, and 2,490 m a.s.l., maximum altitude of the Torrent Stava catchment basin, which is a right-hand tributary of the River Avisio. In particular, the two basins were located at an altitude of 1340 m and 1375 m, respectively, on a slope variably inclined at between 12° and 16°, along the small valley of a secondary brook, called Rio Porcellini. This watercourse is a right-hand tributary of the Torrent Stava, which is characterized by a poorly defined and cut riverbed.
Geologically, the area belongs to the sequence of the "Piattaforma Atesina" in the Southern Calcareous Alps, which characterizes the Dolomite region. The oldest rocks cropping out in the study area are the volcanic Lower Permian Porphyry Formation, with a thickness exceeding 800 m, from which fluorite was extracted. These are overlain by a typical Dolomite sedimentary sequence ranging from the Permian to the Ladinian Marmolada limestones, cropping out on the eastern flank of the Stava valley, which constitute the terminal member of the sedimentary succession. Finally, the Quaternary sediments consist of slope deposits and moraine and glaciofluvial deposits, while Holocene fluvial deposits are found along the main watercourses (Fig. 9).
The above succession, is affected by an important structural feature, the so-called Stava line (Doglioni 1987). This regionally

important tectonic lineament has lifted the porphyries that make up the northern block, whilst the southern lowered one is characterized by the presence of quartz-porphyries and Permian-Ladinian sedimentary formations. In particular, in the Stava area this discontinuity is accompanied by mainly reverse faults, with NE-SW or E-W directions, which determine the lowering of the southern blocks. Other fault systems are present in the upper Stava valley with prevalent N-S and NW-SE trends. These local tectonic features have an important meaning from the hydrogeological standpoint since they bound formations with diverse water conductivity and with possible presence of confined aquifers (Tosatti 2007).

The Prestavèl mine tailings dams were constructed on Würm moraine and glaciofluvial deposits in the Rio Porcellini valley. The latter have a thickness of 50 m to 100 m, and are extremely heterogeneous in their particle-size distribution, with boulders, cobbles and gravel surrounded by a more or less abundant fine matrix. These highly permeable deposits are often in direct contact with more recent talus debris and fluvial deposits.

Following the directions of the Trento Court's Team of Experts (Colombo et al. 1986), in the basins' area some mechanical borings were performed. Of the three deep borings, driven up to a depth of 70 to 85 m, the two eastern ones found the porphyries below the Quaternary deposits, whilst the boring more to the west reached a bedrock made up of limestones and marlstones of the Lower Triassic Werfen Formation.

Given the above data, together with information from more recent geological investigations (Various Authors 2017), it was possible to construct the two sections illustrated in Fig. 9. It is interesting to note, in section B – B', that there appears to be physical continuity in the moraine cover between the deposits of the nearby Rio Gambis valley and those of the Stava valley through a pre-Quaternary buried channel beneath the Rio Porcellini stream.

Until the investigations following the failure, there was little hydrogeological data concerning the study area.

In the Stava valley and surrounding areas, about 110 springs have been identified although knowledge of their flow-rates is very sparse, and only applies to the 1974-1989 period. The few available continuous flow-rate measurements show that the flows closely follow the precipitation trend, with maximum values in the summer months (Fig. 8). Nearly all the springs occur at the foot of the slopes along the main valley trenches, and are linked to the presence of Quaternary slope deposits or, less frequently, to superficial flow within the upper fractured levels of the porphyries and limestones of the Marmolada Formation. These factors enable the correlation between the hydrological regime of the springs, the precipitation trend, the annual total flow and the catchment basin surface, the latter practically coinciding with the hydrogeological basin. Additionally, surface runoff is virtually zero due to the extensive forest cover, predominately made up of conifers such as spruces, larches and fir trees.

Several systematic flow measurements were made at these springs (Colombo et al. 1986) demonstrating that the annual

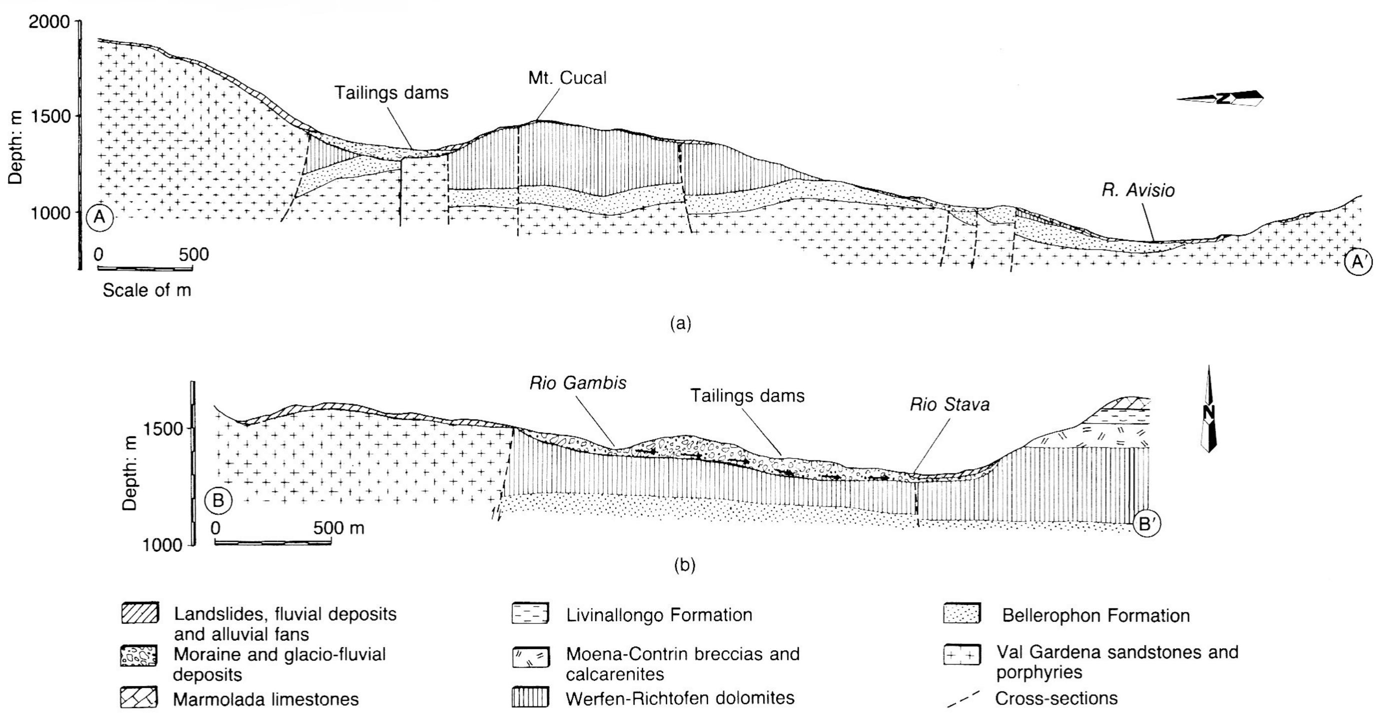

Figure 9 – Geological cross-sections across the failure area at Stava (after Chandler, and Tosatti 1995).

total discharge (c. 1,007,000 m^3/year) is slightly less than the annual precipitation infiltration (less evapotranspiration) into the basin (c. 1,022,000 m^3/year).

These data can be explained if the geometrical and structural characteristics proposed in the geological sections of Fig. 9 are accepted. According to this interpretation, there is a water circulation from the Gambis valley into that of the Rio Porcellini, resulting in the emergence of the Pozzole springs, where the tailings dams stood.

Phreatic fluctuations within the surface layer are closely connected with rainfall, showing maximum values in the May to August period, with a very rapid rise in groundwater level (up to 18 m in May-July). Apart from direct infiltration of rainfall, this particular situation can result also from the high gradient talus debris, which covers the lower part of the slopes, being also characterized by high permeability. Indeed, these slope deposits are geometrically and hydraulically contiguous to the glaciofluvial deposits placed at the bottom of the valley, thus allowing a direct exchange of groundwater.

In summary, the local groundwater conditions in the area of the tailings dams appear to be closely related to rainfall and snowmelt, but are also influenced by flow from adjacent talus debris, and by an underground contribution from the nearby Rio Gambis basin. Such conditions bring about extreme ground water levels in the June-July period: it was in fact in July 1985 that the failure of the tailings dams took place.

At Stava the two earth dams which contained the fluorite mine tailings were raised without considering the negative influence that the marshy nature of the ground and the presence of several water springs would have on the stability of these geotechnical structures. Furthermore, the tailings dams had been built on a very steep slope, with an average inclination of 25%, the dam of the upper basin had an excessive outer slope (over 80%) and did not allow water drainage or the consolidation of the tailings therein contained.

Both dams were poorly built with inhomogeneous materials, with the upper tailings dam resting on the unconsolidated silt of the lower basin. In addition, the overflow and decant pipes had been wrongly placed inside the upper basin and sagged under the increasing weight of the silty deposits, causing significant leaks inside the pond (Fig. 7). Finally, proper stability analyses were never carried out and the soil's susceptibility to failure-induced liquefaction was completely ignored, notwithstanding the good level of technical knowledge that was available from literature (Luino, Tosatti, and Bonaria 2014). In this way, when failure occurred, there was a very fast, destructive flowslide, leaving no chance of escape to whoever was in its course (Fig. 5).

The responsibilities

Ten years had passed from the Stava catastrophe when the book "Stava perché" was written (Lucchi 1995), in which the origin, causes and responsibilities of this disaster are described as they appeared in the committal for trial and in the sentences of the trials. The author was aware that he was unable to write an objective report. He therefore decided to describe exclusively what was written in the report of the Civil Defense Ministry enquiry, which was accepted by the court judges, and in the motivations of the sentences handed out at the trials. "Stava perché" is the story of a sentence that has become final, since none of the defendants or the persons responsible for the disaster ever asked for a review of the trial. As such, this document is incontrovertible and true in a State subject to the rule of law.

According to the preface of this book (De Battaglia 1995), «*the true monument to the 268 innocent Victims of Stava is the silent suffering and resilient and constant commitment that the survivors have transmitted over all these years to keep the memory of their deceased relatives alive. In this way, they could free themselves from the despair of their loss, express true civil redemption with new, more sincere relations among human beings and disseminate the knowledge that the Stava disaster was not an inevitable fatality*».

These words do not represent just the commitment of the relatives of the Stava Victims, but also show the true cause of the disaster. This is to be found in people's relationships that in the years before and after the Stava catastrophe were characterized by superficiality, lack of care, approximation and hastiness, mere economic interest and arrogance, accompanied by subjection and complete lack of professional ethical responsibility.

The top managers of Montecatini, who in the early 1960s constructed the plant for treating the fluorite ore in a zone that was defined "perfectly functional" from the economic standpoint, showed all these negative attitudes. Although they were aware that the site chosen was the least suitable for a tailings dam, they did not hesitate to construct it on a steep marshy slope. Indeed, this was the worst place from the technical viewpoint and ten years before failure, some of their technicians had warned them that the stability of the upper basin was close to breaking point. Notwithstanding this, they ignored this alarm and continued to raise the dam.

The same negative attitudes were found also in the top managers of Prealpi Mineraria, who ignored the leakage problems that affected the basins in January and May 1985, when it should have been obvious that they were a premonition of impending failure.

The same firms that constructed and managed the Stava tailings dams again showed arrogance and presumptuous-

ness when they accused the inhabitants of the Stava valley for having built their homes near the basins, without worrying for their stability. As if those homes had been destroyed because of those who had built them, when in fact they had been constructed long before the tailings dams.
Subjection was shown also by the local authorities, which, in the early 1960s, favored the construction of the mining plant of Montecatini on Mt. Prestavèl in the name of industrialization, which – according to them – would have brought social and economic progress to the Stava valley. In particular, the administrators of the Autonomous Province of Trento, who were responsible for mining activities and should have considered the risks related to the conservation of the environment, totally ignored the hazard resulting from these high tailings dams. Furthermore, they never worried about the pollution of the watercourses caused by mining activities, as they never cared about the landscape ruined by the constant growth of these geotechnical monstrosities. These so called 'qualified technicians' submitted their expertise to economic choices, thus betraying their professional integrity.
We shall never get tired of exhorting these technical experts to claim dignity and responsibility in their professional activities. We shall never get tired of promoting new relationships among human beings, based on reciprocal respect, accountability and complete awareness of the risks involved. Hazardous industrial activities, such as the exploitation of mining resources and the use of water for economic purposes, should be based on the respect of rules, the care for the safety of people, the integrity of the environment and the correct use of natural resources. Therefore, in order to avoid the repetition of other, similar disasters, it is necessary to establish higher standards for the civil responsibility of all those who are in charge of the construction and management of potentially hazardous structures like tailings dams.

The aftermath: reconstruction, recovery of memory and social commitment

Today the Stava valley no longer shows the wounds that it received on July 19, 1985. The rebirth of a community is not measured only by the capability to restore the places where they live. Grass regrows quickly. On the contrary, human relations, the social texture and the will to look forward need time, tangible signs, practical actions and constant confrontation in order to reaffirm themselves after a tragedy of such proportions.
The rescue operations that were activated immediately after the Stava catastrophe were a first example of the active and positive reaction of the Tesero community. The subsequent vast interventions carried out by the rescue volunteer structures, which in the Alpine regions claim a centuries-old tradition, offered a demonstration of a high efficiency based on a strong human solidarity, although it was not possible to save many human lives.
At the same time, the population of Tesero started the reconstruction of the village of Stava and of all the structures that had been destroyed by the mudflow. This was carried out according to new urban planning (Fig. 10), which took into account the exposure of property to hydrogeological risks such as floods and landslides, though mining activity is no longer carried out in this valley. All the hotels were rebuilt in new, more favorable positions and the inflow of tourists is now higher than before the disaster (Viola 2011).
In the aftermath of this catastrophe, the relatives of the victims and all those who had suffered moral and material damage founded the "Victims of the Stava Valley Association". This association supported the claims of over 180 plaintiffs during the various stages of the trials that followed, with the assistance of a team of experts formed by university scientists from Italy, Great Britain and the United States. In addition, it promoted many cultural and commemoration initiatives aiming at preserving the memory of this disaster and prepared the ground for the establishment of the "Stava 1985 Foundation" (charity).
Indeed, preserving memory is a crucial duty at the service of the communities struck by catastrophic events that unfolds into several functions, as follows: 1) a healing function in the elaboration of bereavement and losses; 2) an ethical function warning against the repetitions of similar tragedies; 3) an educational function that facilitates prevention; 4) an aggregating function supporting the wounded identity of single persons and communities; 5) a generative function capable of activating new and resilient energies and 6) an exorcising function against the repetition of similar disasters also by means of rites, ceremonies, monuments (Fig. 11) and plaques.
An extraordinary event striking an entire community is inevitably an element of historical discontinuity. References to July 19, 1985, although not explicit, have entered daily relations, so much so that at Tesero the "before" and "after Stava" frequently emerge from the conversations, similarly to what was common for our parents and grandparents when they talked about "before" or "after the war".
Inevitably, living in the place where this tragic event took place, together with the desire to look beyond, has led the local inhabitants to live this tragedy with reservedness verging on modesty.
Diametrically opposed is the situation of the relatives of the victims from outside the village – nearly three quarters of the total – who were tourists from various Italian regions. For these, the opportunity to come to terms with what happened at Stava has come only in rare moments linked to the tragedy

Figure 10 – Houses and hotels in the new village of Stava (early 2000s).

Figure 11 – The monument to the Stava Victims in Tesero cemetery.

anniversaries, apart from the family sphere.

The Victims of the Stava Valley Association has been the main point of reference for overcoming bereavement thanks to the organization of the anniversaries and their meaningful contents, carried out together with the institutions. For this purpose, particularly significant was the visit of Pope John Paul II, which in 1988 brought together the community on the third anniversary of the Stava catastrophe (Various Authors 1989).

In 2002, the relatives of the Victims of the Stava Valley disaster established the "Stava 1985 Foundation", so that the 268 innocent people killed on July 19, 1985 did not die in vain. This Foundation is a non-profit organization of social utility. Its main goal is to maintain the active historical memory of the Stava catastrophe and strengthen the culture of prevention, correct management of the territory and safety of these structures in order to avoid other similar disasters.

Since the opening of the Information Centre – the seat of the Foundation – thousands of visitors, among them many students, have spent a day of environmental education in Stava, reflecting upon the importance of individual accountability (Fig. 12). These topics are dealt with daily in university institutes and high schools, thanks also to the Foundation's rich archives, where it is possible to find in-depth information about the origins, causes and responsibilities of this disaster. Most of these archives have been stored in digital format and are available on line (www.stava1985.it).

The Stava 1985 Foundation promoted and supported the post-university Master in "Analysis and Management of Geotechnical Systems" at Trento University, which was organized in order to disseminate knowledge in the field of Civil and Environmental Engineering, Geological Sciences, Sociological and Economic Sciences (Simeoni, and Tosatti 2010).

Owing to the potential hazard of tailings dams and considering also the norms established by the European Union concerning the management of earth dams and disposal of mining waste (CE Directive 2006/21), these topics have been discussed in detail.

One of the most relevant scientific events organized for the 30th anniversary of the Stava catastrophe (July 2015) was a cycle of high-formation seminars entitled "The safety of earth structures: tailings dams, fills and landfills" that the Foundation organized at Stava together with the Italian Geotechnical Association (AGI) and the Engineers Association of Trento Province.

Thanks to its constant commitment, in 2010 the Stava 1985 Foundation was awarded the Alexander Langer International Prize and in 2015 was presented with the "Green Flag" of Legambiente. The Stava 1985 Foundation is also a founding member of the "Fondazione Museo Storico del Trentino".

Figure 12 – The Information Center of the Stava 1985 Foundation (www.stava1985.it).

Acknowledgements

The Authors wish to dedicate this paper to the memory of all the innocent Victims of the Stava valley disaster.

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Environmental design

Methodologies and Challenges of 'View Protection Areas' for Landscape Planning in Japan

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Keywords: View protection area, Landscape planning, Visual impact assessment, Mt. Fuji, Japan.

Abstract

This paper focuses on the methodologies of 'view protection areas' for landscape planning in Japan. Historically, view protection areas were studied the ad hoc way and the methods of visual impact assessment and building regulations are still under development. The characteristics of objects for viewing and the distance of regulation to these objects are different for each case. View protection areas were officially adopted in landscape plans at local authority level after the first Japanese landscape law (no.110/2004) was passed.

The author studied not only the history of view protection areas for Japanese landscape planning but the recent challenges for view protection from central Tokyo to Mt. Fuji. Through case studies, this paper estimates the influences of the earth's curve and light refraction over a distance of 100 km are estimated, also giving information on regulation methods and the effects on view protection areas. Moreover, this paper offers information on regulation methods and the effects of view protection areas, through the author's experience gained from the urban design committee of Shibuya City and Minato City in Tokyo.

1. Introduction

There are some case studies on view protection areas in Japan but no paper discloses the history and methodologies of visual impact assessment in Japan. As there are no regional systems in Japan, local authorities (prefectures, cities, towns and villages) are responsible for landscape planning, by law. In Kyoto, people were interested in the East Mountain views from the Kamo River side by 'greenery zoning' from 1930, but view protection areas were not a part of landscape planning until 2007.

The oldest example of view protection areas was near the castle of Matsumoto in 1973. The methodologies of view protection areas were developed the ad hoc way till today. Moreover, the control methods are not easy to research as the information on assessment and controls are not usually published. Therefore, the author has presented a few examples of assessments not only through researches but also through the author's involvement in urban design committees.

The objective and methodology of this paper is to clarify the history and typologies of view protection areas in Japan. After the characterization of typologies of Japanese view protection areas and the methods of regulations, this paper proposes new viewpoints and view protections from Tokyo to Mt. Fuji including technical corrections of height.

2. History and Typologies of View Protection Areas

The concept of view protection areas started with the modernization of Japanese cities in the 1970s. Many cities were damaged by the Second World War and many historic buildings were demolished during modernization. Only historic monuments like temples and shrines were protected under the *Law for the Protection of Cultural Properties 1950*, but their number was limited in the case of urban areas.

The first case of view protection area with respect to historic monuments was by Prof Sachio Otani from the University of Tokyo. His research report on the landscape management at Matsumoto castle in downtown Matsumoto City was related to the central mountain ranges named the 'Japanese Alps', in 1973. This report focused on the height control of buildings near the castle for its surrounding mountain views. The regulation methodology defined three viewpoints at the front of the castle, using height control at the maximum elevation angle of two and three degrees which respect the surrounding views of mountains (Fig.1 and Fig.2). Matsumoto City adopted the concept of this report for view protection areas and followed the height control.

The second case of view protection areas was seen in Kurashiki City and Okayama Prefecture, located near Hiroshima, western Japan, in 1990 and 1992. During this period, people worried about the emergence of high-rise buildings at conservation areas under the pressures of economic development. The local governments had to protect the cultural properties of historic buildings and gardens from the development of high-rise buildings. They made an effort to reduce the visual impact with respect to cultural properties and covered the view protection areas (Fig. 3 and Fig. 4).

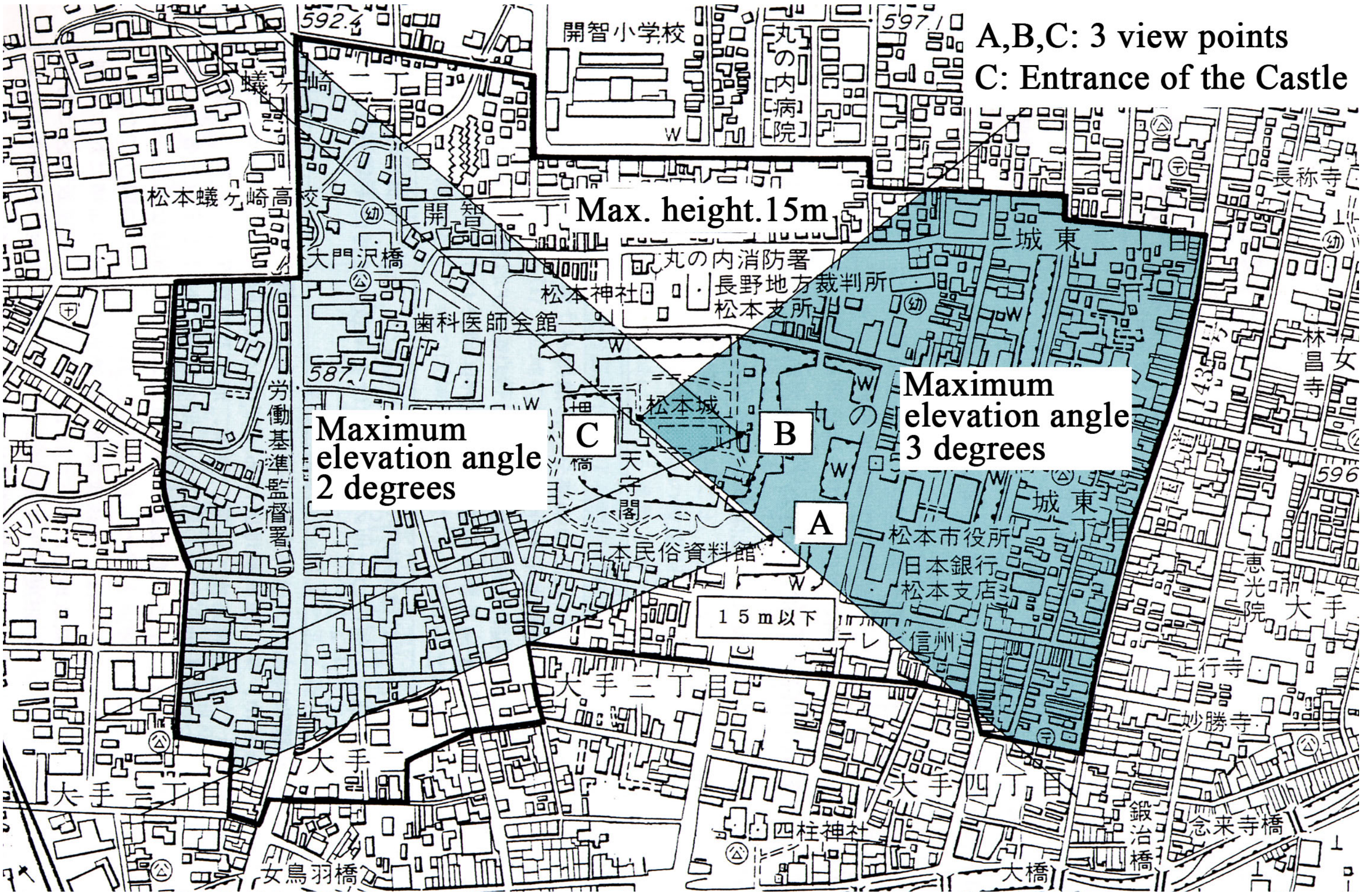

Figure 1 – Three view protection areas, reported by Prof Sachio Otani of the University of Tokyo, for the view protection at Matsumoto castle, in 1973 (reproduction in 1986). Credit: Matsumoto City.

Figure 2 – View of Matsumoto castle and its surroundings from viewpoint B, located in the view protection map of Figure 1. Credit: Masaru Miyawaki.

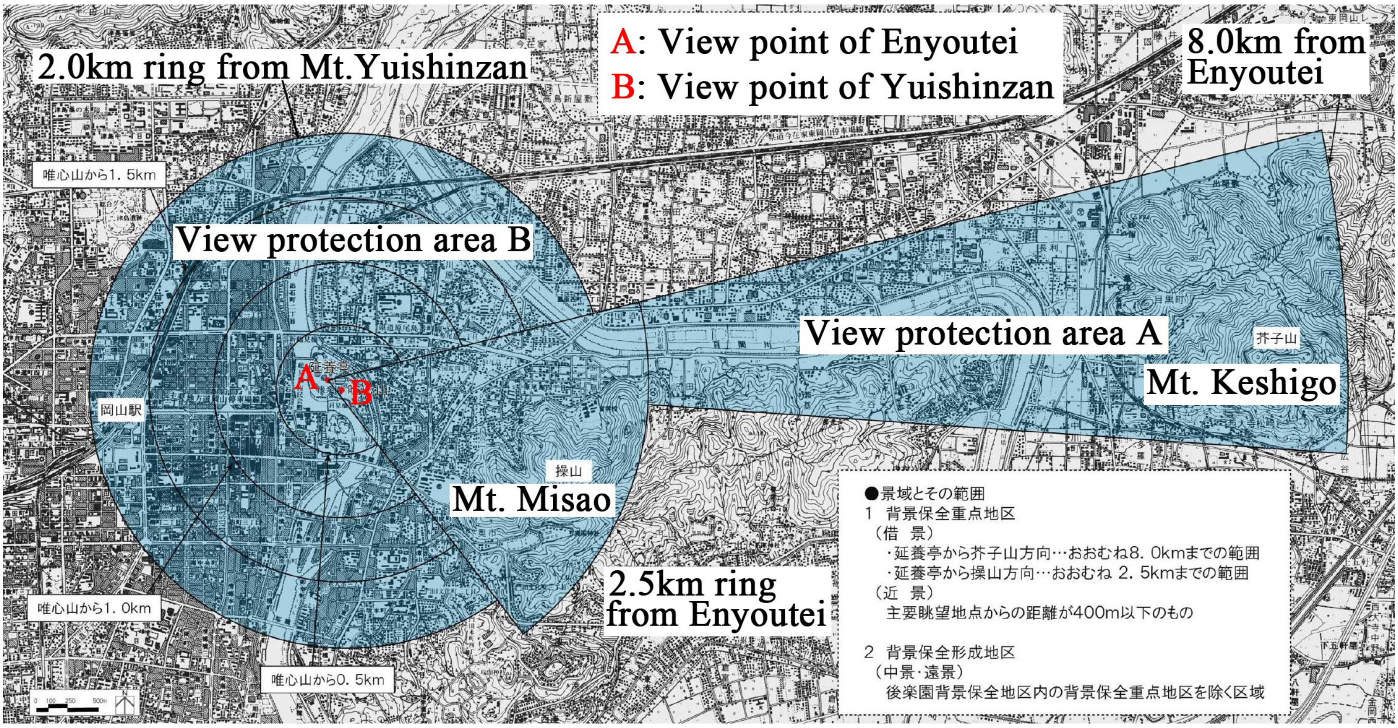

Figure 3 – Two view protection areas designated by Okayama Prefecture with the landscape ordinance in 1992. The viewpoint of Enyoutei (A) reveals the view from the villa in the Japanese garden 'Korakuen', established in 1700. The longest view measures 8 km till Mt. Keshigo which is outside the garden but the view was originally designed from the garden. The other viewpoint of Yuishinzan (B) shows the view from the small mount in the garden. The view measures 2 km in the central area of Okayama City. The two view protection areas were adopted in the landscape plan of Okayama City by the landscape law in 2007. Credit: Okayama City.

Figure 4 – The 8 km view from the viewpoint of Enyoutei (A) till Mt. Keshigo. The mountain is located on the outside of Kourakuen garden of Okayama City. Credit: Masaru Miyawaki.

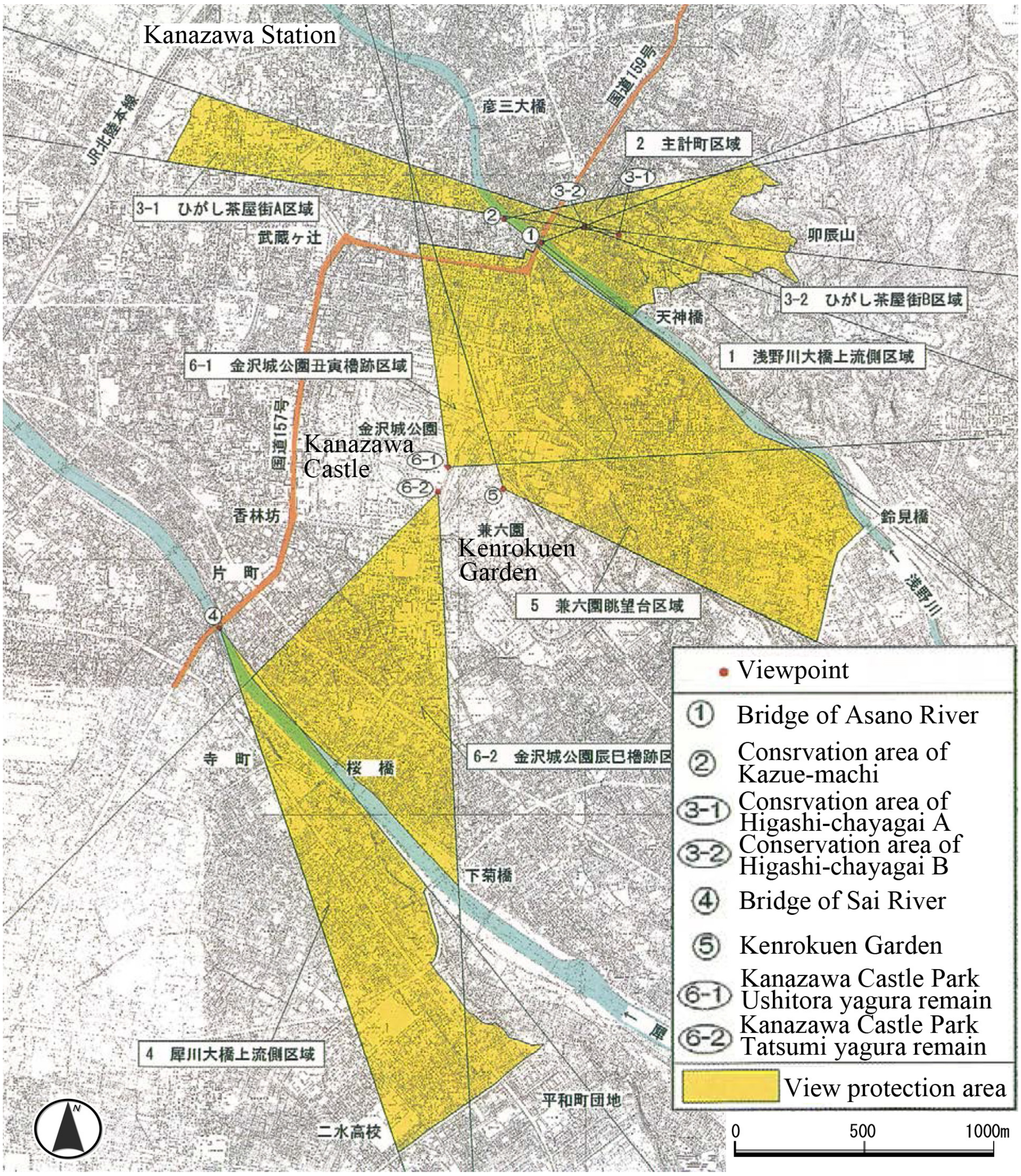

Figure 5 – Eight view protection areas published by the City's ordinance in 2003 and designated in the landscape plan of Kanazawa City by the landscape law in 2009. Credit: Kanazawa City.

The third case of view protection area was researched for all viewpoints in Kanazawa City from 2001 onwards. Kanazawa City assigned eight view protection areas to the historic townscape, city panoramas, and mountains, adopted by the landscape ordinance in 2003 and the landscape plan in 2009 (Fig.5). For example, in the view protection areas of Kanazawa City, there were risks involved in high-rise buildings in front of the national conservation area from the viewpoint 3-1 (Fig.6). The visual impacts of such developments were simulated depending on the height of the buildings on the historic street axis (Fig.7).

After the first Japanese landscape law (no.110/2004), Kyoto and Tokyo adopted a more general method for view protection areas in 2007. The methods for landscape planning in Japan are well known. In the case of Kyoto City, 38 sites were picked for view protection areas and surrounding assessment areas with three types of visual impact assessment and regulations. The first is the view from the riverside and parks to the historic 'Gozan no Okuribi', a spiritual festival in which five giant bonfires are lit on mountains surrounding Kyoto (Fig.8, Fig.9, and Fig.10). The second is the surrounding assessment area (max. 500 m distance) for historic gardens, temples, and so on (Fig.9 and Fig.10). The third is the design control area respecting the view (max. 3 km distance; Fig.9 and Fig.10). The height regulations of Kyoto City are used in the urban area, but the height control of the view protection areas is severer than the height regulations.

In the case of Tokyo metropolitan government, a local au-

Figure 6 – The view from the viewpoint of 3-1 (Conservation area of Higashi-chayagai A). Credit: Masaru Miyawaki.

Figure 7 – The simulation of the visual impact of high-rise buildings (from 16 m to 31 m in height) from the viewpoint of 3-1. Credit: Kanazawa City.

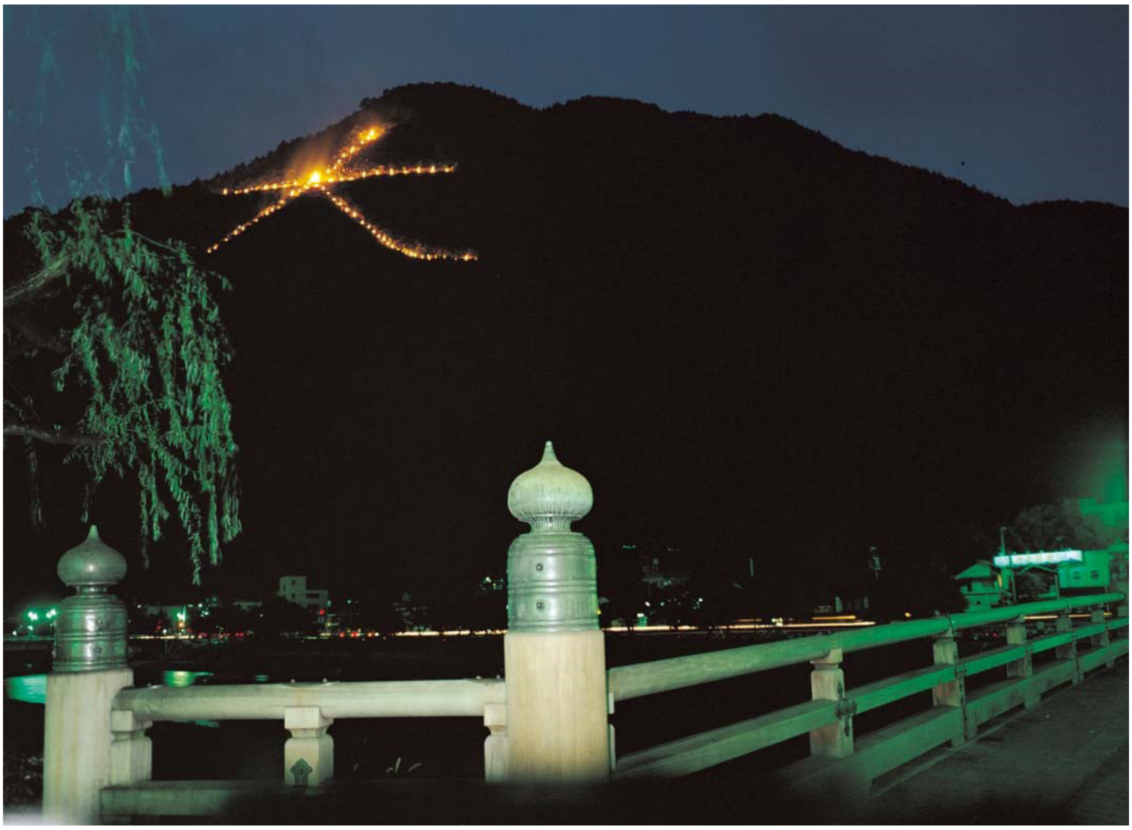
Figure 8 – The image of 'Gozan no Okuribi', a spiritual festival where five giant bonfires, forming characters, are lit up on the mountains surrounding Kyoto every year, on 16 August. Credit: Kyoto City.

thority managing the territory of the prefecture, the four view protection areas to historic buildings like the National Diet Building (1936), the National Guest House of Akasaka Palace (1909), Meiji Memorial Picture Gallery (1926), and Tokyo Station (1914) were adopted in the landscape plan of Tokyo by the landscape law (2007; Fig.11 and Fig.12). In this case, the view protection areas are through the city boundaries, so they are at the prefectural scale. The view protection areas are limited to only the width of the top of symmetric buildings, from its front and back.

Moreover, the ten surrounding assessment areas were adopted for the following historic gardens in Tokyo: Hamarikyu Gardens (17 century, Fig.13), Kyu-shibarikyu Garden (17 century, Fig.13), Kiyosumi Garden (1891), Shinjuku Gyoen (1906), Koishikawa Botanical Gardens (1681), Koishikawa Kōrakuen Garden (1629), Rikugien Garden (1695), Kyu-iwasaki-tei Garden (19 century), Kyu-furukawa Gardens (1917), and Tonogayato Garden (1915). For the historic centre in Tokyo, viewpoints were added to the surrounding assessment area of Tokyo Imperial Palace which had replaced from the Castle of Edo and moat system after Meiji Revolution (1868).

For understanding the characteristics of major view protection areas, this paper uses the following typologies according to objects:

1) The surrounding protection of historic gardens: Okayama (1992), Kyoto (2007), and Tokyo (2007).
2) The view protection to historic buildings and townscape: Matsumoto (1973), Kurashiki (1990, 2014), Kanazawa (2003), Kyoto (2007), Tokyo (2007), Hikone (2007), Yokohama (2007), and Minato (2015).
3) The view protection to the mountain: Morioka (1984), Okayama (1992), Kanazawa (2003), Kyoto (2007), Kagoshima (2008), and Ishikawa (2008).
4) The view protection to the sea: Yokosuka (2006), Kagoshima (2008), and Ishikawa (2008).
5) The view protection to the city: Kanazawa (2003).
6) The view protection to historic characters: Kyoto (2007).

The surrounding protection of historic gardens was first applied in the case of Okayama Korakuen and the concept was diffused to the gardens of Kyoto and Tokyo. The view protection areas to historic buildings were effective in the central areas for controlling new developments outside of conservation areas in Japanese cities. Therefore, view protection areas to historic buildings used a quick method to manage new developments if they remained in the centre of modern cities in Japan. On the other hand, view protection areas to the mountain, the sea, or the city could be used as a method for landscape management for their identity in the territory. Only the case of Kyoto shows the view protection areas to objects of historic characters on the mountains during the spiritual festival. There are minimum views in the cities but efforts are on to preserve their visual identities by landscape planning.

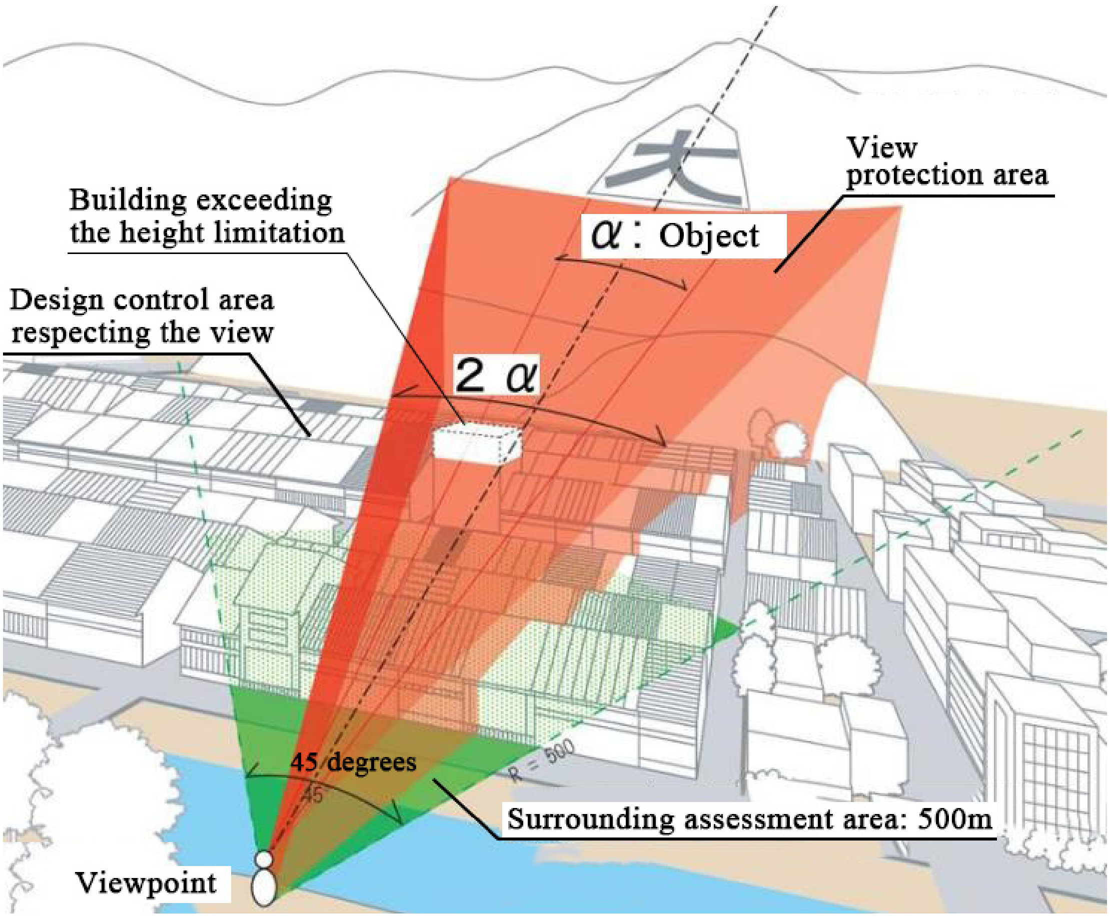

Figure 9 – Three types of control areas are designated in the landscape plan of Kyoto by the landscape law (2007). The first is the view protection area (in red), the second is the surrounding assessment area (in green, max. 500 m distance), and the third is the design control area respecting the view (max. 3 km distance). The widths of the view protection areas are designated by twice the width of the object of historic characters. Credit: Kyoto City.

3. Visual Impact Assessment

The varied methodologies of view protection areas are developed with an attempt to introduce it to the landscape plans. The distance of assessment is important for view protection of objects from its front and back. This paper defines four distances depending on objects in Japanese landscape plans: neighbourhood view (0-500 m), short view (500 m-3 km), medium view (3-6 km), and long view (over 6 km), as seen in the following cases:

1) Neighbourhood view (500 m): historic gardens and monuments (Kyoto).
2) Short view (500 m to 3 km): historic buildings (Matsumoto, Kurashiki, Kanazawa, Hikone, Yokohama, and Minato), historic gardens, and monuments (Kyoto, Tokyo).
3) Medium view (3 km to 6 km): historic building (Tokyo), and mountain (Ishikawa).
4) Long view (over 6 km): mountain (Okayama).

The historic gardens and monuments have very sensitive surroundings where higher impact evaluation could reach from the neighbourhood to a few kilometres away. The short view protection areas, from 500 m to 3 km, can control panoramic views or wider views for monuments. In the case of Ishikawa Prefecture, the panoramic road is also controllable up to 4 km for the mountain in the field. In the case of Okayama City, the long view, over 6 km, is controllable to the mountain in the non-urbanized areas.

On the other hand, view protection areas in the centre of Tokyo reach from 2 km to 4 km and the protected widths of the objects are limited from 20 m to 90 m. In the European situation, the longest view of St Paul's Cathedral (protected width of 300 m) and its back protect around 19 km from King Henry's Mound at Richmond Park in Greater London. Similarly, the protected view of the Louvre Palace and its back reaches around 8 km from the Arc de Triomphe in Paris. These are similar to the cases in Tokyo as the type of view comes from the view protection areas in urbanized areas.

The methodologies of visual impact assessment have not been researched well as the information of the assessment is not usually published in Japan. Private developers could realize their projects without making any announcements and the local governments would not publish their control.

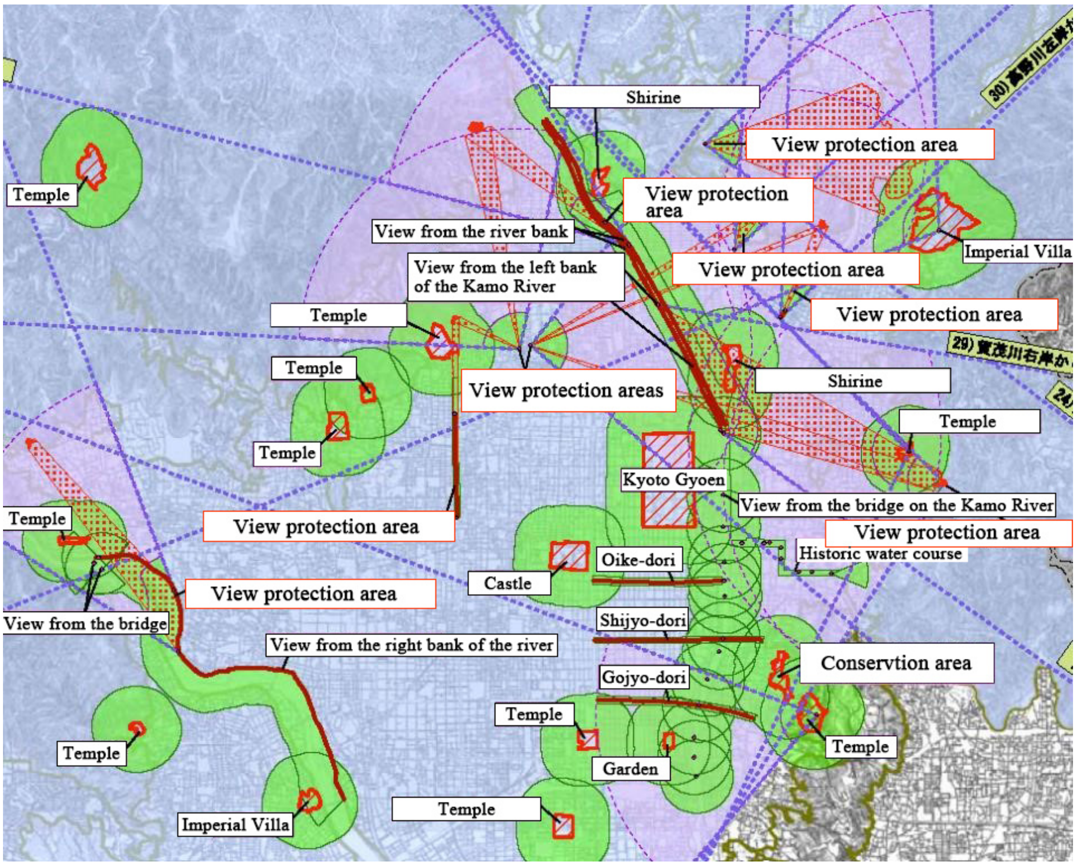

Figure 10 – A central part of the view protection map of the landscape plan of Kyoto (2007). View protection areas (in red dots), the surrounding assessment areas (in green), and the design control areas respecting the view (in violet), cover all the important monuments and views. Credit: Kyoto City.

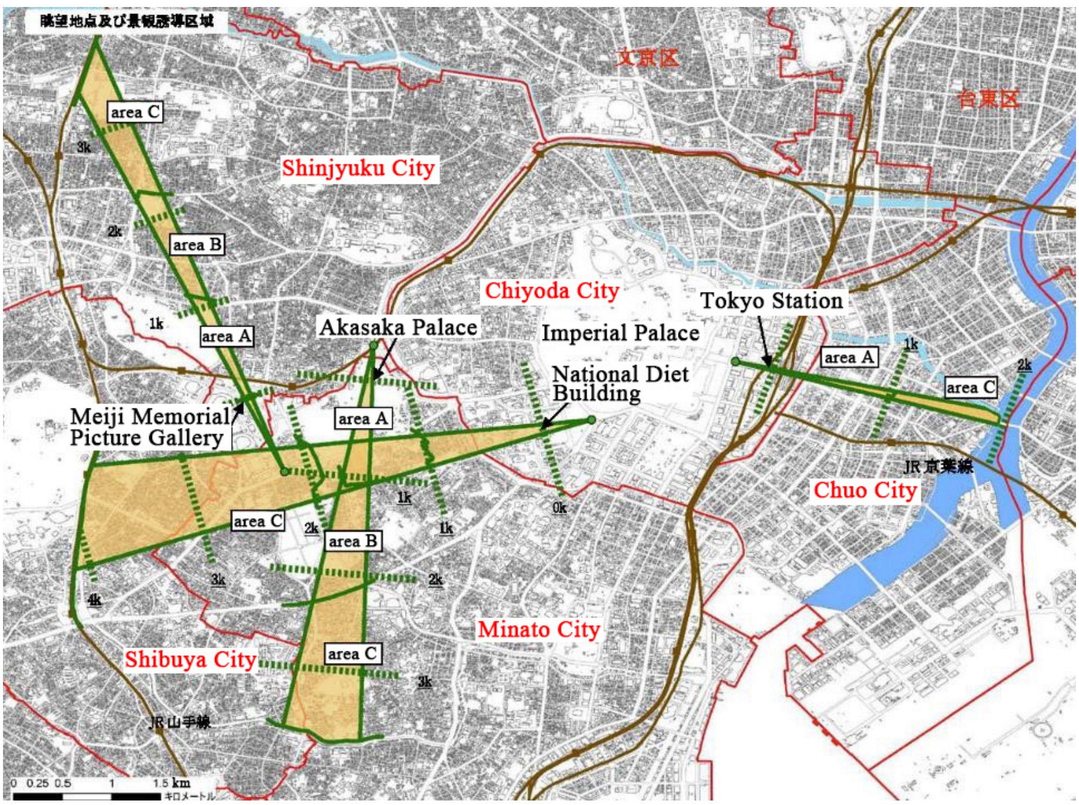

Figure 11 – Four view protection areas (in yellow) in the landscape plan of Tokyo (2007). All viewpoints are on the streets. The effect of the view protection appear behind historic buildings in the case of many skyscrapers in Tokyo. Credit: Tokyo metropolitan government.

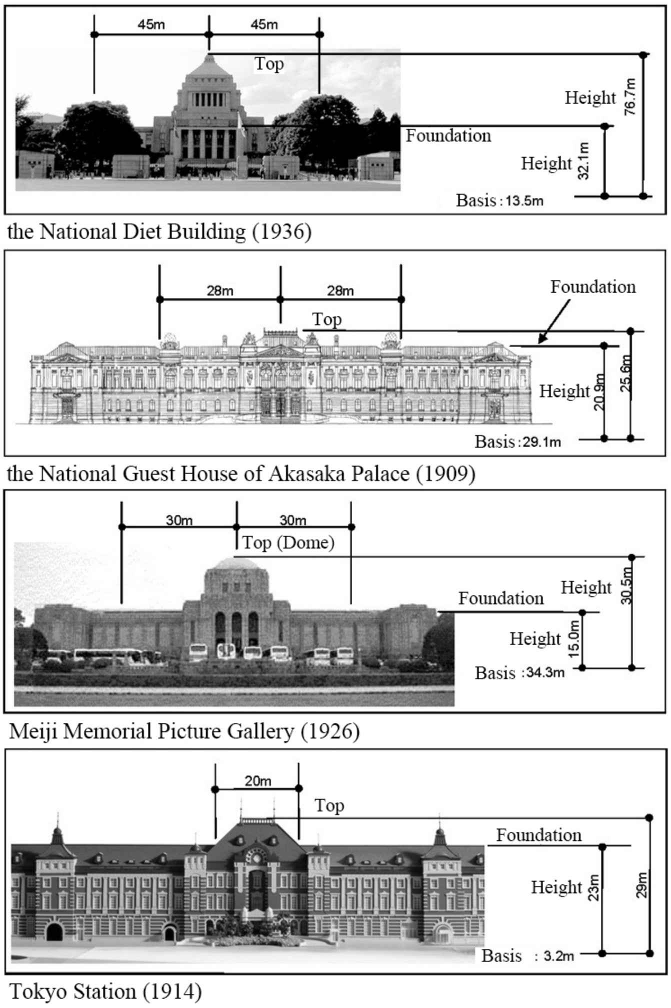

Figure 12 – Four historic buildings of Tokyo as the object of view protection (2007). View protection is limited to only the width of the top of symmetric buildings from its front and back. Credit: Tokyo metropolitan government

The visual impact assessment is not for environmental impact assessment (EIA) by the environmental law in Japan but for landscape assessment which is requested by the landscape law or landscape ordinances.

The first case of visual impact assessment at view protection areas was attempted by balloons to survey the real height of the project in Kurashiki City. The balloons were visible and it was easy to understand the impact on the historic centre of Kurashiki City. In this case, the height of the project was reduced from five floors to four while other changes included colour modification and design change to Japanese style. There are some practices of visual impact assessment in Kurashiki City.

The second case of visual impact assessment at the view protection areas was conducted with visibility check maps for long distance, by Okayama Prefecture.

After the Okayama case, Kurashiki City adopted the developed method and has been using the visibility check map for short distances of 1 km since 2014 (Fig.14). The visibility check map can help to quickly evaluate the visual impact from the viewpoints.

The visual impact assessment case of Tokyo was conducted with the height regulations of new buildings at areas A and B (Fig.11). The height of new buildings behind the historic buildings at areas A and B should be reduced. Area C, at the longer distance, is the consulting area for reduction of visual impact but the height control is ambiguous.

Moreover, the author's ten year experience as an urban design committee director of Shibuya City helps shed light on view protection areas in Tokyo following the landscape law. Neighbourhood surrounding views are projected very often and usually presented by computer simulated 3D images from the viewpoints which are indicated on the map of landscape plans in Tokyo. After visibility checks, the methods of regulations and mitigations were used as follows: the reduction in the height of buildings; the reduction in the impact of design, colour, and advertisement; planting trees for the reduction of the impact of buildings; and the creation of public spaces, etc. There are many practices of visual impact reduction but the actual controls are not published in Tokyo. However, the effects of the landscape plan and visual impact assessment have been seen recently. An example of this is the Shinjyuku Gyoen Park of Tokyo where the landscape looks vastly better than before due to the landscape plan of 2007 (Fig.15 and Fig.16).

4. Research on the Longest View to Mt. Fuji

The author has presented the latest challenges of view protections for Mt. Fuji, from Tokyo Tower and the new national stadium designed for Tokyo 2020 Olympic Paralympics Games.

The first example for the view protection area from the panoramic deck of Tokyo Tower to Mt. Fuji (UNESCO site, 2013 inscription) was proposed by the author as a member of the committee of Minato City in 2013. The proposed view distance of 97.3 km from the deck of Tokyo Tower (145 m height) to Mt. Fuji (3,776 m height) is the longest example in the world (Fig.17). The view was from the same location where the formal guest house 'Kouyoukan' originally stood. The old photo shows Mt. Fuji from the guest house in the 1920s (Fig.18). Today, Mt. Fuji is visible from Tokyo for more than a hundred days a year. This paper cleared the visibility of long distance and the necessity of the height correction by the earth's curvature and light refraction during the 97.3 km distance from Tokyo Tower to Mt. Fuji (Table 1 and Fig.19).

This paper cleared the visibility of Mt. Fuji and proposed the width of view and maximum building height in order to create the view protection area. In this case, it is revealed that

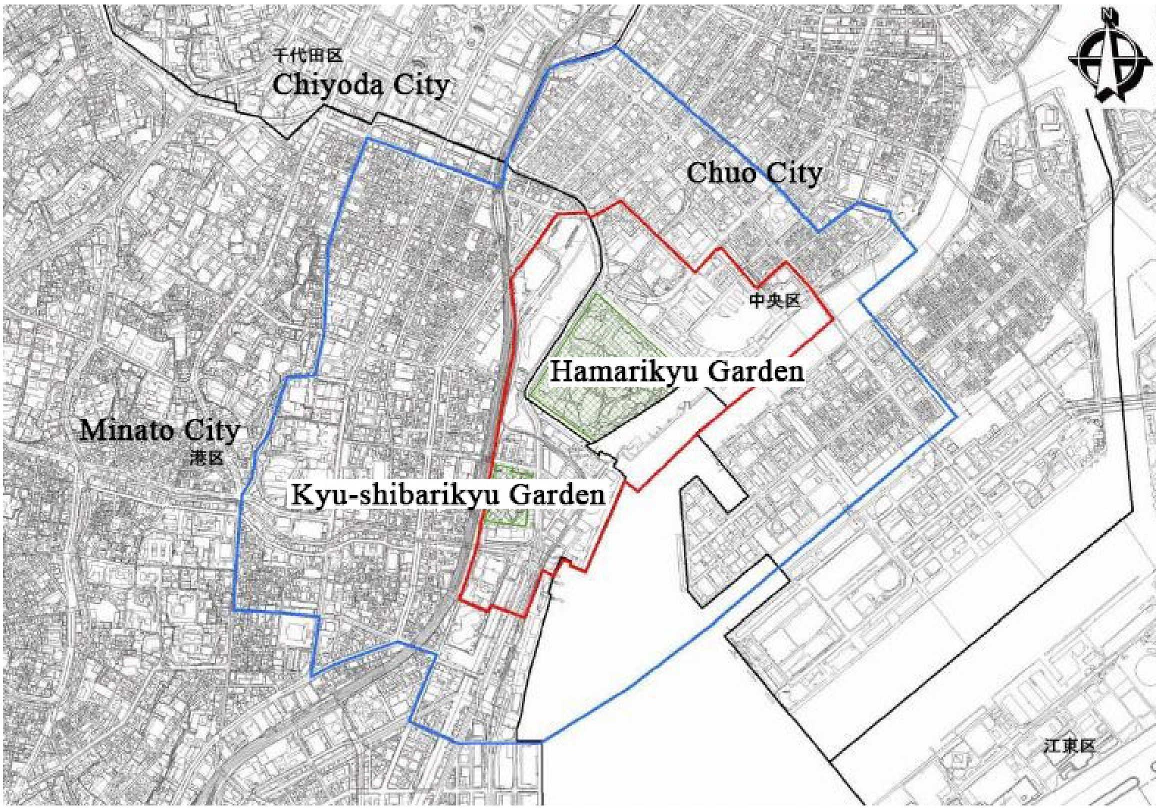

Figure 13 – An example of the surrounding assessment areas of 'Hamarikyu Garden' and 'Kyu-shibarikyu Garden' in the landscape plan of Tokyo (2007). There are two types of surrounding assessment areas. The red line signifies the design and advertisement control area that is lined at a distance of 300 m from the gardens. The blue line signifies the limit of the visual assessment area with a computer simulator. In these areas, viewpoints are designated in the gardens. Credit: Tokyo metropolitan government.

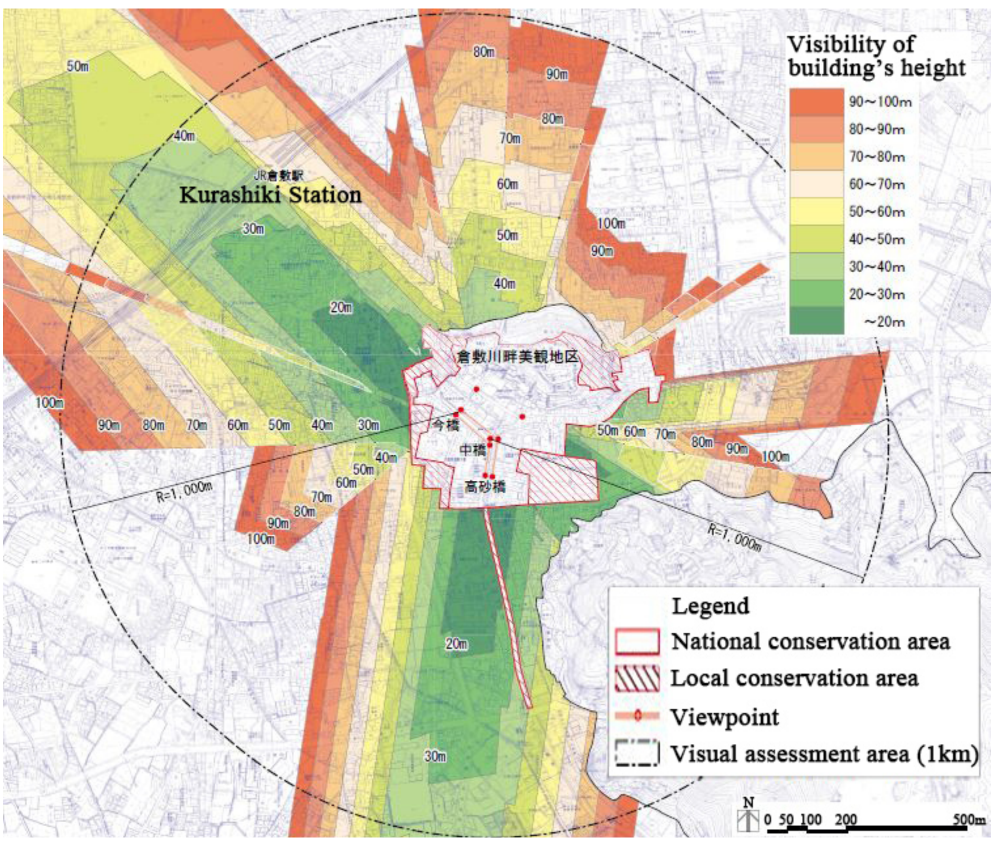

Figure 14 – Visibility check map of Kurashiki City (2014). Credit: Kurashiki City.

Figure 15 – Shinjyuku Gyoen Park landscape before the landscape plan of Tokyo (2007). Credits: Masaru Miyawaki.

Figure 16 – The park landscape seen after the landscape plan (same location as Fig.15, 2016). The difference lies in the removal of the car parking tower advertisement in front of the historic French style garden. Credits: Masaru Miyawaki.

the visibility should be corrected by the earth's curvature and light refraction for the long view, depending on distances. There is no example of visual impact assessment which calculates visibility correction for the earth's curvature and light refraction in Japanese landscape plans.

Following this proposal, Minato City had at least respected the view from Tokyo Tower to Mt. Fuji inside the city boundary and adopted the height regulations by city planning law,

Table 1 – The matrix of the distance and the maximum height of buildings for the view protection from the deck of Tokyo Tower to Mt. Fuji. The corrections of the earth's curvature and light refraction used the following formula: subduction (m) = [distance (km)] ^{2}/14.73. An example of the height correction of Mt. Fuji (distance of 97.3 km) is 3,133.1 m a.s.l. height (original height is 3,776.2 m a.s.l.). This table shows that influences depend on the distances to objects.

Objects	Distance from the deck of Tokyo Tower	Maximum height for the view protection	Correction of the maximum height	Height of mountains	Correction of the height of mountains
Azabujyuuban Station	854.4 m	156.2 m	154.6 m		
Hiroo Station	2,195.4 m	173.8 m	169.8 m		
Ebisu Station	3,449.7 m	190.3 m	184.3 m		
Nakameguro Station	4,456.1 m	203.5 m	196.1 m		
Youga Station	10,683.7 m	285.3 m	272.0 m		
Mt. Hirugatake	58,146.8 m			1,672.7 m	1,443.2 m
Mt. Fuji	97,330.5 m			3,776.2 m	3,133.1 m

but the view protection area was not created by the landscape law because of problems of the intercity scale.

There remain other risks for view protection because of the developments of skyscrapers surrounding Tokyo Tower. Therefore, the view to Tokyo Tower itself was created as a surrounding assessment area of Tokyo Tower, for the historic monument of cultural property, with some viewpoints in the landscape plan of Minato City by the landscape law in 2015.

5. Challenges for the new viewpoint to Mt. Fuji

The latest research example is of the new view in Shibuya City. The extremely long view from the garden of 'Meiji Shrine Gaien' to Mt. Fuji was proposed to the urban design committee of Shibuya City in 2016, as ICOMOS (International Council on Monuments and Sites) Japan issued the state of view from 'Meiji Shrine Gaien' to the UNESCO site of Mt. Fuji behind the new national stadium for Tokyo 2020 Olympic Paralympics Games. Originally the historic garden 'Gaien' had been designed by the street axis to Mt. Fuji. The 1964 Olympic Games stadium had blocked the view to Mt. Fuji for a long time. Following the design competition for the new stadium at the same location and the destruction of the old stadium, the view from the garden to Mt. Fuji appeared to the public in 2016 (Fig.20 and Fig.21). The landscape plan of Shibuya City did not indicate any view protection areas because the view had been forgotten for a long time.

The author, as the director of the urban design committee of Shibuya City, advised to respect the new views from the

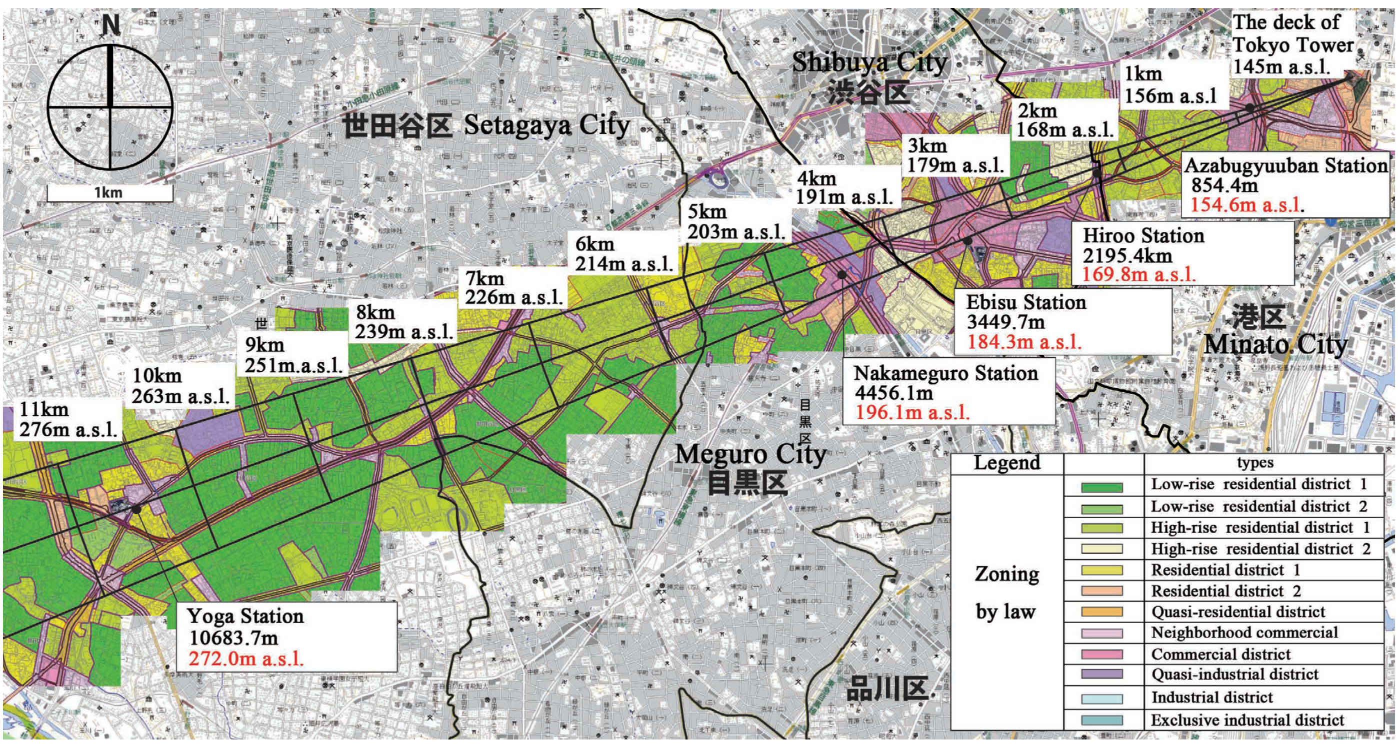

Figure 17 – A proposal of the view protection area from the deck of Tokyo Tower to Mt. Fuji. This map shows the maximum height of the buildings, respecting the view according to the distance from the viewpoint. The width of the view corresponds to the proposed width of the object (4b) in Fig.19. Credit: Masaru Miyawaki.

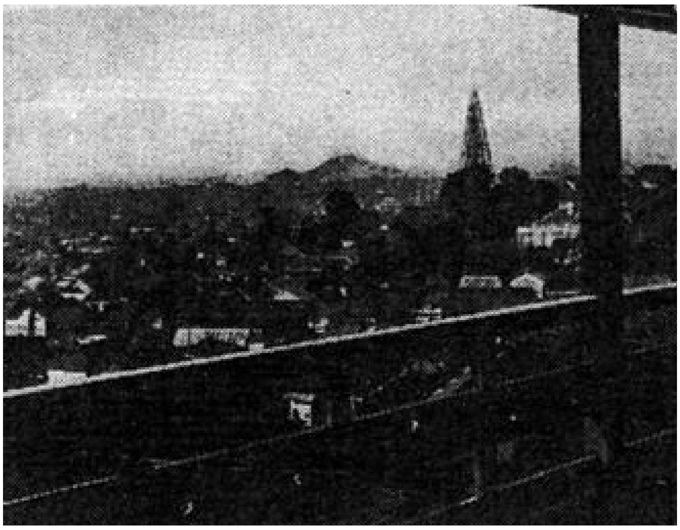

Figure 18 – An old photo of Mt. Fuji from the formal guest house 'Kouyoukan' (1920s).

ground floor and panoramic corridor of the new stadium by using the computer simulation from 2016 to 2017. The methodology of height correction by the earth's curvature and light refraction was officially applied and the 3D simulator cleared the problems of surrounding urban areas to protect the view to Mt. Fuji from the panoramic corridor of the new stadium.

In conclusion, this paper declared that there was no visibility from the ground floor of the stadium or from the park side after construction. The urban design committee therefore called the promoters and architects to keep the views from the higher level of public spaces of the panoramic corridor for mitigation.

Tokyo is an ever changing metropolis with no conservation area. Even then, the view protection areas are possible to apply in order to protect the identity of the landscape and the visibility for public.

6. Conclusion

This paper reviews the history of Japanese view protection areas. The trials for the view protection areas were conducted by local authorities in order to reduce the visual impact of the new developments from the '70s. After the landscape law of 2004, some view protection areas were attached with the landscape plans by law. Their methodologies and plans for the view protection areas are varied. This paper explains the view protection areas as effective, not only for historic towns like Kyoto, but for modern cities like Tokyo as well.

It is clear from the case studies that objects such as the historic garden, the historic building, the historic townscape, the mountain, the sea, the city, and the historic character vary for view protection areas. The methods of the regulations also vary. The distances and widths of view protection areas are different for each situation.

Although the results of the visual impact assessment for actual projects are usually not published in Japan, this paper gives examples of recent landscapes changed for the better by view protection areas.

From the author's experience of urban design committees in Tokyo, the proposed extremely long views from Tokyo to

Figure 19 – A recent photo of Mt. Fuji from the deck of Tokyo Tower (Jan. 2013, 52.5mm lens; human eye view). Fig.18 and Fig.19 are situated at the same place. The Tokyo Tower (registered building) was built in 1958. The proposed view width of frame 4b (four times of width b) in the photo corresponds to the width of the view protection area in Figure 17. Credit: Masaru Miyawaki.

Figure 20 – The view of Mt. Fuji from the street of 'Meiji Shrine Gaien', in front of the Meiji Memorial Picture Gallery in 2016. Credit: Research Group of the Vista of Fuji-mi-zaka (Fujimizaka Chobou Kenkyukai).

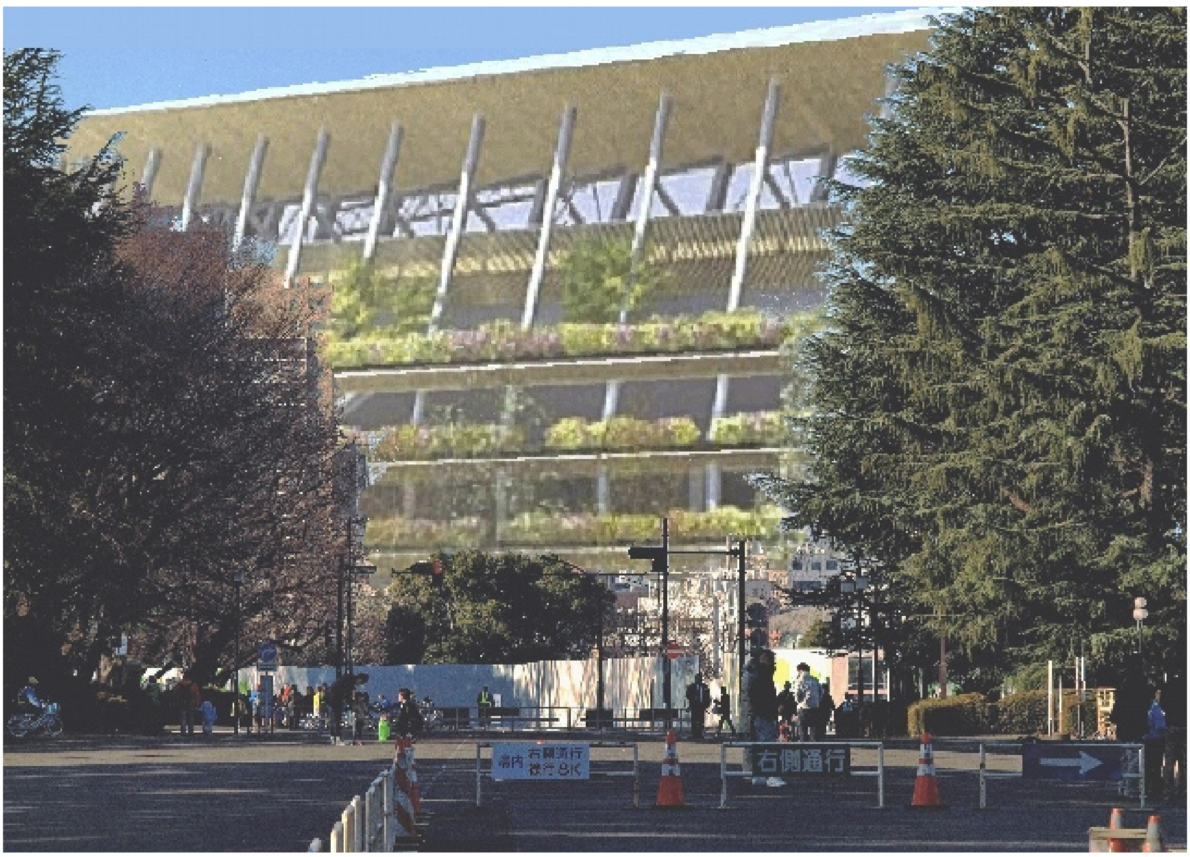

Figure 21 – Visual impact simulation from the same viewpoint of Figure 20. The view to Mt. Fuji is blocked by the new stadium from the park side. However, the stadium is designed to include a green facade and public space of the panoramic corridor on the higher level. Credit: Research Group of the Vista of Fuji-mi-zaka (Fujimizaka Chobou Kenkyukai).

Mt. Fuji (about 100 km distance) are analysed as the very symbolic views that should be protected for the future. This paper noted the necessity of the height correction by the earth's curvature and light refraction for such long views, and the necessity of territorial coordination between local governments for creating a territorial landscape plan.

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Aesthetic vs. functional restoration of urban and peri-urban rivers: the Manzanares River in Madrid (Spain)

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Keywords: urban rivers, riverfronts, river restoration, Madrid

Abstract

The Manzanares River (Madrid, Spain) is living an ongoing process of transformation, essential if we understand the number and intensity of human pressures it has experienced during the last decades. It is also a paradigmatic case study of the current debate about the most suitable restoration approaches to urban and peri-urban rivers: aesthetic-based or functional-oriented alternatives have been proposed in different urban sites worldwide. This work analyses when and how those approaches can be used, which should be selected under the light of the present knowledge on urban rivers, and in what conditions they can coexist. All these questions have been addressed for the specific case of the Manzanares River, allowing some insights which can be transferred to other urban and peri-urban rivers, both in Mediterranean and non-Mediterranean areas. In this work, a multi-functional approach to urban rivers is proposed, considering the importance of providing self-sustaining actions, which can rehabilitate essential river processes inside the city, and which offer relevant ecosystem services to city dwellers. With that aim, some of the measures which are being taken in the Manzanares River to reach those goals are listed and presented. Among them, rehabilitation of relevant hydromorphologic processes, allowance of natural river forms to develop inside the riverbed, re-connection of the urban reach with upstream and downstream semi-natural and protected river reaches, improvement of riparian stands, and rehabilitation of the river corridor to allow the improvement of the ecological, landscape and recreational connectivity.

1. Introduction

After decades of relative forgetfulness and abandonment, urban rivers have been rediscovered over the last years as essential components of the cities. Their natural values and functions, and the large array of ecosystem services they provide, explain their importance for nature and people, and the legal, scientific and social recognition they have acquired during the last years (Gurnell *et al.*, 2007; Everard & Moggridge, 2012). Improvement of urban water environments may be of major significance for: i. reducing flood risk and optimizing flood risk planning; ii. allowing the city to better deal with water pollution and the degradation of its drainage network, by incorporating Sustainable Drainage Systems (SuDS) and natural water retention measures (Woods-Ballard *et al.*, 2007; Strosser *et al.*, 2015); iii. contributing to reduce the negative effects of the urban heat island; iv. enhancing recreational opportunities around natural and heavily modified channels; v. improving aquatic and riparian habitats (EEA, 2016).
In the legal sphere, some of the most relevant European Directives and policies refer to the necessary good status, integrity and resilience or urban rivers. The Water Framework Directive (2000/60/EC) and the Directive on the assessment and management of flood risks (2007/60/EC) define the main environmental objectives and managerial strategies of urban and non-urban water bodies, as integrated in urban and water planning. River Basin Management Plans and Flood Risk Management Plans contextualize, after the publication of the Directives, the efforts for the improvement of urban rivers. Both plans must be well coordinated, and incorporate public participation, something which may be especially relevant in urban environments (European Commission, 2014). The EU Urban Agenda coordinates efforts to deal with the urban aspects of EU and national legislation, and defines integrated sustainable urban development as one major milestone of the EU policies. The EU Urban Agenda and the Europe 2020 Strategy place sustainability in the urban areas in the centre of the socioeconomic and environmental discussion for the present and future of Europe. The ongoing preparation of an Urban Water Agenda 2030, focused on water and resource efficiency, water quality, sustainability of urban water infrastructures, flood prevention and nature based solutions, and citizens involvement too, shows the interest of the cities for their waterscapes, as well as their main concerns on this topic.
From a scientific perspective, different authors (Eden & Tunstall, 2006; May, 2006; Petts, 2006, 2007) have analysed the social and ecologic (sometime confronting) approaches to the restoration of urban rivers. Those works highlight the difficulties which arise from the commitment of the managerial

targets associated to the river biodiversity and habitats, to the minimization of flood risks, or to the need to respond to the expectations of different sectors of the society. Nowadays, urban rivers are being acknowledged as vertebral elements of the cities, capable of creating structural and functional connections with other components of the land matrix. For instance, Baschak & Brown (1995) discussed alternatives for the physical planning, design and management of urban river greenways. Walsh *et al.* (2005) presented methods to diagnose some major alterations of urban rivers and streams. Moreover, Martín-Vide (2001) and Findlay & Taylor (2006) offered clues for understanding the necessary rehabilitation of urban rivers, and some possible ways for designing those measures.

In social terms, the rediscovery and reconnection of people with rivers has only recently begun. In Europe, and particularly in Spain, social approaches to urban rivers have dramatically evolved during the last century. From near-natural channels where citizens fulfilled many of their daily routines (drinking, bathing, washing clothes, collection of natural resources or recreation) in the 30s, rivers became near-artificial canals for conveying wastewaters in the 60s, and almost fully degraded systems by the 80s (Chin, 2006). However, the last two decades have seen the social reborn of many rivers, thanks to the intense improvement of water quality, the rehabilitation of recreational activities and even the restoration of aquatic and riparian habitats, and their related landscape and ecosystem services (Paul & Meyer, 2001; Gómez-Baggethun & Barton, 2013).

Over the last years, an intense debate has confronted two very different ways to manage urban and peri-urban reaches. One, clearly focused on the aesthetic and landscape values of city rivers, which has emphasized the construction of design parks around them. And a second one which prioritizes the rehabilitation of critical river processes and aims at the recovery of their functionality, despite the many unsolvable constraints which cannot be mitigated.

A number of restoration or rehabilitation works recently developed, or under development, in the Manzanares River in Madrid has helped to reopen the aforementioned discussion in Spain, and to check what kind of measures are feasible in severely degraded urban and peri-urban reaches. This work tries to give insights into the discussion, by giving answer to the following questions:

1. Which measures were designed for the restoration or rehabilitation of the urban and peri-urban reaches of the Manzanares River?
2. Which are the goals of each measure in terms of functionality or aesthetics improvement?
3. How do the measures should be understood as part of the water legal framework in Spain and Europe?
4. Which would the best future managerial approaches for achieving the desired scenarios in the Manzanares River and in its drainage network, as a paradigm of other relevant urban river systems?

2. Materials and methods

2.1. Study area

The Manzanares River is one of the main river systems of the Madrid region, in Central Spain (Fig.1). It is considered an element of special interest because of its vertebral character of the territory, connecting the Guadarrama hillrange at the north of the region (at over 2000 m.a.s.l.) with the Lowland areas and the Countryside at the south (ca. 500 m.a.s.l.), along a rivercourse of 92 km. But also, because it is the most significant river that runs through the city of Madrid, in which it has historically been a social, cultural and environmental reference.

The river has suffered for centuries, and precisely because of its location and its characteristics, many human pressures, which have gradually changed its flow pattern, geomorphic features, ecologic processes, and the environmental services it provides. Those pressures have become especially relevant since the mid-twentieth century, transforming the landscapes of the Manzanares River in an intense but heterogeneous way, depending on the original conditions and the dynamics of each river reach.

One of the most outstanding sections of the river, according to its present values and social and ecological potential, is the peri-urban reach that runs upstream from the city of Madrid, in the surroundings of the historical site of El Pardo, and of the homonymous dam, which regulate the river flows in downtown Madrid, and which is nowadays the lower limit of the natural protected areas which were created to protect the environmental values of the river, in its upper and middle sectors (Guadarrama National Park, Manzanares River Reserve, and Regional Park of the Upper Manzanares Basin).

In this 15-km-long section, the geomorphological pattern of the Manzanares channel has evolved from multi-thread, braided and sediment-dominated to mono-thread, incised and narrow, due to: i. flow regulation by two large reservoirs: one constructed for domestic water supply (Santillana Reservoir) and a second one for flood risk management (El Pardo Reservoir), ii. progressive occupation of the river margins, and iii. modification of the hydromorphological characteristics of its drainage network (Fig.2).

In this peri-urban reach, several works have been carried out during the last decades:

- transversal works, such as gauging stations and weirs, which generate artificial backwaters, producing a dense de-

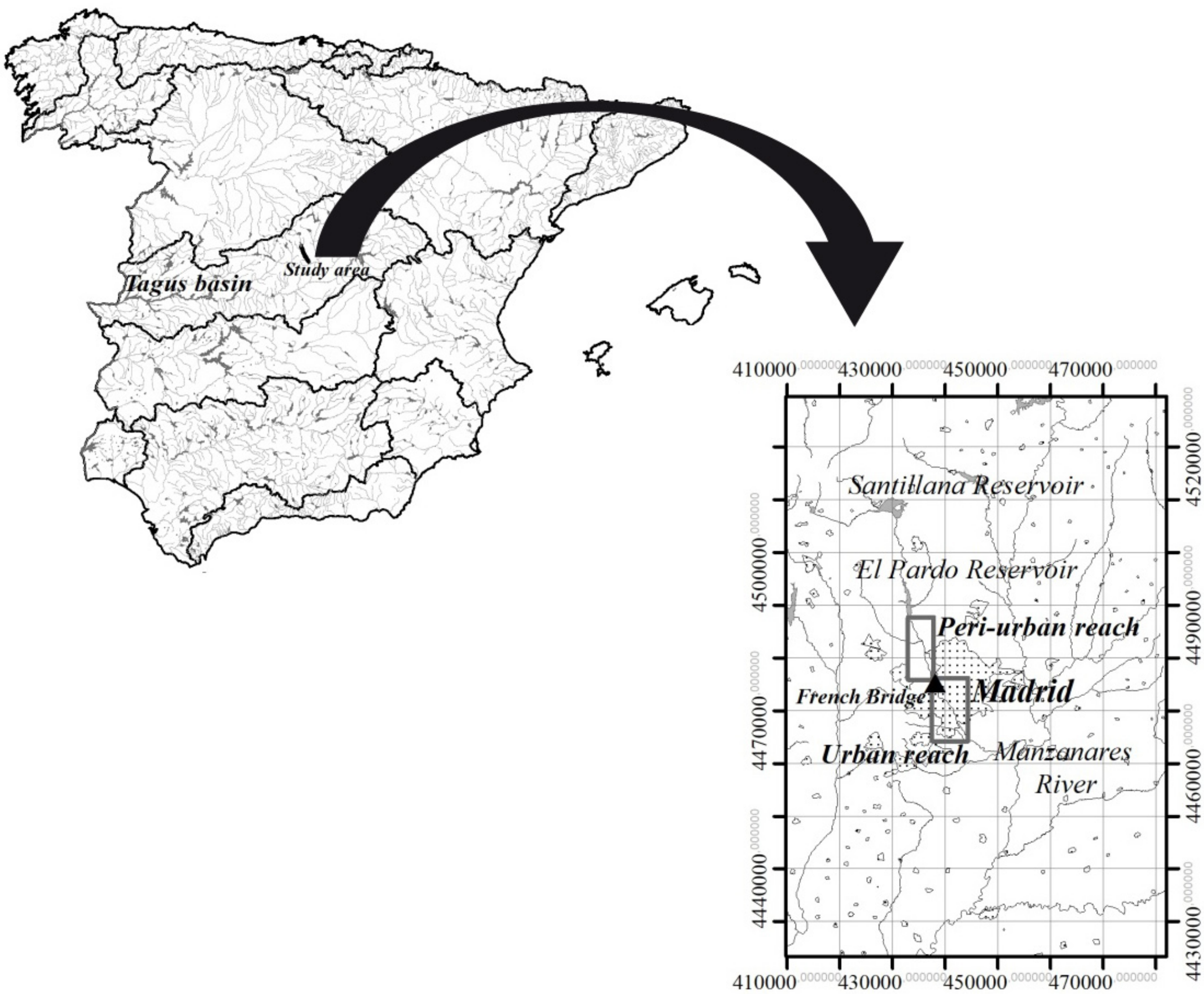

Figure 1 – Study area in the Manzanares River, Central Spain. Two reaches have been analysed: a peri-urban reach upstream and close to Madrid city, and a genuine urban reach which crosses the downtown area (Geographic coordinates system is ETRS89).

velopment of pioneer vegetation, in which the abundance of helophyte plant species stands out.

- longitudinal works, such as dredging and removal of sandy islands in the channel, or longitudinal levees to avoid overflowing and flooding, and to facilitate the urban occupation of the floodplain, which have resulted in loss of river space, simplification and impoverishment of aquatic and riparian biotopes, loss of transversal connectivity, loss of accessibility to the banks, loss of scenic values and reduced contact with the river (MAPAMA, 2015).

Downstream of the aforementioned reach, the river enters downtown Madrid, along a 10-km reach, which borders the historical city and some of its more renowned corners. This reach, which originally offered essential services to the city (water for domestic supply, bathing and washing clothes, sediments for construction, and many recreational values – as historically illustrated by famous painters), was canalized in the early 20th century (Fig.3). After the canalization, the river progressively suffered higher anthropic pressures. Among them, the construction of a large motorway on both margins, the total urbanization of its floodplain or the large decrease of its water quality (Valcárcel *et al.*, 2011).

Along with all the above pressures, the river flow pattern in both reaches also suffers additional alterations due to the homogenization of the flow features of its main tributaries. This being mainly caused by the regime of discharges of the sewer plants of the medium-sized municipalities that pour their purified wastewater into those tributary streams. The alteration of the flow patterns of the drainage network has also had effects on the genesis and transport of sediments throughout the whole system, enhancing unbalanced erosional and sedimentary processes in many different locations. Similar eco-hydromorphological processes have been described in other Mediterranean sites worldwide (e.g.,

Figure 2 – Aerial and detailed views of some segments of the Manzanares River peri-urban reach which is presently being restored: (a) occupation of the former river left floodplain, which has contributed to the present narrow structure of the river system; (b) weir which creates an artificial backwater, where a fish ramp will be created; (c) artificial backwater which has motivated the death of the riparian stands; the dead trees have already been eliminated and the backwater will soon be reduced by allowing a better sediment transport; (d) massive public use along the reach, but disconnected from many river values; the paths will be improved and reconnected with the river banks, and cycle and pedestrian differentiated paths will be created.

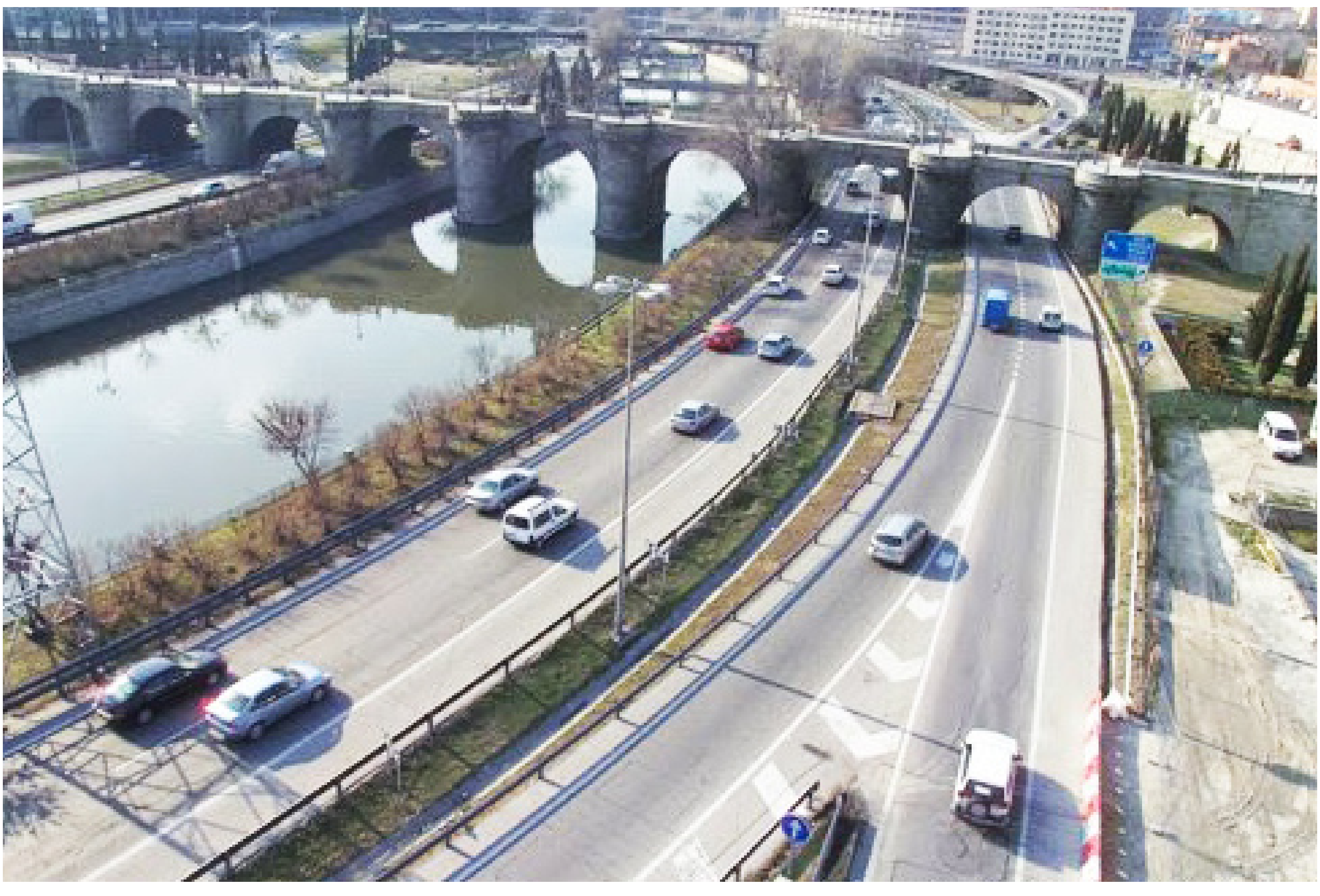

Figure 3 – Evolution of the urban reach of the Manzanares River near the historical Toledo Bridge: (a) by the early 20th century, showing the characteristic patterns of the near-natural multi-thread river channel; (b) in the 80s, after the canalization of the river and the construction of motorways along its banks; (c) in the early 21th century, after the motorways burial and the construction of a huge river park, but still with the weirs closed along the rivercourse; (d) after the full opening of the weirs and the allowance of a seminatural dynamics inside the limited space of the river (Photo sources: Madrid City Council and CEDEX).

Magdaleno *et al.*, 2017).

Regarding the ecological status of both reaches of the Manzanares River, it has also undergone significant changes over the last years. Because of the changes of the river flow and geomorphic pattern, the vegetation of banks and riparian areas has been modified in structure and composition, adapting to the new conditions. In the peri-urban reach, a more continuous presence of water, even in times of drought, has favoured the development of a greater vegetal biomass, and a linear structure in the riparian stands. Decades ago, vegetation was less likely to colonize the riverbed. The sandy substrate and the frequent occurrence of natural very-low flows during summer, naturally prevented the consolidation of a thick gallery forest. In the urban reach, a set of regulatory gates which enhance totally artificial hydraulic conditions has made unfeasible the colonization of the riverbed by any plant community.

From a socio-cultural perspective, the study reach constitutes an area of very high public use, due to its proximity to natural areas, its relevant landscape values, and its good accessibility from the city. Its recreational values ensure, daily, but especially during weekends and holidays, the arrival of thousands of visitors. In the network of paths which run parallel to the river, pedestrian and cycling uses coexist, not always easily due to the lack of separated infrastructures.

Finally, it should be mentioned the inherent difficulty of the management of the study area by different authorities, sometimes with concurrent competences: the Tagus Basin Authority, Madrid City Council, Regional Government of Madrid, the public water operator of the region (Canal de Isabel II), and the public entity National Heritage, which manages most of the riparian areas historically owned by the Spanish monarchy. Also, various departments of the Ministry of Agriculture and Fisheries, Food and Environment (such as Water, Environmental Assessment, or Climate Change, among others) participate in different legal or administrative procedures. Additionally, it is also necessary to refer to the municipalities which pour their purified wastewater into the river drainage network, affecting its hydromorphological and ecological dynamics. Finally, from the perspective of the social and environmental organizations which have participated in the river improvement, many were active during the process, such as WWF-Spain, *Ecologistas en Acción*, and different local groups.

Under the aforementioned scenario, and due to the problems presented by the Manzanares River in the study area, the competent authorities agreed, during the years 2015 and 2016, on the development of a comprehensive set of measures for: i. the improvement of the urban river reach which crosses downtown Madrid; ii. the restoration of the upstream peri-urban river reach between El Pardo reservoir and the urban segment.

2.2. Methods

A wide number of alternatives were assessed during the technical screening of the restoration projects. Hereinafter those alternatives are described and ordered, in accordance with the intensity of the projected actions. Once the best alternative was chosen, in terms of costs and benefits, a number of restoration actions were selected and designed. These are later explained.

- *Alternative 0 – Trend scenario*

  This alternative would involve developing no action in the river, neither in the urban nor in the peri-urban reach. Lack of any intervention in the river, according to the present dynamics and to the expected future functioning would probably lead to an accentuation of the unbalanced erosive and sedimentary processes which are causing a degradation of the aquatic and riparian habitats in the peri-urban reach, and an increase of the decay of ecologic processes and ecosystem services in that reach. This would probably contribute to a further deterioration of the reach, in social and environmental terms. In the urban reach, the trend scenario would involve the maintenance of the present ecohydraulic conditions, which involve very poor habitats and an almost total lack of ecologic connectivity and social connection with the river.

- *Alternative 1 – Holistic re-naturalization*

  The re-naturalization of the river´s processes and landscapes would require the restoration of the flow and geomorphic patterns: restoration actions should lead to a wide braided planform with many secondary channels, vegetated and non-vegetated bars and islands, associated to very variable flow levels. Considering the present constraints of the river in both reaches, this alternative is technically and economically unfeasible.

- *Alternative 2 – Rehabilitation of critically degraded areas*

  Along the river reaches under study, many sites can be found, where the hydrological, geomorphological and ecological degradation has been more intense, enhancing a clear decay from the desired environmental and landscape scenarios for the river. Under this alternative, the restoration actions would be focused on those especially degraded sites. Alternative 2 could fully shift the present degrading trends of those sites, but would not consider the overall processes which are contributing to the river´s degradation, and would not be based on the idea of generating a long and well-connected river corridor around the city, and along the own downtown areas.

- *Alternative 3 – Structural and functional restoration of the river corridor*

  This alternative was devised to restore some of the more important processes lost by the river, in terms of hydromorphology, ecology and ecosystem services. The restoration actions would be linked to an objective-based approach, attempting to reach the best possible status under those anthropic pressures and constraints which are technically and economically impossible to eliminate or even mitigate. This approach would consider those sites which are more critically degraded, but to boost an overall improvement of the river, avoiding the maintenance of *black spots* in the watercourse. Thus, the restoration would be targeted to the whole river corridor, on the basis of the recovery of some essential processes and patterns, and the amelioration of the sub-reaches which may hamper the status of the entire river system.

After a thorough compared analysis of the assessed alternatives, number 3 was deemed to be the best in terms of cost-benefit and cost-efficiency. But even so, requiring a continuous monitoring of the restored reaches, which may lead to their adaptive management, and to the optimization of the efforts undertaken by authorities and stakeholders.

3. Results: restoration actions

3.1. Peri-urban reach

Along the peri-urban reach, many different actions have been included and designed in the restoration project of this reach. The execution of these works began in January 2017, and will develop along three years, with a total budget of around 2 M€. The restoration actions have been designed with the objective of providing an integral improvement of the study area, of being well coordinated and multi-functional, and of avoiding any disturbance to the native and protected habitats and species which use the reach during their biological cycles.

Figure 4 outlines the main restoration measures planned to reduce the hydrologic, geomorphic and ecologic alterations of the peri-urban reach, and to optimize ecosystem services in it. Some of those measures are the following:

- **Improvement of environmental flow regime:** The Basin Management Plan of the watershed already defines an environmental flow (e-flow) regime for this river reach. However, the hydromorphological diagnosis carried out has shown that the e-flow regime should be optimized to allow for a better river dynamics. Especially in its summer flows, and with the discharge of episodic controlled floods, capable of regenerating the riverbed and improving the solid transport (Magdaleno, 2017). The characteristics of these floods have been designed and proposed to the water authorities.
- **Rescue and transfer of native ichthyofauna**: various actions have been designed to reduce impacts to fish fauna, focusing on those river sections in which the need to permeate artificial barriers has been detected. The works will consist of carrying out rescue operations of ichthyofauna (capture and transfer) immediately prior to the improvement of the longitudinal continuity of the channel. In this way, specimens of barbel (*Luciobarbus bocagei*), Iberian nase (*Pseudochondrostoma polylepis*) and Iberian gudgeon (*Gobio lozanoi*) will be captured, as well as any other native species inhabiting the sections considered.
- **Increased complexity and hydraulic diversity:** The technique consists in increasing the complexity and hydraulic diversity of the reach by using materials of coarse granulometry at certain sections, favoring the generation of optimal erosion and sedimentation patterns. The action would be carried out considering the morphosedimentary and hydromorphological pattern of the river, the ecological requirements of the aquatic species, and the lack of proper mechanisms of the river for the improvement of aquatic habitats.
- **Forestry works and removal of exotic vegetation:** They would be based on the improvement of the structure and composition of the riparian vegetation of the Manzanares River according to the existing densities (low, medium or very high) along the entire left margin of the river. These works include the cutting of dry or dying vegetation, or the pruning of specimens that require an improvement in their structure or that have risks for the visitors. In addition, in different sites distributed along the corridor specimens in poor phytosanitary status and exotic species have been located (mainly ailanthus –*Ailanthus altissima*-, box elder –*Acer negundo*- and false acacias –*Robinia pseudoacacia*-). After a tree-by-tree analysis, the specimens will be selected and removed.
- **Restoration of riparian vegetation:** Four categories of revegetation have been established, according to the distance to the channel and the height above the water table:
  - river banks: located in areas where the slopes will be morphologically naturalized, using species such as *Salix alba, Salix salviifolia, Salix atrocinerea, Lonicera periclymenum subsp. hispanica, Clematis campaniflora* and *Rubus ulmifolius*.
  - margins: located in the upper range of the paths to be created, after the re-design of the slope, with *Populus alba, Populus nigra, Rosa canina, Ulmus minor, Crataegus monogyna, Pistacia terebinthus, Pyrus bourgaeana* and *Rubus ulmifolius*.
  - floodplain and distal areas: located in the upper part of the areas affected by the slope redesign and in the slope with scarce vegetation. They will be planted with species included or associated with the association *Junipero oxycedri-Quercetum rotundifoliae*.
- **Removal of excessive patches of helophytic species in**

the channel: Helophytic vegetation (reed -*Phragmites australis*- and narrowleaf cattail –*Typha angustifolia*-), which has boosted in the channel due to the existence of artificial backwater in the river will be extracted in those sections where their abundance is considered negative for the hydromorphological and ecological dynamics of the river reach.

• **Removal of obsolete transversal works and artificial barriers:** The progressive removal of obsolete works and artificial barriers has been designed. This includes the remains of an old gauging station, and some sedimentary heaps (with a total volume of 10,000 m^3) accumulated in the channel which are creating large backwaters, and which have been colonized by pioneer vegetation.

and to allow visitors to perceptually reconnect with the river. Therefore, land movements in will be carried out along the whole reach. Earthmoving on the banks will aim to achieve slopes 2(H):1(V), whenever possible. In all cases, the newly created surfaces will be re-vegetated, using plant propagules from the area.

• **Improvement of trails:** The project will include the adaptation of existing paths, in order to guarantee the safety of different users, by differentiating cycling and pedestrian trails, and relocating some narrow pedestrian paths along the river banks. A new pedestrian bridge will also be constructed, 20 m-long and whose hydraulic section is prepared

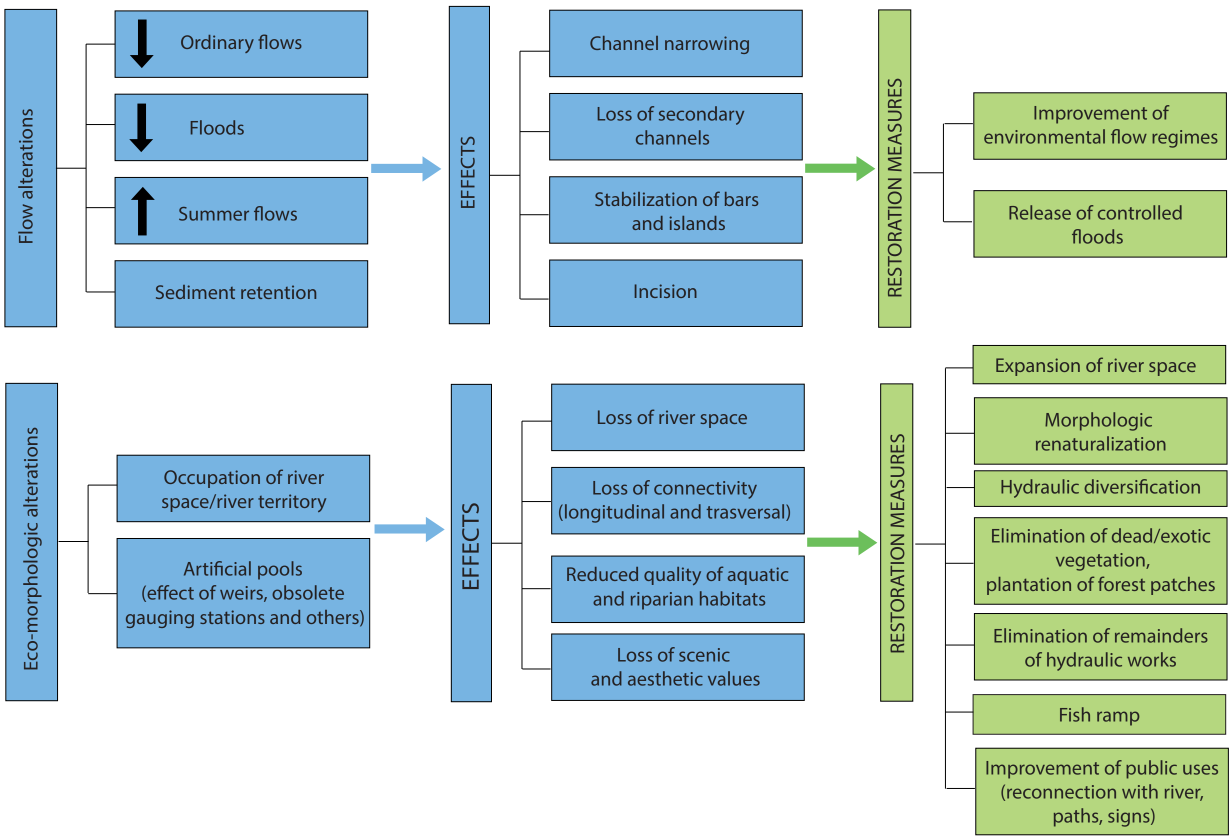

Figure 4 – Schematic diagram of the main flow and eco-geomorphic alterations which the Manzanares River peri-urban reach suffers today, their effects along the river, and the restoration measures under development (Source: J.A. Fernández Yuste, C. Martínez Santa-María, F. Magdaleno, pers. comm., 2015).

• **Construction of fish ramp:** The main constraint for the design of this fish pass is the migration ability of the species that inhabit this reach of the Manzanares River, without this reducing the supply of water from the weir to the legal users. The ramp will be constructed in rock, embedded in the water, and designed to allow an optimum permeability for fishes.

• **Removal of landfills in the riparian areas:** The main purpose of the earthmoving activities in the river margins is to recover a certain degree of naturalness in the transversal profiles of the channel, which are now very much incised,

for the 10 years return interval, to allow visitors to enjoy a circular route along both margins of the river. Different signs and educational materials will also be installed, to better allow them to know the natural and culture values, and environmental services provided by the restored river.

3.2. Urban reach

In 2016 and 2017, the Madrid City Council, echoing the requests of various conservationist and neighborhood associations, proceeded to the progressive opening of the regulatory gates of the Manzanares River. The first effect of this opening was the reduction of the artificial depth of the dammed river (close to or greater than 2 m), the recovery, after decades of complete immobility, of sediment transport and the reappearance of a wide number of species of fauna and flora associated with the recently created fluvial forms. The creation of sandy islands and bars along the urban reach, and their rapid colonization by natural vegetation, has accelerated the change of the fluvial landscape, and the discussion on the optimal measures for its progressive re-naturalization. The city newspapers and many thousands of citizens are following the fast transformation of this river, which has been optimal considering the short time passed and the overall degradation of the river system in the early stages of the project. The re-colonization of the reach by many different species of aquatic and riparian birds is one of the effects which have been more impressive for managers and neighbours, creating an atmosphere of support to the project in most Madrid citizens.

The City Council plans, at this moment, the creation of bioengineered slopes in the banks formerly covered by rip-raps, the planting of riparian species in the upper part of these slopes, and some other landscaping and environmental design project (such as the creation of a fish pass in one of the regulatory gates, the reintroduction of native ichthyofauna, or the creation of a fish breeding centre, among others). The budget for the first phase of the re-naturalization project is around 1.2 million euros, and its execution period is 9 months, for a first sub-reach of 1.3 km (French Bridge to Queen Victoria Bridge). New phases are being planned and will probably be executed during the following years.

4. Conclusions

i. The restoration projects under execution or recently implemented in the urban and peri-urban reaches of the Manzanares River in Madrid have shown the high capacity of historically degraded rivers to enjoy a fast recovery of many important functions and services, following a correctly designed hydromorphological and ecological restoration or rehabilitation.

ii. Even the more constrained urban reaches may sustain interesting aquatic and riparian habitats, and attract many different floral and faunal species. This is the case of the urban downtown reach of the river, which has bloomed in terms of bird and fish communities immediately after the restoration of some basic hydrogeomorphic patterns. In this case, the maintenance of a managerial approach strictly based on certain aesthetic values would have involved keeping the river in a very poor condition, with no natural processes attached and a total lack of relevant biotic communities.

iii. Restoration of a minimum functionality of urban reaches requires restoring, as far as possible, the dynamics of the peri-urban reaches both upstream and downstream. The urban reach must not be an isolated water shackle, unable to constitute part of a river corridor which offers a large diversity of functions and services to the city and to its citizens.

iv. The legal, scientific, technical and social advances recently developed in the approach to rivers must be reflected in their management. Strictly engineered solutions are frequently not cost-efficient, since they use to leave aside a wide number of the rivers´ functions and services. Self-maintenance or self-restoration of rivers is also not an appropriate solution in most cases, since the pressures and constraints around rivers require active managerial approaches. Green infrastructures and natural water retention measures, as presently considered in the literature and in the legal context, may guide the efforts to restore urban and peri-urban rivers, because they involve multi-functional solutions, and can create the necessary links between the many different laws and policies which nowadays rule urban and peri-urban rivers.

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Energy Efficiency in Buildings and Districts

Estimating Naples' urban heat island effects using the March 20, 2015 partial solar eclipse

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Abstract

During the partial (~50%) solar eclipse occurred on March 20, 2015, we monitored the time evolution of air temperature and of incoming solar radiation above the historical center of Naples and of Casamicciola town, on the island of Ischia. These measurements were useful to determine the radiative emissivity ε of the two different locations. The experimental conditions were optimal because of the clear sky situation over Italy. The eclipse lasted about 2 hours between 9:25:06 (UT+1, local Italian time) and 11:43:09 (UT+1, local Italian time). We obtained an emissivity of ε=0.86 for the historical center of Naples and ε=0.96 for Casamicciola town. We used these emissivity estimates, the surface air temperature and solar radiance records to characterize the urban heat island of Naples as due to an additional source of heat of about W/m2 at maximum in respect to Casamicciola.

1. Introduction

Urban heat island (UHI) influences all metropolitan areas (Environmental Protection Agency, 2008; Bottyan, et al., 2005; Fortelli et al. 2016). UHI is a significant warming excess occurring in urban areas relative to the surrounding countryside ones. In densely urbanized areas, UHI can reduce or improve the human comfort according to the season. For example, enhanced heat waves could lead to emergency conditions during summer times (Di Cristo et al., 2007; Li and Bou-Zeid, 2013). Moreover, the specific temperature areal variation inside a city determines also the demand of energy for cooling or heating buildings in the summer or winter times, respectively (Scafetta et al., 2017).

An important issue is to characterize UHI for a specific city (e.g., Naples) and better understanding its causes. Fortelli et al. (2016) showed that the historical center of Naples is about 2.1 °C warmer than the surrounding countryside areas (e.g. relative to Bacoli town). In order to better characterize the phenomenon, we propose to apply the Stefan-Boltzman equation to determine the different emissivities between the historical center of Naples and the island of Ischia located at about 20 km from Naples. This information can then be used to evaluate the hypothetical energy flux addition explaining the UHI of Naples.

We hypothesize that this emissivity measurement can be obtained when the outgoing radiation from the surface is known. This can happen when the system is in thermal equilibrium with the incoming solar radiation. Scafetta and Mazzarella (2016) observed that, during the solar eclipse of March 20, 2015, the air temperature in Naples remained constant from about 10:00 to 11:00 am. We hypothesize that such a temperature constancy could be due to a transient equilibrium between the incoming and outgoing radiations. Therefore, the direct measurement of the incoming solar radiation during that period could be assumed to be a valid estimate of the outgoing radiation in that same moment. We understand that our hypothesis is an approximation based on the assumption that the physical properties of the system remain constant: e.g., the wind and other processes of heat transport are assumed to be stationary during the analyzed period and, therefore, their action negligible.

An eclipse constitutes a rapid, profound and widespread perturbation of the solar radiation received by the Earth's surface and its atmosphere at a given location. The occurrence of an eclipse provides an occasion to measure a set of atmospheric parameters (such as surface air temperature, atmospheric pressure and incoming solar radiation) useful to measure the emissivity of the site on which the observation is made. We use the eclipse occurred on March 20, 2015 whose peak occurred around 9:46 UT on the ocean between Iceland and Norway (lat. 64°25'54"N, long. 6°38'48"W).

The meteorological data were collected from two observatories:

1) The Meteorological Observatory of San Marcellino is attached to the Department of Earth Sciences, Environment and Resources and is located in the historical center of Naples. It is the highest institution regarding the knowledge of meteorological events of the city of Naples and one of the oldest meteorological centers in Italy.
2) The Casamicciola Geophysical Observatory was established shortly after the earthquake of July 28, 1883, which

dramatically hit Casamicciola. The seismic event prompted the Italian Government to establish a network of geophysical observatories in Italy.

Herein, we propose the following methodology: 1) we measured the incoming solar radiation during the eclipse of March 20, 2015, both at the Meteorological Observatory of San Marcellino in the historical center of Naples and at the Geophysical Observatory of the town of Casamicciola on the island of Ischia; 2) we measured the surface air temperature at the same observatories during the same eclipse; 3) finally, we used the Stefan-Boltzman equation to determine the different emissivities.

This study is relevant because the two chosen sites are characteristic of two alternative environments and experience a different response to a sudden variation to radiative forcing. In fact, the historical center urban area of Naples, where the Meteorological Observatory of San Marcellino is located, is heavily built, densely populated and characterized by tall buildings made mostly of concrete and clay tiles, and by asphalt and lave rocks streets. On the contrary, the Geophysical Observatory of Casamicciola is located on an island that is poorly populated and it is surrounded by a green park and a large wood.

2. Meteorological data during the eclipse

Figure 1 depicts the eclipse path map. It was mostly visible from the North Sea, the Faeroe Islands and Svalbard, but partially visible throughout Europe. The response of the atmosphere to an eclipse event strongly depends on the local coordinates, geography and meteorological conditions. Studying total and partial eclipses is equally important for a better understanding of its effects on the environment (Muraleedharan, 1998; Kazadzis, 2007; Zerefos, 2007).

In Italy, the Sun was obscured by 39% to 67% depending on the latitude and longitude of the observation: see Figure 2. Herein, we study how a sudden decrease of solar radiation during an eclipse can provide a different response in surface air temperature in two different locations few kilometers apart: the historical center of Naples and the town of Casamicciola, on Ischia island. The eclipse lasted from 9:25 to 11:43 am and the Sun was obscured up to about 50% in both locations (Scafetta and Mazarella, 2016).

The solar eclipse of March 20, 2015 was quasi total in the United Kingdom (98% at Edinburgh) but the meteorological conditions were of cloudy sky for the presence of an high pressure over the British Islands and of numerous cold fronts and instability lines on their North-Western coasts (Figure 3) (Hanna et al., 2016). On the contrary, a stable area of high pressure over Italy determined a weather sunny and cloud-free sky (Scafetta and Mazzarella, 2016) (Figure 3). Most Italy benefited meteorological conditions favorable to study the meteorological consequences of the eclipse.

We collected surface air temperature and solar radiation data at the Meteorological Observatory of the University of Naples Federico II, (lat. 40°50’50.2”N, long. 14°15’28.7”E, altitude 50 m) and at the Geophysical Observatory of Casamicciola town on Ischia Island (lat. 40° 44’ 48.7” N, long. 13°54’ 5.6” E, altitude 125 m).

Figures 4 and 5 show the total solar irradiance records measured at the two observatories on the eclipse day. The data are 10-minute averages. The colored area in Figure 4 highlights the period of the eclipse’s occurrence from 9:25 to 11:43 local time. The dimming of the surface solar radiation records during the eclipse is evident in both observatories. Until noon the solar radiation record is very smooth, a fact that confirms that the sky was cloud free during the entire eclipse period.

In Naples, at the eclipse’s beginning (9:25 am, local time), the total solar irradiance was 552 W/m^2. It reached a minimum of 334 W/m^2 at the eclipse’s apex at 10:32 am, local time, and it increased to 760 W/m^2 when the eclipse ended at 11:43 am, local time.

In Casamicciola, at the eclipse’s beginning (9:25 am, local time), the total solar irradiance was 600 W/m^2. It reached a minimum of 368 W/m^2 at the eclipse’s apex at 10:32 am, local time, and it increased to 840 W/m^2 when the eclipse ended at 11:43 am, local time.

The air temperature remained stationary during the eclipse both at Naples, with a value equal to T=14.8 °C + 273.15 °C = 287.95 K, and at Casamicciola, with a value equal to T=13.6 °C+273.15 °C = 286.75 K.

3. Evaluation of the radiative emissivity in the historical center of Naples and in Casamicciola town

The emissivity ε varies from 0 to 1 and measures the effectiveness of a surface in emitting energy as thermal radiation. It is the ratio of the thermal radiation J from a surface to the radiation from an ideal black surface at the same temperature according to the Stefan-Boltzmann law:

$$J = \varepsilon \sigma T^4 , \quad (1)$$

where the Stefan’s constant is $\sigma = 5.67 \cdot 10^{-8}\ Wm^{-2}K^{-4}$.

The stationary meteorological condition observed during the eclipse, from about 10:00 to 11:00 am, were used to conclude that during that time the mean incoming radiation was likely in balance with the emitted one. Thus, we assume that

the J value in Eq. 1 is equal to the measured incoming solar radiation at the eclipse apex, that is, we assume that the heat conduction (e.g. with the material under the surface) is negligible during the eclipse. In such a condition, the average emissivity ε of the historical center of Naples and of the town of Casamicciola could be calculated using Eq. 1.
Under the above hypothesis, we obtained ε=0.86, typical of concrete, for Naples (see Google map in Figure 4) and ε=0.96, typical of a green park, for Casamicciola town (see Google map in Figure 5).

4. UHI in Naples relative to Casamicciola

Figure 6A shows the incoming solar radiation reaching the surface in the historical center of Naples and in Casamicciola as measured at the two observatories. We found that for the month of July 2015 the maximum of the incoming solar radiation in Naples was about 900 W/m^2 while in Casamicciola was about 1200 W/m^2. Thus, the historical center of Naples receives about 75% of the solar radiation received in Casamicciola. Probably, this difference is due to the fact that the Observatory in Casamicciola is about 75 m higher than that in San Marcellino and that the air in Ischia is significantly clearer than in the urban center of Naples.
Figure 7B shows the surface air temperature measured in the two observatories in July 2015. We found that the mean maximum diurnal temperature during July measured in San Marcellino is about 2.5 °C higher than in Casamicciola. In the hottest day, on July 18, 2015, the maximum air temperature in San Marcellino was about 37.0 °C while in Casamicciola was 33.5 °C, which is 3.5 °C lower.
Because the Observatory of Casamicciola is located about 75 m higher than in that in San Marcellino, it accounts for about 0.6 °C cooling due to the lapse rate. It is noteworthy that the normalization process of different air masses is done through potential temperature θ. This is the temperature that an air mass assumes when it is lowered adiabatically from its altitude (characterized by a determined atmospheric pressure P and air temperature T_0) to sea level atmospheric pressure of 1013 hpa. The potential temperature is governed by the adiabatic Poisson equation:

$$\theta = T_0(1013/P)^{0.287} \qquad (2)$$

that implies a mean lapse rate of about 0.8 °C for each 100 m of altitude (Holton, 2004). Thus, San Marcellino which is 75 m lower than Casamicciola was, on July 18, 2015, effectively about (2.5+0.6) °C = 3.1 °C warmer than Casamicciola during the maximum diurnal temperature. This result evidences the UHI effects of the historical center of Naples.

We used the Stefan-Boltzmann law, Eq. 1, to calculate the thermal radiation J associated to the two measured maximum air temperatures on July 18, 2015. We found that for San Marcellino J=450 W/m^2, while in Casamicciola J=480 W/m^2.
Considering that San Marcellino received an amount of solar radiation equal to 75% of that received in Casamicciola, if San Marcellino environment were similar to that of Casamicciola, we would had to obtain J=480*0.75=360 W/m^2. Thus, it is like as if in summer the air in San Marcellino received about 90 W/m^2 at maximum more than what expected. This amount will decrease by a certain fraction if, for example, during the eclipse the emitted radiation was the same fraction of the incoming radiation due, for example, to heat conduction, that above was neglected.

5. Discussion and conclusion

Surface air temperature and solar irradiance were measured in historical center of Naples and in the town of Casamicciola on Ischia Island, in Central Italy, during the partial (~50%) equinoctial solar eclipse occurred on March 20, 2015. This information was useful to determine the radiative emissivity ε of the two places. We found an emissivity ε=0.96 in Casamicciola town but a lower value ε=0.86 in the historical center of Naples. This difference was expected because Casamicciola's environment is comparable to that of a green wood park while the historical center of Naples is made mostly of concrete, asphalt and bricks (cf. Sobrino et al., 2012). In fact, Ischia is called the Green Island (Mennella, 1958).
Moreover, we found that despite the historical center of Naples receives 75% of the solar radiation received in Casamicciola, its maximum daily air temperature in summer is about 3.1 °C warmer than in Casamicciola. This evidences that the historical center of Naples is influenced by a strong urban heat island effect.
We calculated the different heat flux associated to the two sites and we concluded that, relative to a wood green park, the historical center of Naples is like as if it is warmed by an additional source of heat of about 90 W/m^2 at maximum.
We conclude that in order to mitigate the urban heat island effect of Naples, it would be opportune to make the city greener (Lee et al., 2014; O'Malley et al., 2015). Moreover, it would be useful to create a detailed emissivity map of the city to better determine and understand the local patterns of the UHI effect in Naples (Palumbo and Mazzarella, 1984; Di Cristo et al., 2007; Mazzarella and Giuliacci, 2011).

Figure 1 – Path of the solar eclipse of 20 March 2015,showing fractional obscuration of the Sun at maximum eclipse. Image courtesy of http://www.greatamericaneclipse.com;copyrightMichaelZeilerandreproducedwithpermission

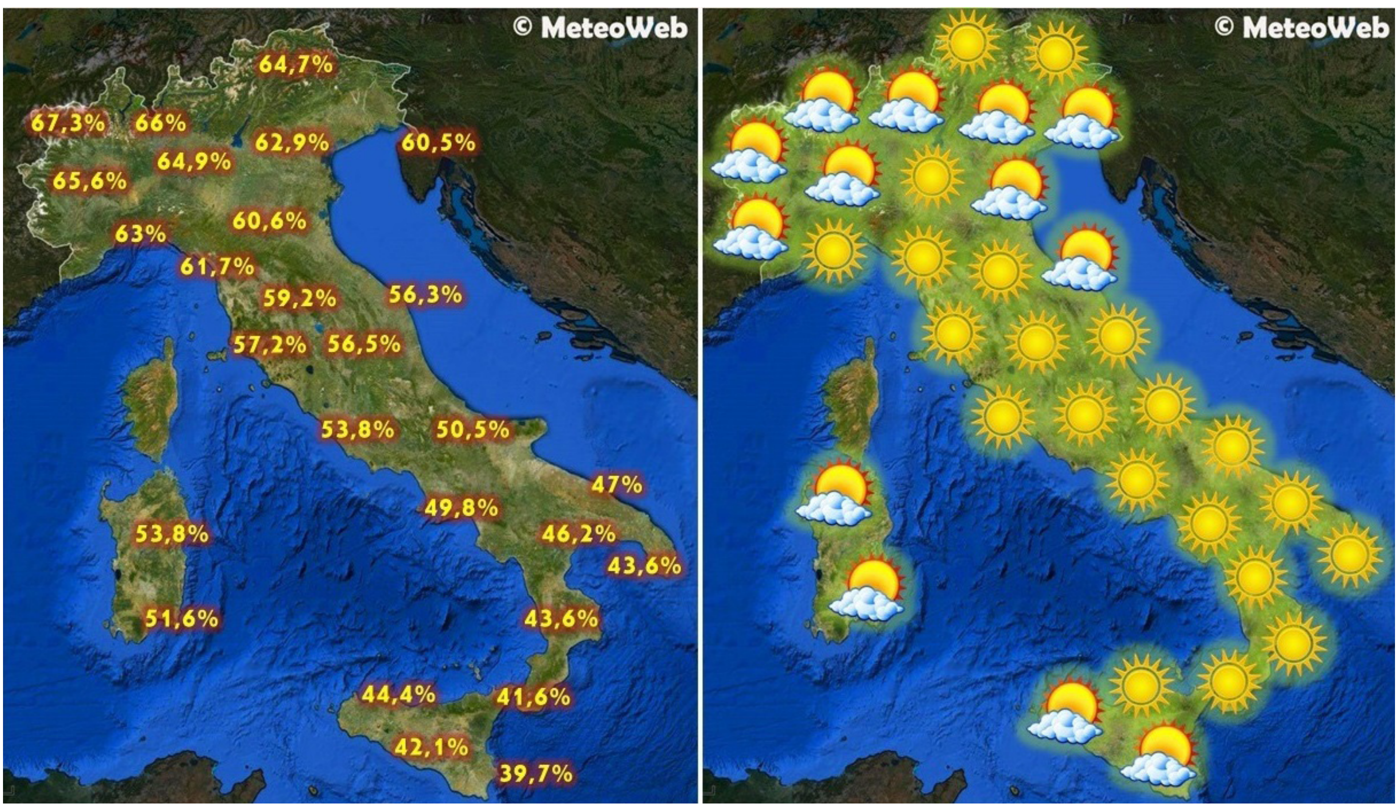

Figure 2 – Eclipse of 20 March 2015: percent of the Sun’s dimming and meteorological conditions in Italy.

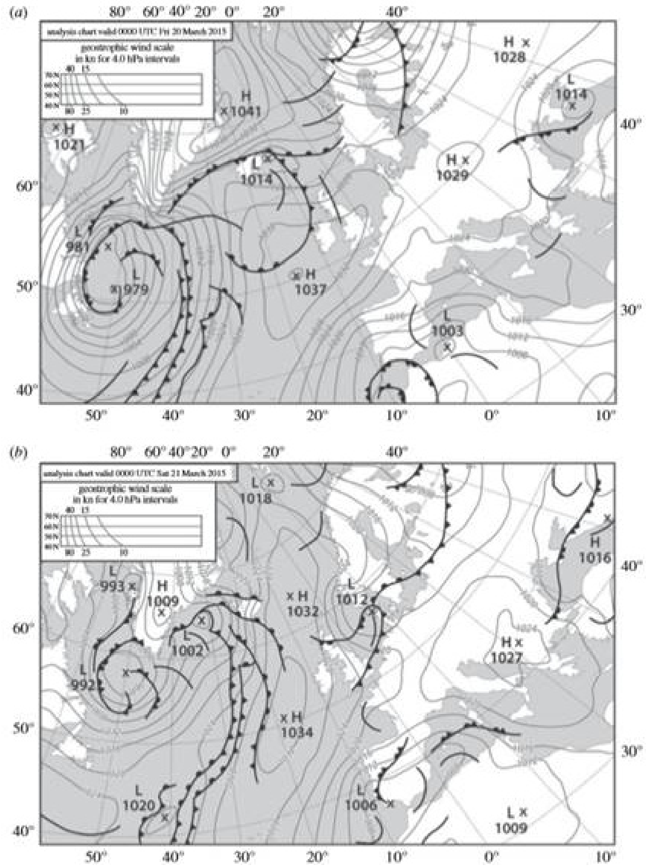

Figure 3 – Met Office mean sea-level pressure chart for (a) 00:00 UTC on 20 March 2015 and (b) 00:00 UTC on 21 March 2015 (redrawn). Original charts obtained from the Wetterzentrale Topkarten website (http://www.wetterzentrale.de/).

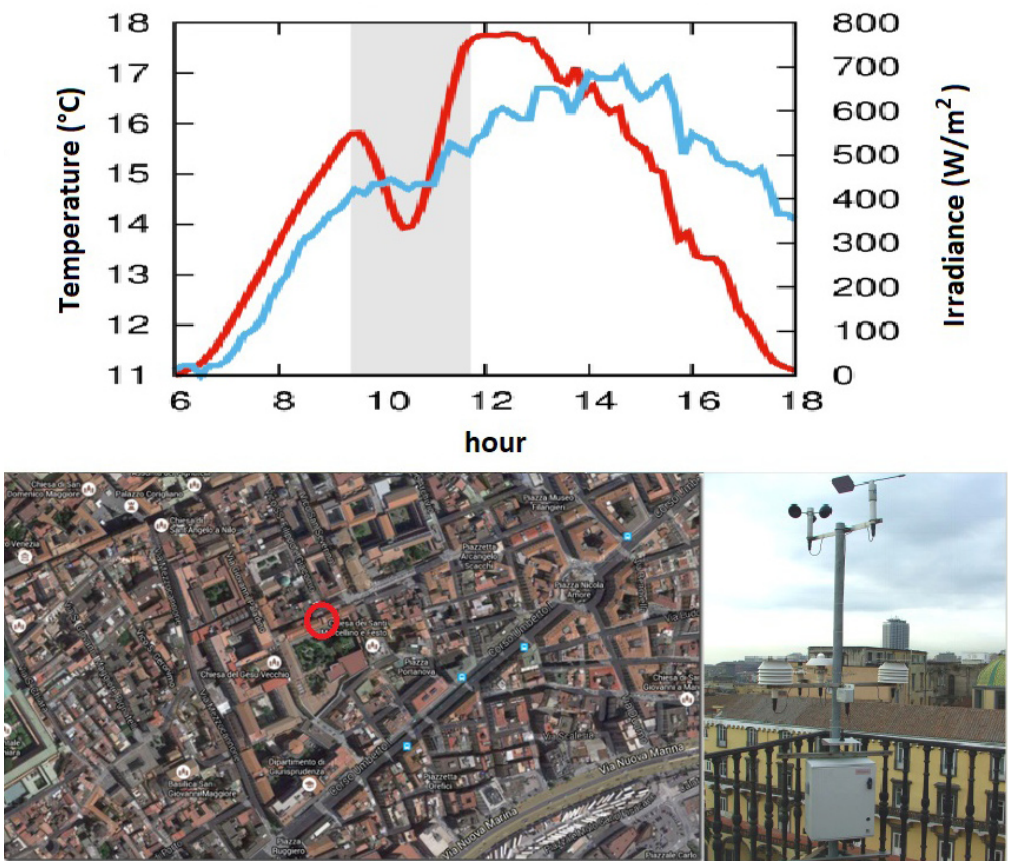

Figure 4 – (Top) Temperature and solar irradiance measured in the historical center of Naples. (Bottom) Photographs of the Meteorological Observatory of San Marcellino indicated by the red circle.

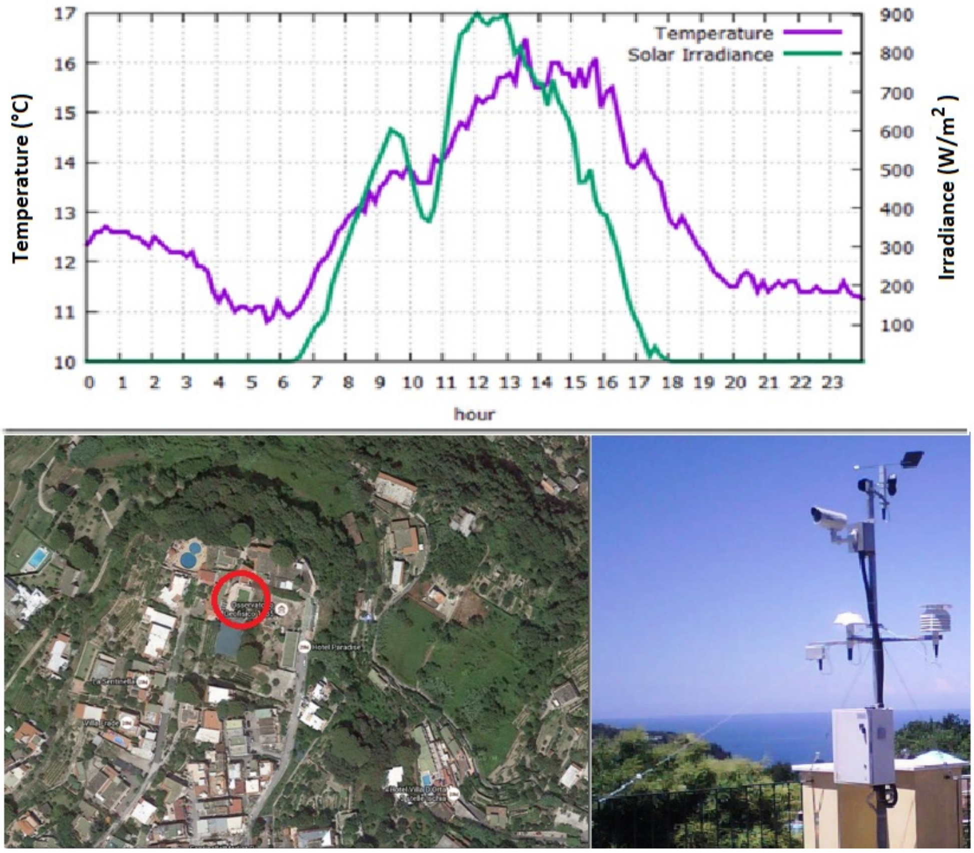

Figure 5 – (Top) Temperature and solar irradiance measured in Casamicciola. (Bottom) Photographs of the Geophysical Observatory in Casamicciola indicated by the red circle.

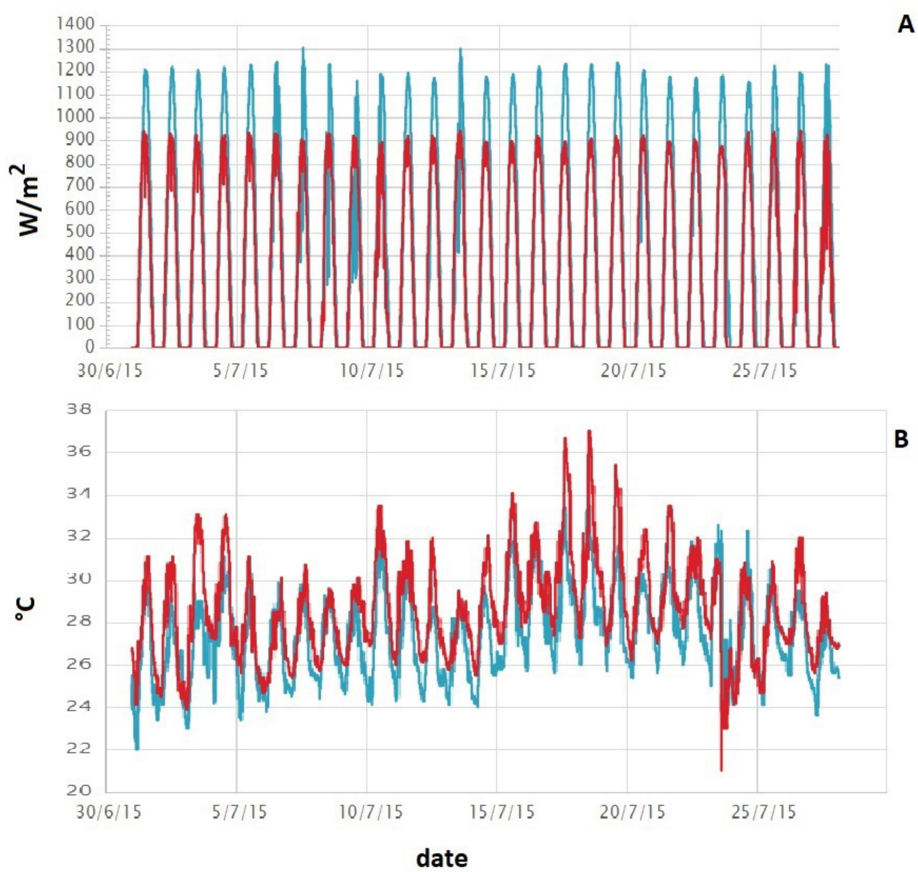

Figure 6 – (A) Solar irradiance measured in the meteorological observatory of San Marcellino Temperature (red) and in the geophysical observatory in Casamicciola (blue). (B) The air temperature measured in the two observatories, respectively.

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Roman buildings: mortar, hydraulic mortar and pozzolanic concrete in the Gulf of Naples, Campania – Italy

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Keywords: Roman mortar, pozzolana, maritime concrete, Campi Flegrei, Vesuvian ancient cities.

Abstract

The aim of article is to summarise the information published with regard to research carried out into mortar and concrete materials in relation Roman buildings in the gulf of Naples, Italy.

The region due to its geological formation and the historical significance of Roman cities and its monuments implicated in multidisciplinary studies on the raw materials and Roman construction technologies for an in-depth knowledge of the composition of geomaterials degraded in time and structural problems with a view to restoring the archaeological heritage.

The article describes the case studies of two geographic areas in particular, the sites of the Phlegrean Fields (Puteoli, Baia, Misenum) and the Vesuvius area (Pompeii, Herculaneum, Stabia, Surrentum). The results showed that important complexes and monuments have a composition of mortars and conglomerates which is found to match what is indicated by the sources and that malfunctions made in different chronological periods do not always retain the same composition. Futhermore, results confirmed that Roman engineers extensively used local geomaterials such as volcanic and sedimentary aggregates mixed with hydrated lime.

Introduction

Recipes for mortar-based building materials may change over time and differ in various construction and restoration phases. They normally reflect craftsmen's knowledge, availability of raw materials, and also the importance of the building in which they are found.

The use of particular materials and certain constructive techniques has allowed to preserve Roman buildings to this day; these monuments that are part of our Cultural Heritage require accurate and specific restoration work.

The Romans developed the technology of building with burnt-lime mortars to a very high level; they developed a sophisticated empirical understanding of the effects of production methods and mortar additives.

Knowledge of components (mortars, binders and stone materials) of ancient wall structures is therefore crucial for the preservation of archaeological monument.

Ancient literary source (*Vitruvius* and *Plinius Secundus*) give us many information about Roman tecnologies. In his handbook of architecture *Vitruvius*, in the 1th century B.C., describes many materials, designs, and types of construction, and he occasionally turns to the process itself.

The author describes the terms for various aspects of architecture as well as architectural practice. The provision of special materials such as *pulvis Puteolanus,* a characteristic material of the volcanic formation of the Phlegrean Fields, which was mainly used to make hydraulic mortar and to realize maritime infrastructures.*Vitruvius* suggests the utility of concrete in constructing buildings with vaulted roofs. The ancient *pulvis Puteolanus* apparently originated in the region around *Puteoli*, as the name suggests, and around the Bay of Pozzuoli in the Phlegrean Fields volcanic district near *Baiae*, as stated by *Vitruvius*. This same origin is specified by *Strabo*, Pliny, and Seneca (Passages 12, 14, 16). *Plinius*' handbook contains a rich store of miscellaneous information relevant to ancient technology too.

For this reason the aim of some researches is to investigate, by means of laboratory tests, the mechanical features of pozzolanic mortar of Phlegrean Fields and Vesuvian sites (Figure 1) to make a reproduction of mortars having physical, mechanical and chemical compatibility to the original mortars, by using natural materials.

Increasing sophistication in conservation, mirrored by increasing technical understanding of traditional and other modern man made building materials resulted in greater demands for better performance of materials used in conservation and restoration and their compatibility with historic originals.

These elements can be useful for structures built with similar techniques and are absolutely indispensable to safeguard the monumental heritage of Vesuvian sites and Phlegran Fields, constantly threatened by eruptions, earthquakes and age-long alternation of positive and negative phenomena of bradyseism capable to submerge a significant part of the ancient settlements to a depth of 15 meters below sea level.

Figure 1 – Roman cities in the Gulf of Naples.

Materials

Mortars were usually inhomogeneous because they were produced manually. The study of ancient mortars and concrete is therefore of twofold interest: mortars provide information on raw materials and technologies available at the time of production; knowledge of the main physical properties of a mortar and its state of conservation is a prerequisite for the process of restoration and conservation. Science methodologies can be used to measure the main characteristics and properties of ancient mortars and their components (binder and aggregate). Since it is not always possible to measure directly all properties of binders and aggregate fractions, some properties are obtained through data processing.

Mortar

The use of cement works spread to Rome and Campania from the 3rd century B.C. through Oriental and Hellenistic influences; Previously only the binder was clay while the lime mortar was introduced by the Romans (Giuliani 2006).

Mortar generally indicates a dough of earth and grain or straw, or land mixed with inerts or lime and sand or puddle (*materia ex calce et harena* Plin. N.H. 35, 169); In Roman times generally the dough was composed of sand and grass in ratio of 2:1 and water. The abundance of water in the dough is an element that differentiates the ancient conglomerate from the modern one. Vitruvius (2, 5, 1-2) indicates the proportions of the components to make good mortar (table 1).

Plinius Secundus (N.H. 36, 176) instead, shows that many buildings collapsed because the right amount of lime mixed with water was not met.

Hydraulic mortar instead served to make quick water intake and the Romans obtained it by mixing fat lime and *pulvis puteolanus* (pozzolan) or adding ceramic fragments (brick or pottery) to lime and sand. The mortar thus obtained began to grip after four days even if completely immersed in the water.

Table 1 – Ancient proportions (by Vitr. 2, 5, 1; Plin. N. H. 36, 175)

Pure lime paste	Quarry sand	Sea or river sand	Pozzolan	Sea or river sand and brick fragments
1	3			
1		2		
1			2	
1				3 (2 sand + 1 brick)

Opus caementicium

The name comes from stone fragments joined to mortar to form the compound. Its composition is described by *Vitruvius* (Vitr. 5, 12, 5).

Cocciopesto
It is a mixture of lime, sand or pozzolan and homogeneously distributed brickwork breaks, giving mortalities hydraulic properties. It was used as a waterproofing layer of wall structures placed in damp environments and as a coating of tanks.
This mixture, even if used as a lining or floor covering, is a concrete composite; In layers of a certain thickness it has a traction-resistance capacity.

Opus signinum
It is a conglomerate that is often identified with the cocciopesto and it is mentioned by *Vitruvius* when it speaks of the construction of the tanks (8, 6, 14); The same passage is quoted by *Plinius Secundus* (*N.H.* 35, 173) and by Colummella (R.R. 9,1) for rainwater tanks in wildlife farms.

Roman buildings in the gulf of Naples

Roman cities along the Gulf of Naples emerged in an area whose volcanic geological features were crucial for the supply of raw materials used for the construction of ancient roman buildings and maritime structures.
Vitruvius, writing in the first century BC, described a powder that produced 'wonderful' results when added to a simple lime-water mix. This 'powder', composed of tuffs derived from the volcanic province of Phlegrean Fields on the Gulf of Naples, enabled mortars and concretes to set in the presence of sea water and, in addition, to produce stronger structures than those built with lime cement alone. The tuffs were quarried from the vicinity of the modern town of Pozzuoli. The Romans called this material *pulvis puteolanis,* dust of Puteoli, Puteoli being the Latin name for Pozzuoli, which in turn has given the modern term 'pozzolana', widely applied to all additives to cements that produce a hydraulic set. The unique properties of this material were probably discovered as the local tufts, scoria and lavas were the aggregate of choice for the construction of the harbours and the port at Roman *Puteoli* (Lippiello 2011).

The Campi Flegrei (*Phlegrean Fields*)
The coastline of the Campi Flegrei is a geologically active area: bradyseism, frequent earthquakes, fumaroles and bubbling mud pots, and the occasional smell of sulphur are constant reminders of the defining presence of Campi Flegrei and Mt. Vesuvius. This area, located to the west of Naples and *ca.* 200 km south of Rome, is part of an ancient caldera in the Campi Flegrei (Phlegraean Fields) volcanic district. It was bounded by the Roman colony of *Puteoli* to the east and *Misenum*, the home of Rome's Western Mediterranean fleet, to the west. August's interest in the Phlegrean Fields district gave rise to the expansion of coastal cities and to the enormous development of port and road infrastructures, thus developing new building technologies using local raw materials.

Puteoli
The city was founded by the Romans after the Second Punic War, as part of a political plan of colonial foundations at strategic points of control of the coast of Campania in particular, became one of the most important harbour cities of the Roman Empire, for the strategic importance of its port. Archaeological Superintendence helped to enrich the knowledge of the ancient Roman city of *Puteoli*; in particular the archaeological surveys carried out since the nineties of the last century, as part of a large project to re-qualify and enhance Rione Terra, a promontory on which the late Roman Republic colony was allocated, allowed to acquire important information about the Roman city (Figures 2-3).
The archaeological investigations have allowed us to deepen the study of the building techniques from the foundation of the Roman colony to the 3^{th}-4^{th} century A.C., when the promontory was abandoned. The project, founded in 2004 by a multidisciplinary collaboration, analyzed mortars used in the northeast of the area (Imperatore and Proietti 2004).
The typological identification of building techniques is not only a useful support for documentation of digging data and for the diachronic evolution of mortars (i.e. verifying whether over the centuries there have been variations in the binder component) but it is an important element for diagnostics and preservation of ancient building. Mortar analysis has been useful in identifying components and their percentages to reproduce and use them in restoring patches.
The analysis found that ancient mortars are made up of a lime-based binder and a siliceous aggregate of volcanic origin, pozzolanic or volcanic sand coming from the territory. A clear change in aggregate-binding ratio was observed in the transition between the late republican age and the Augustan age (Paternoster et al. 2007).

Baia
The ancient *Baiae*, famous for its beauty and thermal water springs, was the holiday resort of the Roman aristocracy. The surrounding hills and the coastal coastline were occupied by luxurious villas whose owners are famous by literary sources. This area due to bradyseism has dramatically changed its coastal profile and some of these residential villas have been submerged (Figure 4).
Now the remains of the city lie underwater along up to a distance of 400–500 mt. far from the modern shoreline. Here, over the years, the restoration of sectors of several buildings

Figure 2 – *Rione Terra in Pozzuoli*, view from the sea.

Figure 3 – *Rione Terra*, Roman Building, detail.

Figure 4 – *Baia*, Roman submerged building, detail (Photo by ASNA archiv).

has been carried out: the Villa with entrance as a prothyrum, Villa dei Pisoni, a sector of the so called *Via Herculanea* and the Building with porticoed courtyard near *Portus Iulius*.

The hydrothermal and volcanic phenomena prompted scholars to experiment innovative methods of conservation and protection of archaeological heritage through the analysis of geomaterial and building techniques used in this area; In particular innovative restoration and conservation methods have been applied to underwater Roman buildings that require special conservation measures due to its characteristics.

To date, multidisciplinary studies focused on the analysis of the ancient mortars of the archaeological complex "Thermae di Baia" and some Roman buildings of the underwater parks of the Baia.

The archaeological site of "Villa a Protiro" (*Prothyrum Villa*) is located at 5 mt. depth; the rooms composing the Villa extend for 40 mt. along the road, flanked by *thermae*, *tabernae* and other villas; however, its real size should have been larger. The name "prothyrum" is derived from the presence of two stuccoed column shafts, no longer in existence, that were placed on two short partition walls built in front of the threshold. Sampling (12 mortars) was performed on several walls of the archaeological complex. The results obtained from petrographic analysis, showed the presence of different technology of production of mortars in term of type of aggregate, aggregate-binder ratio. In some samples they are marble fragments, testifying the Roman marble re-use in the mixture of mortars. In particular, there is a good correlation between the location of sampling sites within the different residential rooms and the minero-petrographic, morphologic and chemical features of the analysed fragments. This study is crucial since the most recent guidelines of scientific and international cultural heritage protection bodies agree in promoting underwater archaeological and historical heritage. (La Russa et al. 2015).

The so called archaeological complex "Terme di Baia" is an archaeological park extending along 40.000 sq.m. and it is divided in five sections: *Villa dell'Ambulatio, Mercurio* area, *Sosandra* area, *Piccole Terme* and *Venere* area that embrace patrician residences and a thermal complex (Figure 5).

A multidisciplinary group works to improve the knowledge of Roman construction techniques by means of detailed microstructural and compositional examinations of cementitious binding matrix and aggregates aiming at pointing out provenance of raw materials, mix-designs proportioning and secondary minerogetic processes.

Mineralogical-petrographic characterization of samples confirmed that Roman engineers extensively used tuff aggregate, hydrated lime, and *cocciopesto*. The main aggregate is *cocciopesto*, characterized by a mixture of lime, *pozzolana* and a part of the inert formed by shattered tiles, bricks and pottery. It is exactly the presence of *cocciopesto* which confers hydraulicity to the mortar (Rispoli et al. 2016).

The port facilities of the *Lacus Baianus* and *Portus Iulius* have been the subject of the ROMACONS project, because these structures do represent the first significant effort of building on a large scale in the sea (Figure 6).

The first site that we investigated was the entrance channel to *Baianus Lacus*, distinguished by two long moles or breakwaters. Each mole is about 9.5 mt. wide, while the channel between them is about 32 mt. wide. A similar location selected for coring was the entrance channel to the now submerged harbour of *Portus Iulius*. This installation was the first one built in the Italian peninsula specifically to serve as a base for a naval fleet. It was constructed clandestinely in the early 30s B.C. by Marcus Agrippa (Brandon et al. 2014).

Figure 5 – *Baia*, Archaeological complex of "Terme di Baia" (Photo by ASNA archiv).

Misenum

Misenum was the harbour of Rome's Western Mediterranean fleet. In the territory of Agrippa made significant engineering infrastructures linked to road and aqueducts.

The *Piscina Mirabilis* was the terminal point of Serino aqueduct; it is a water resevoir, with rectangular shape by

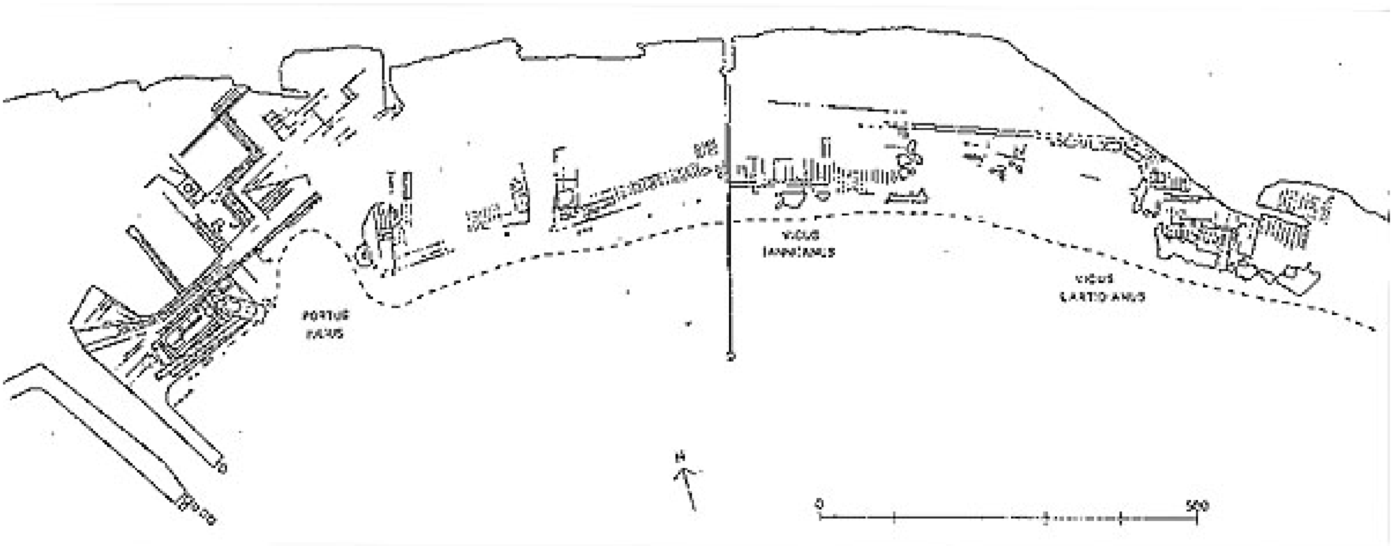

Figure 6 – *Lacus Baianus* and *Portus Iulius* (Photo by Miniero 2010).

a capacity of 12000 cbm water. It's 15 mt. high, 72 mt. long and 25 mt. wide. The internal space is based of 48 cross-shaped pillar, located on four lines, making five corridors with a barrel vault; the access was built by two stairs held by three archs, located in NO and SE corners. Next to the west entrance the intake pipe is located to allow the water supply. In the ground of the short corridor there is a little escavated basin with a depth of 1,10 mt., with an exit hole on the right end, that probably was used as settling tank.
The walls were built in *opus reticulatum* with lanes of bricks in the middle and pillar of tuff block, they have a coat of cocciopesto with a curb at the base to prevent infiltrations (Figure 7).
Mineralogical and petrographic examinations performed on geomaterials from the *Piscina Mirabilis* point out that hydraulic raw material was mixed with the lime for casting the mortars.
The main aggregate is cocciopesto, characterized by a mixture of lime, pozzolana and part of the inerts formed by shattered tiles, bricks and pottery. It is exactly the presence of cocciopesto which confers hydraulicity to the mortar. In fact, this component plays a pozzolanic reaction or reacts with free lime, forming hydraulic compounds, with long-term stability and water resistance. Extremely interesting is the composition of the cementiceous binding matrix, with the contemporary presence of gel-like C-S-A-H, derived from the reaction between lime and cocciopesto, calcite, gypsum, and, finally, tobermorite (Rispoli et al. 2015).

The Vesuvian sites

The eruption of Mount Vesuvius in 79 A.C. has allowed to preserve the Roman cities located at the foot of the volcano. The remarkable state of preservation of the murals and decorative structures in recent years has focused on the safeguarding of sites through multidisciplinary and international projects.

Pompeii
The site for the particular circumstances that have led to a remarkable state of preservation of the wall painting of public and private buildings has always been the subject of multidisciplinary teams, as well as the excavation campaigns to investigate the construction phases preceding the 79 A.C., they continue to enrich the knowledge of the ancient city (Figure 8).
Numerous international teams and diagnostic projects carried out by the Superintendence have deepened the study of the mortars of some public and private buildings in the city to identify the raw materials used in the mixture. Because they are artificial materials, mortars have diverse compositional and material characteristics, as a result of different construction needs and the technological knowledge of the workers who produced them.
The *Garum* Workshop is located in the *Regio* I of the archaeological site of *Pompeii* (I, XII, 8) and was devoted to the manufacture, storage and sale of *garum* famous Roman fish sauce. Probably the building was originally a private residence, later transformed into a workshop (De Luca *et al.* 2014).
D*omus of Octavius Quartio* occupies the entire *insula* 2 of *Regio* II in Pompeii, representing one of the most important domus of the archaeological site. An interdisciplinary approach has been adopted in order to plan conservative, preventive and restoration actions aimed at the requalification of *Pompeii* within the frame of "Grande Progetto Pompei" program. The *domus* was investigated by means of a multi-analytical and multi-disciplinary survey in order to define the state of conservation of the masonries. The method here proposed started with a precise mapping by laser-scanner that provided a precise measured-base for mapping geomaterials,

Figure 7 – *Misenum, Piscina Mirabilis*.

Figure 8 – *Pompeii*, Archaeological site, detail.

weathering forms and damage categories (Grifa et al. 2016).
The House of the Vestals, an ancient elite house in Pompeii (*Regio VI, insula 1*), shows different types of mortar.
Another research describes the compositional characterisation of coccciopesto and natural pozzolanic mortars sampled in the *Regio* VI area of the archaeological site of Pompeii, with particular reference to the Casa di Pansa in *Insula* 6 and Casa 17 in *Insula* 2. (Miriello *et al.* 2010).
Ariadne's House or "dei Capitelli Colorati", is located in the *Regio* VII, *insula* 4, in a privileged location at the center of the city, less than 100 meters from the forum. With 1700 sq.m., it is one of the biggest stately *domus* of the private Pompeian architecture (Pèrez *et al.* 2013).

The raw materials used in the mortars are related to the geology of the area and are fully compatible with the pyroclastic deposits of the Vesuvius.
The mortars were characterised by their aggregate-binder ratio, the mineralogy of the aggregate, which was fully compatible with that of the pyroclastic deposits of Vesuvius, and the composition of the binder, which revealed pozzolanic hydration phenomena caused by the reaction of natural pozzolana and cocciopesto with hydrated lime.
These data may be useful in the future to prepare mortars of high compatibility for use in restoration operations or detailed studies on the provenance of the raw materials used for their preparation.

Herculaneum
The Herculaneum Conservation Project is a public-private initiative to conserve and enhance the Roman city of Herculaneum and HCP team carried out an extensive sampling campaign across the site of both original and restoration mortars, used during the nineteenth and twentieth century excavation and restoration campaigns (Figure 9).
The composition and quality of the original construction mortars used in Herculaneum's walls do not only have archaeological value, but are also fundamental for understanding the structural capacity of the wall itself. This study will not only increase knowledge about the site but will also contribute to the conservation of Herculaneum and other open-air archaeological sites, thanks to the development of works strategies that consider quality, cost and time parameters when working with each type of mortar identified. (De Vita et al. 2010; Leone et al. 2016).
Stabiae
Ancient *Stabiae* is located on the Pianoro of Varano, a plateau in the junction between the Lattari Mountains carbonate ridge and the Sarno River flood plain. This settlement nowadays consists of several *otium villae* and rustic villas. During its life span, this otium villae complex was subjected to several geological risks related to the seismic and volcanic activity of this area, such as the earthquake in 62 A.C. Subsequently, it was completely buried by pyroclastics (several metres thick) from the 79 A.C. eruption, and subsequent slope instabilities, which in turn altered the ancient coastline. Villa San Marco is a huge building of approximately 11,000 sq.m., of which only a part has been excavated (Figure 10).
The other important materials of the mixtures have a volcanic origin. The source of such sand can be ascribed to the southern Bay of Naples where the Somma-Vesuvius finger-print can be easily recognised. As far as the volcanic aggregate is concerned, the mortar-based materials were made using a recipe of lime and volcanics, both available in the Vesuvius environs. The comparison with published research on mortar-based materials from other sites of the Vesuvius environs confirmed a wide utilisation of local raw materials (Izzo *et al.* 2016).

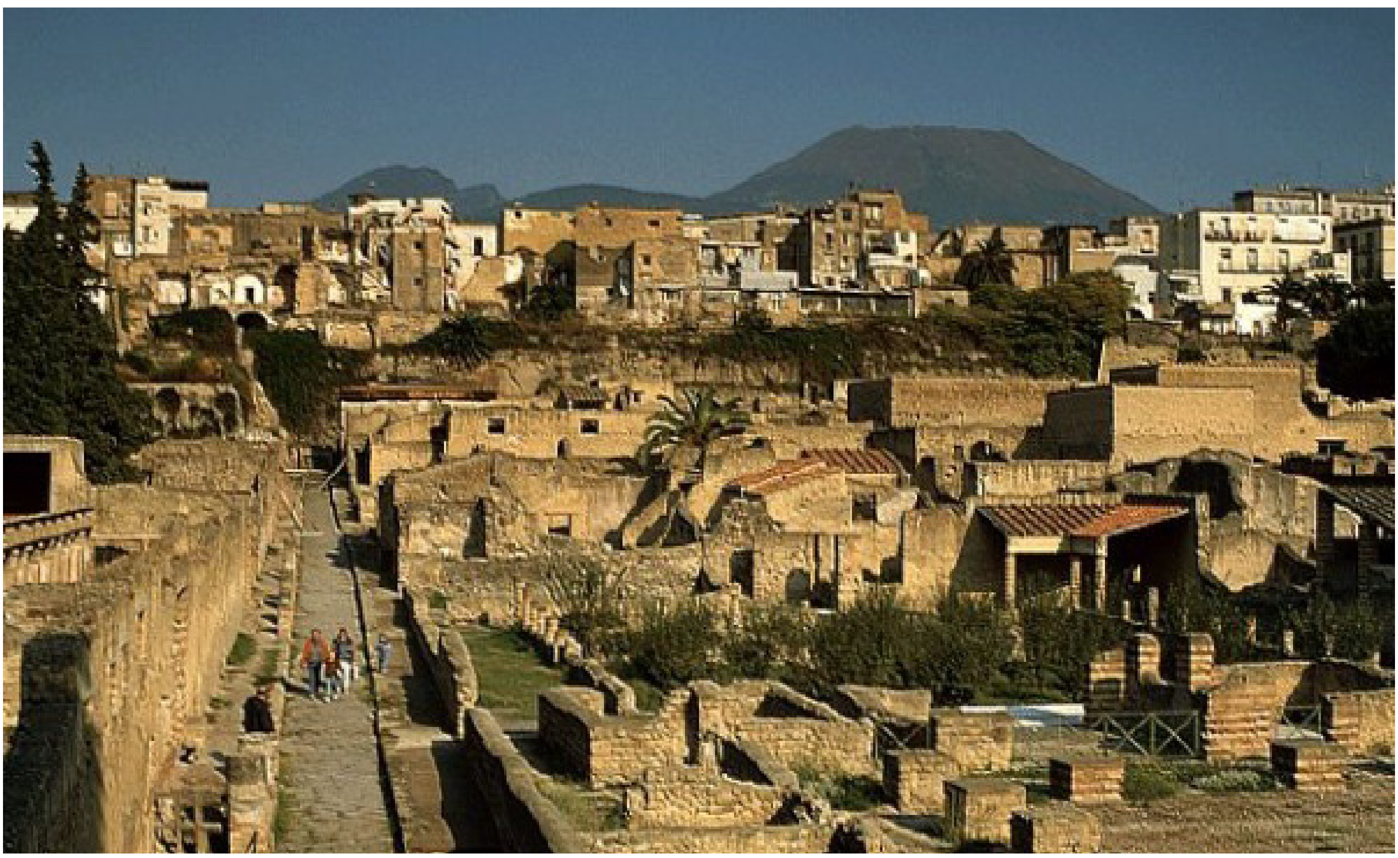

Figure 9 – *Herculaneum*, Archaeological site, detail (Photo by ASNA archiv).

Figure 10 – *Stabiae*, Villa San Marco, detail.

Surrento Peninsula

Remains of a Roman villa are visible near the eastern side of the Marina d'Equa bay, at the foot of the promontory of Vico Equense, in the Sorrento peninsula.

Rooms were seriously damaged by sea erosion and for this reason is almost impossible to recognize the original building plan. The villa was certainly damaged by the Vesuvius eruption of the year 79 A.C., whose products covered the stairs of access to the residence by the sea. The decoration of the Roman villa is documented by some sporadic marble findings, now kept at the National Archaeological Museum of Naples.

Geomaterials from the *Villa*, in particular mortars, are here studied in order to improve the knowledge on raw materials used to produce mortars, as well as their alteration products. Mineralogical and petrographic examination, performed on mortars from *Villa del Pezzolo,* evidenced that hydraulic raw material was mixed with lime for casting the mortars.

The volcanic aggregates were represented by some grey tuff fragments and leucitic scoria (Rispoli et al. 2016).

Conclusions

Multidisciplinary studies have shown that Roman buildings located in the Gulf of Naples, both public and private, were constructed using mortars produced with local raw materials; the area falls into two volcanic districts, the Campi Flegrei and Vesuvio, which have prime materials ideal for the composition of mortars and concretes so much to be cited by the literary sources (*Vitruvius* and *Plinius Secundus*). Results also showed that within the same for a given chronological period, differently quality mortars could be used, (perhaps due to the function of the building or to the wealth of the owner), and that qualitatively and quantitatively different mortars were used over the centuries and this could be associated with the use of certain building techniques over the centuries and could have affected the structural solidity of buildings.

Lastly, the pozzolan of the Phlegrean Fields has been identified in the maritime concrete infrastructures of the ports of the eastern Mediterranean and *Portus* near Rome (Stanislao et al. 2011; Brandon et al. 2014), proving that this raw material was also exported especially to make harbor and maritime infrastructures solid and resistant, as the hydraulic capabilities were better, just as *Vitruvius* prescribed.

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Geology

Evaluation of recent vertical motions along the Island of Capri: geoarchaeological evidences and implications at the Roman villa of Palazzo a Mare

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Keywords: coastal geomorphology, archaeological markers, sea-level rise, Capri, southern Italy

Abstract

This paper presents new geoarchaeological and geomorphological results along the northern and central coasts of the island of Capri where the submerged ruins of Villa Palazzo a Mare enabled the ancient position of both the sea level and the coastline to be reconstructed, as well as making it possible to evaluate the type, entity and rate of vertical ground movements. The surveys covered a maritime villa attributed in its first phase to Augustus. The sea level in Roman times, deduced from the submersion measurement of archaeological markers, has highlighted that despite the general trend of stability of the island of Capri locally many events after the Roman age occurred. Therefore, a rapid displacement due to aseismic and microseismic phenomena occurred during post-Roman age, which caused the coast to drop with consequent shoreline adjustments. An integrated approach linking the morpho-evolution of the landscape to proper management of exposed cultural heritage and the resolution of coastal hazard, is essential, particularly if we consider the population concentration in coastal zones.

Introduction

The research illustrates geomorphologic and geoarchaeological results concerning the northern coastal sector of the Island of Capri, in the Gulf of Naples, between Marina Grande and Punta Bevero, where the Roman age ruins of Palazzo a Mare have been discovered. New investigations in this coastal area have been triggered by the propensity of the island for recreational and touristic activities, combined with a millennial cultural heritage, which makes it a highly vulnerable area to climatic and morphological variations. In this sense, studying the position of the shoreline over time is crucial to understand i) the coastal system changes with its complex dynamics, ii) the coastal response to changes related to the relative variation of the mid-sea level, iii) if and what kind of actions and interventions for proper territorial planning could be useful, ecosustainable, and accepted by the society. Taking a long-term view about coastline management and coastal hazard, shoreline changing can be used to calibrate the forecast scenarios of sea-level rise, taking also into account the tectonic features of coastland margins. Actually, a proper coastal zone management should consider both the global sea-level rise and the local geological components that can modify its entity, even significantly. The interactions between global and local dynamics over the last 10,000 years, have contributed to change the morphology of coastline and to delineate its current conformation.

The IPCC (Intergovernmental Panel on Climate Change) report has shown that variations of the marine level in the Mediterranean do not follow global trends (Woodward et al., 2014), since they are largely influenced by regional and geological climatic features. IPCC scenarios consider the elevation of the sea level only, while they do not consider the negative contributions (acceleration of the submerged) or positive (stability or emersion) depending on other movements unlinked to ice melting, such as isostatic, bradyseismic and volcano-tectonic movements. Campania is an example of what had been said so far, where the effects of all the movements above mentioned create complex dynamics, quite difficult to discriminate.

Modern measurement techniques as metric tilt monitoring, IFSAR (Interferometry SAR), precision leveling and GPS can measure the relative motions with remarkable accuracy. Unfortunately, these data have very short time series which are never larger than 20 years. To reconstruct past dynamics and measures useful to understand modeling caused by vertical motion, data derived from geoarchaeology are used, which through the spatial arrangement of archaeological elements combined with geomorphologic study, gave information and measures to understand the morpho-evolution of the landscape and littoral erosion from Greek-Roman age to the present.

Geological and geomorphological framework

Morphostratigraphic and structural layout of the sea bottom in the perimeter of Capri and of the overlooking southern sector of Sorrento Peninsula, from Punta San Lorenzo (NW) to Punta Campanella (SW), is linked to its tectonic-eustatic evolution and to its control on coastal morphogenetic processes (Fig.1).

Morphobathymetric trend shows a tight relation with emerged landscape, underlining the physiographic framework. The seabed in front of the steep carbonate cliff may assume a large variety of forms, with an articulated topography reflecting there recent tectonic activity affecting this portion of the Apennine Chain during the Quaternary, when extensional subsidence and uplift resulted in a *horst* and *graben* structure (Brancaccio et al., 1991).

In the geodynamic evolution background of the Apennine Chain, the island can be considered as the unique emerging relic part of the western belt belonging to the Campano-Lucano Apennine, lowered and buried under the Tyrrhenian coastal plains during the Quaternary extensional tectonic phases (Signorini, 1950; Beneo, 1951; Sgrosso, 1986).

In particular, along the island northern side (Marina Grande) layers of debris and incoherent detritic soils, containing gravel sand mainly carbonate heterogeneous and cataclastic blocks in thin matrix, as well as reworked pyroclastic deposits lying on the clay substratum, outcrop.

History of Capri Island

The human presence on the Island of Capri has been attested since the lower Paleolithic, but the historical development of the island occurred with the colonization of the Greeks who made it a crucial point for maritime trades. Capri was part of the territory of *Neapolis* and politically depended on this city until Augustus made the island its own property, giving the Neapolitans the volcanic Island of Ischia, in the Gulf of Naples, and starting a massive building activity on the territory. Differently from Augustus, his successor, Tiberius made Capri

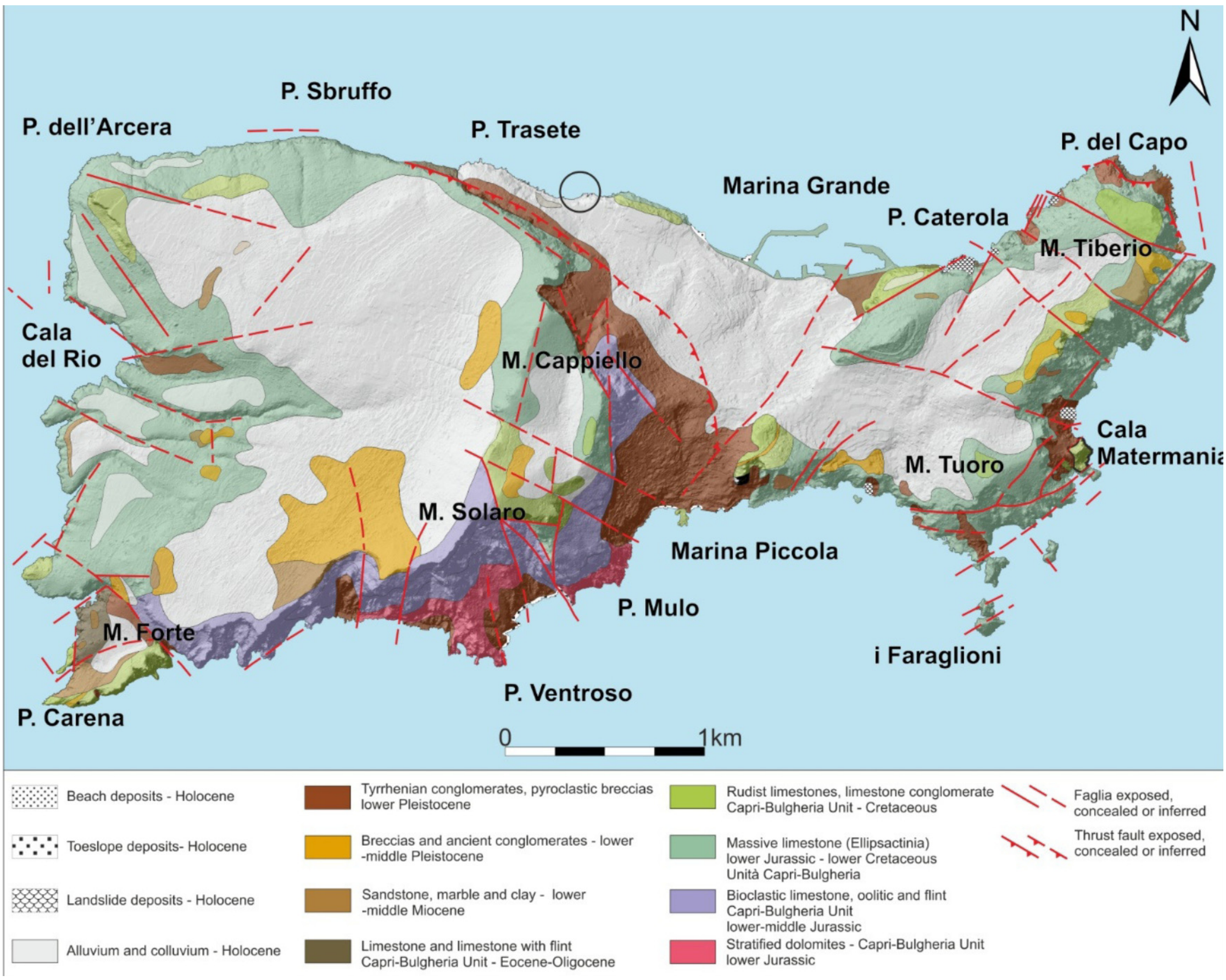

Figure1 – Schematic geological map of Capri Island (after Barattolo et al., 2016); open circle is the study area.

Island a stable location between 27 and 37 AD. The choice to retire on the island maybe coincided with the new policy of Tiberius, whom aiming for a dictatorship government form interrupted the cooperation with the senate, elevating Capri as the new capital of the empire. Tiberius, in a clear break with Roman politics, was surrounded by Greek philosophers and Babylonian astrologers, continuing the building policy inaugurated by Augustus, building twelve huge villas, also providing implantation of nymphs in various island caves.

One of the most significant Roman villas is Palazzo a Mare. The *villa* extends over a large area, from Cape Bevaro to the beach, known as "Bagni di Tiberio", with various nucleus between the sea and the promontory, reflecting the usual type of the *villa maritima*, characterized by scattered architectural elements in a panoramic position. The structure consisted essentially of a long staircase covered with barrel vaults, a private marina and a semicircular exedra-nymphaeum decorated by columns (Di Franco, 2015) (Fig.2).

The *villa*, attributed to Augustus with subsequent modifications due to Tiberius, was stripped of its pavements, capitals and marble columns in the 18th century by Hadrawa. It suffered further damages during the French occupation at the beginning of the 19th century, when a fort was built and the central part was turned into a parade ground. Modern building stock has further transformed the appearance of the areas, hence just some submerged elements of the imperial house remains, partitions of terracing walls, some cisterns and ruins of residential quarters.

Figure 2 – Reconstruction of the *villa maritima* in a painting of Michele Ogranovitsch, 19th - 20th century.

Analytical Methods

The study was focused on a critique reading of coastland geomorphologic literature, evaluating maps about geomorphological characteristics aimed to highlight coastal hazard and morphoevolution. Detailed fieldwork has been executed in order to take a census of archaeological sites and to understand the morphoevolution of the coastal zone from the Greek-Roman age to the current. On these sites, geomorphologic and geoarchaeological evaluations, both terrestrial and underwater, were carried out by repeated measurements with depth gauges, poles and measuring tapes. Moreover, meteomarine climate data have been analyzed, and historical and structural seismic catalogues were consulted (Working Group, 2004; Guidoboni, 2007).

Measurements of the depth (q), in centimeters below sea level, at which the archaeological structures lie were corrected by the formula of Leoni & Dai Pra (1997):

$$q = Q + h_i + \Delta h_p \tag{1}$$

which considers the depth of archaeological remain (Q), hydrometric level at the time of measurement (h_i) and the barometric correction (Δh_p). Hydrometric level was calculated by records of the nearest station (The National Tidegauge Network of ISPRA, mareografico.it). The barometric pressure, measured in *situ,* was mediated by the record of the Meteorological Observatory of the University of Naples Federico II. The Δh_p was calculated considering a regression coefficient of -1 cm/mbar (Palumbo & Mazzarella, 1982).

In order to use the archaeological finds as a marker of the Roman sea level, the depth measurement has been completed with the functional elevation (f_e), which is the original elevation of structure above sea level. Therefore, the formula can be developed as follows:

$$q = Q + h_i + \Delta h_p + f_e \tag{2}$$

The error on the position of the sea level is related to the type of marker. Coastal archaeological sites places in the intertidal zone, such as Roman fishpond, can provide very precise estimates of these changes, while the outer walls are unreliable (Anzidei et al., 2003).

In order to identify the directions of provenance of sea storms and improve the correction factor of the functional elevation (f_e), the calculation of geographic (Fgeo) and effective (Feff) fetches (Fig.3) was carried out at 5° angle intervals for each direction (α). The effective fetch was calculated adding ±45° to limits of the coastal sector, according to the method of Milano (1977) through the following expression:

$$F_{eff} = \frac{\Sigma F_{geoi} \cos^2 \alpha_i}{\Sigma F \cos^2 \alpha_i} \tag{3}$$

Analysis of wind direction and velocity and related frequency was carried out using 3-hour data provided by the meteorological station of Ustica Island, southern Italy, 2 m asl (38°42'28.12"N 13°10'39.23"E), between 1951 and 1998. These data were integrated with anemometric data recorded by Naples tidal station of ISPRA national tide gauge network, located in the port at 1.7 m asl (40°50'27"N, 014°16'09"E), during 1997-2007 period.

Finally, geodetic parameters used to process geo-thematic maps and the digital restitution of collected data are DATUM WGS84, UTM Zone 33, False EST: 500,000 m, False north: 0 m, Latitude of origin: 0° N, Longitude of origin: 15°E, scale factor: 0.9996.

Results

The archaeological complex is greatly deteriorated by continuous architectural changes occurred during the last three centuries. According to Maiuri (1956), the real emperor residence was in the fort area, later converted into a private villa, where some areas of uncertain function, tanks and an impluvium are still recognizable. Maiuri attributes functions of fish tanks and docking to the currently submerged structures. Underwater surveys show that of the archaeological complex (Fig. 4a) remains just some parts of the nymphaeum and few submerged elements (Fig. 4b).

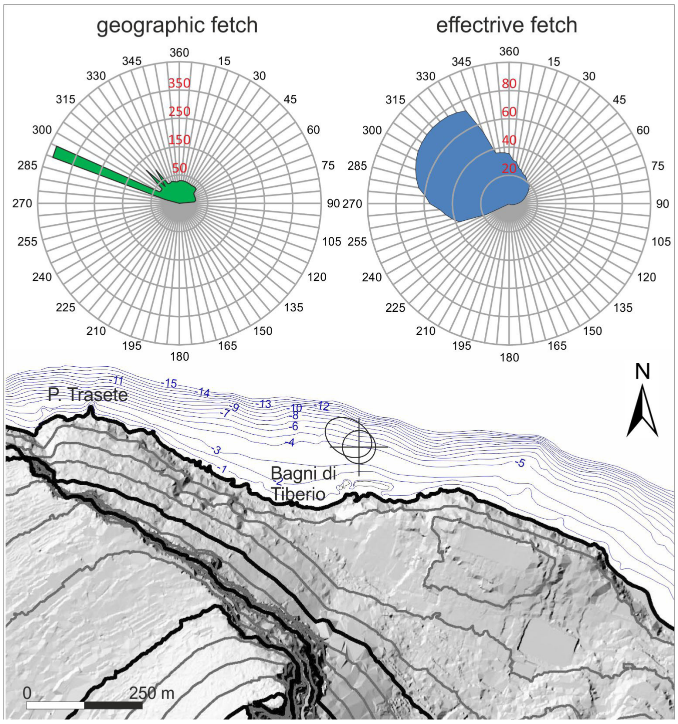

Figure 3 – Polar diagrams of geographic and effective fetches calculated in A, according to Milano (1977), considering extension of offshore, the study area; isobath (-m bsl) from Piano Stralcio di Bacino per la Difesa delle Coste – Autorità di Bacino Campania Centrale.

A ramp with marble steps, currently hidden by vegetation, led to the maritime quarter of the villa, in the middle of which the large exedra-nymphaeum is located. The latter is made of *opus reticulatum* alternating with rows of tiles. Probably, hydraulic mortar used in the structure was mixed with materials coming from nearby volcanic districts of the Phlegrean Fields and the Mt. Somma-Vesuvius (Rispoli et al., 2015; Stanislao et al., 2011). Submerged structures, useful as geoarchaeological markers, consist of a underwater arch (Fig. 4c), whose base is placed at -4.2 m depth, made of bricks and mortar. A similar submarine arch was discovered only along the coast of Naples, at about -2.2 m deep, partly cut in tuff (Donadio et al. 2015).

The tunnel (Fig. 4d), at -1.6 m deep, cuts orthogonally the structure with respect to the coastline. It is not possible to observe the docking spotted by Maiuri. Probably, the modern breakwater barrier, located on the east side of the wall, obstructed the small Roman harbour. Furthermore, the surveys show that the structure in place is not disjointed, collapsed

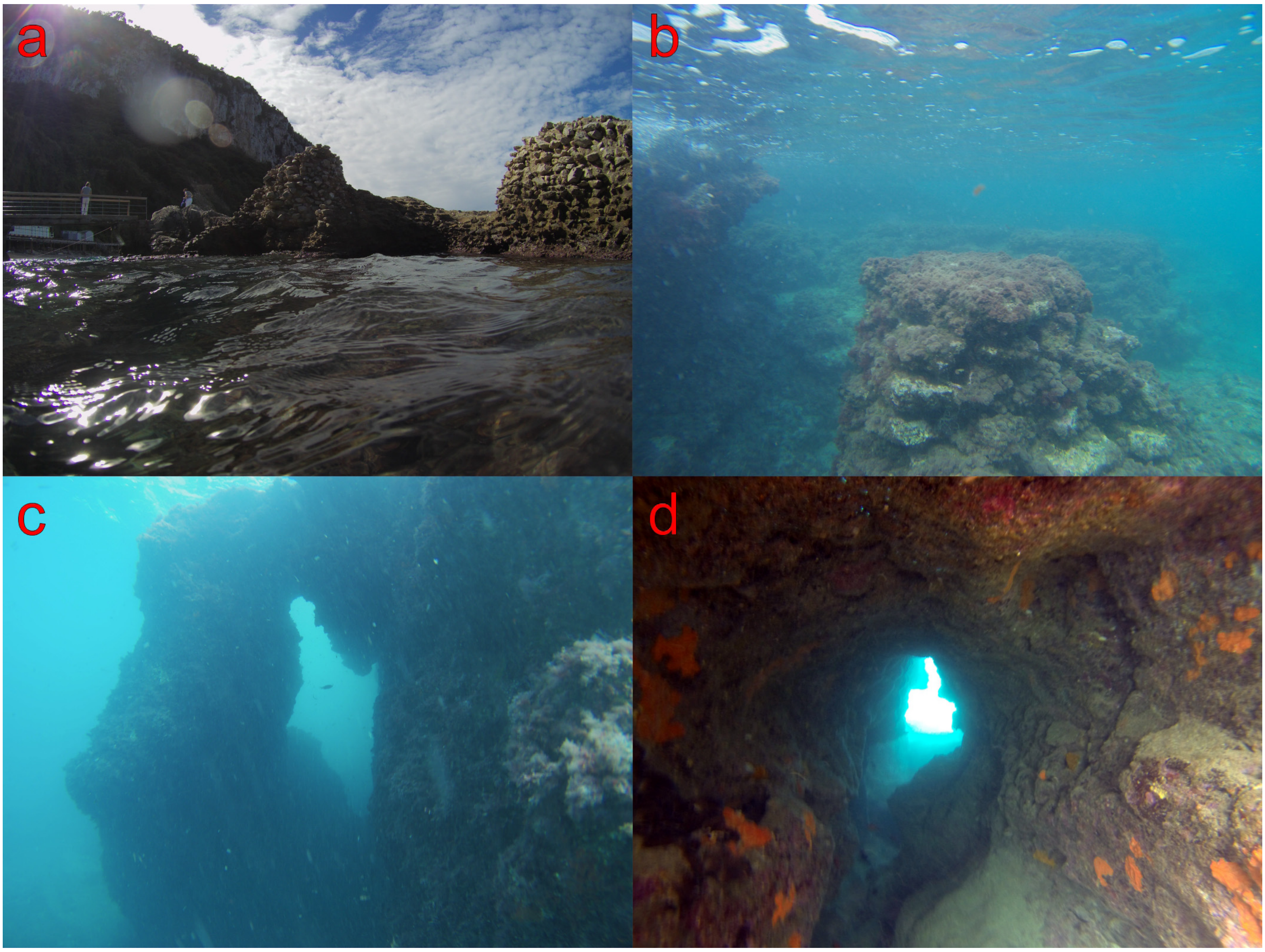

Figure 4 – Emerged (a) and submerged (b) ruins of Palazzo a Mare; c, submerged arch; d, tunnel (photos a-c by C. Stanislao, 2015; photo d by C. Donadio, 2015).

or inclined towards the sea, so its elevations and measures can be considered meaningful and reliable.

Discussion

The mutual interaction between tectonics and glacial-hydrostatic adjustment has controlled the structuring of coastline. Moreover, these factors contributed to the development of the physiographic units and to the genesis of more recent morphologies set on inherited landscapes. These last have been modeled in tectonic and climatic conditions which are very different from present ones: in fact, they manifested before and then during the Quaternary, especially in the last 10,000 years (Holocene). Therefore, in the current coastal landscapes of Campania both different tectonic styles and morphoclimatic systems no longer active are recognizable.
From the archaeological point of view, this part of coastline stimulates great interest, although it has not been the subject of systematic researches aimed to the knowledge of the territory and to the realization of an archaeological map for protection and safeguarding of the underwater heritage. Among many Roman villas of the Island of Capri, Palazzo a Mare is partially submerged with a maximum depth of-4.2 m (Fig. 5).
At this depth, 1 m for a maritime structure must be added in order to preserve the functionality of the structure itself even under severe sea storms. A total drowning of 5.2 m was evaluated. (Fig.6). This value was calculated with equation (3).
The meteomarine climate of the Capri Island shows a geographical fetch with main sector towards northwest, extending about 450 km, with winds coming from the first and fourth quadrants; the effective fetch, calculated for the maximum extension with northwest direction, is equal to 70 km.
Wind that generate significant sea storms blow mainly from the northwest, is a destructive agent to archaeological structure, which extends parallel to the shoreline with N90° direction.
This submerging can be partly attributed to the glacial-hy-

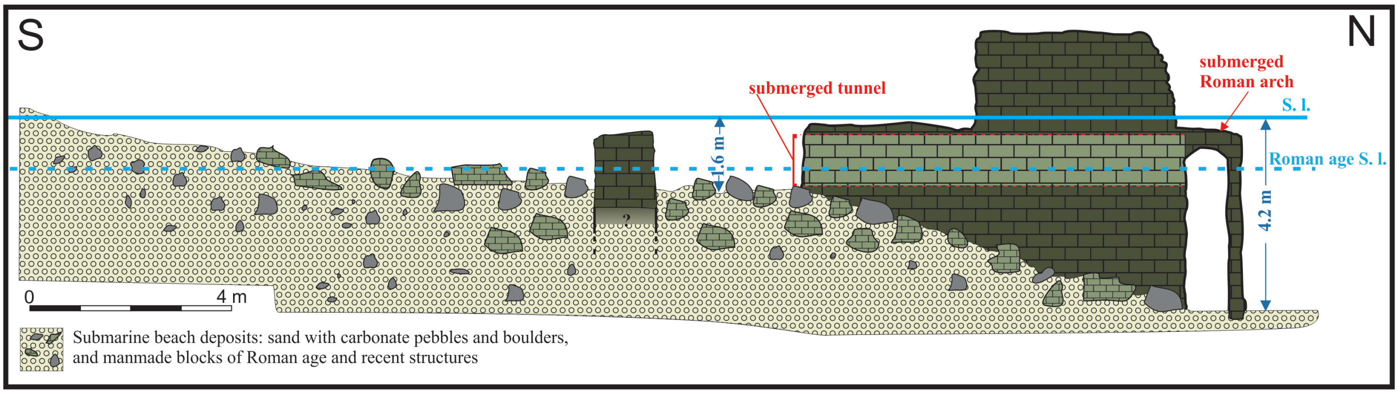

Figure 5 – South-North section of archaeological structures at Roman villa of Palazzo a Mare; depth is in meters bsl.

drostatic adjustment, whose causes can be summarized in: i) changes in the volume of water (melting glaciers, thermal expansion of ocean water masses), ii) lifting of emerging lands and lowering ocean beds as consequences of the gla-

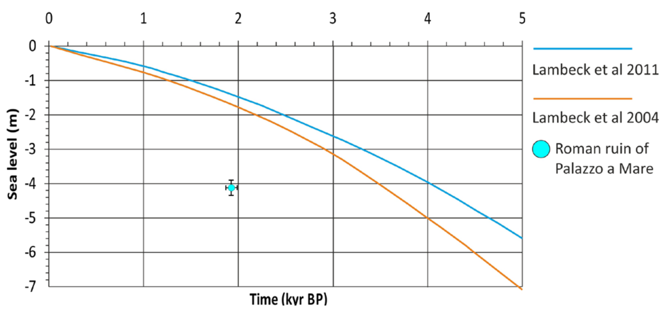

Figure 6 – Position of archaeological markers linked with predicted sea level curve for the site of Campania.

cial crusts melting, according to the rheological response of the lithosphere. This adjustment from Greek-Roman period is about 1.25 cm (Lambeck et al., 2004, 2011).

Moreover, a slight subsidence was recorded, with average rate of -0.12 cm/yr in the 2002-2011 period (Fig.7) by radar PSI technique-SAR (permanent Scatter Interferometry – Syntetic Aperture Radar) and by ERS satellites with ascending orbit (IREA, webgis.irea.cnr.it). Considering this value for the last 2000 years, since Roman age a subsidence of 2.4 m occurred.

These phenomena partially justify the drowning of submerged ruins, because other factors influenced the examined area. In the literature (Working Group, 2004; Guidoboni, 2007) there are no significant earthquakes able to dip the area, confirming the absence of seismicity linked to the Apennine chain.

A plausible mechanism is represented by aseismic and microseismic movements along the faults reticulum linked to the fault principal system, NE-SW oriented. These phenomena surely act slow ground vertical movements in a range of -0.6 and -0.8 cm/yr, which could increase coastal hazard due to sea cliff erosion and landslides (De Pippo et al., 2009). This interpretation is supported by the local displacement of the Tyrrhenian (125 kyr BP) marine terrace and sea notch (Ferranti et al., 2007).

Conclusions

Several areas along the Mediterranean coasts show submerged ruins of Greco-Roman Period few meters under the current sea level (Auriemma & Solinas, 2009). The causes of the drowning of archaeological ruins are mainly attributed to the interactions between sea-level rise and subsidence, while in volcanic areas the adjunctive effect of tectonics, seismicity and locally brady-seismic phenomena determined a higher and rapid soil down lifting such as recorded in Campania (Aiello et al., 2007; Putignano et al., 2014).

The historical evolution of the carbonate Island of Capri has been influenced by sea-level rise due to the glacio-hydro-isostatic effect (*sensu* Lambeck et al., 2011) and wave erosion, which have led to the submersion and retreat of the coast. Locally, this trend has been influenced by geological component.

The Roman ruins of Augusto's maritime villa are located at -4.2 m depth. Even considering the sea level during Roman age (-1.25 m lower than the present day), the downlift is incongruent with the general island uplift of ~1.5 m due to tectonics, marked along the cliffs by the current elevation of the palaeo-sea notch modeled at 5.5 m ~125 kyr BP (MIS 5.5 high stand, Tyrrhenian). Likely, a rapid displacement due to aseismic and microsismic movements during post-Roman age occurred.

The analysis of meteomarine conditions show that the villa is exposed to the northwest storms, which developed waves crashing sine 2000 years on the Palazzo a Mare, the last archaeological evidence of *villa maritima* on the island. Therefore, it should be protected and restored with a land-sea project following and adaptive strategy and environmental design approach.

Moreover, to estimate the coastal hazard is necessary to evaluate the recent data on the predictions of sea-level rise

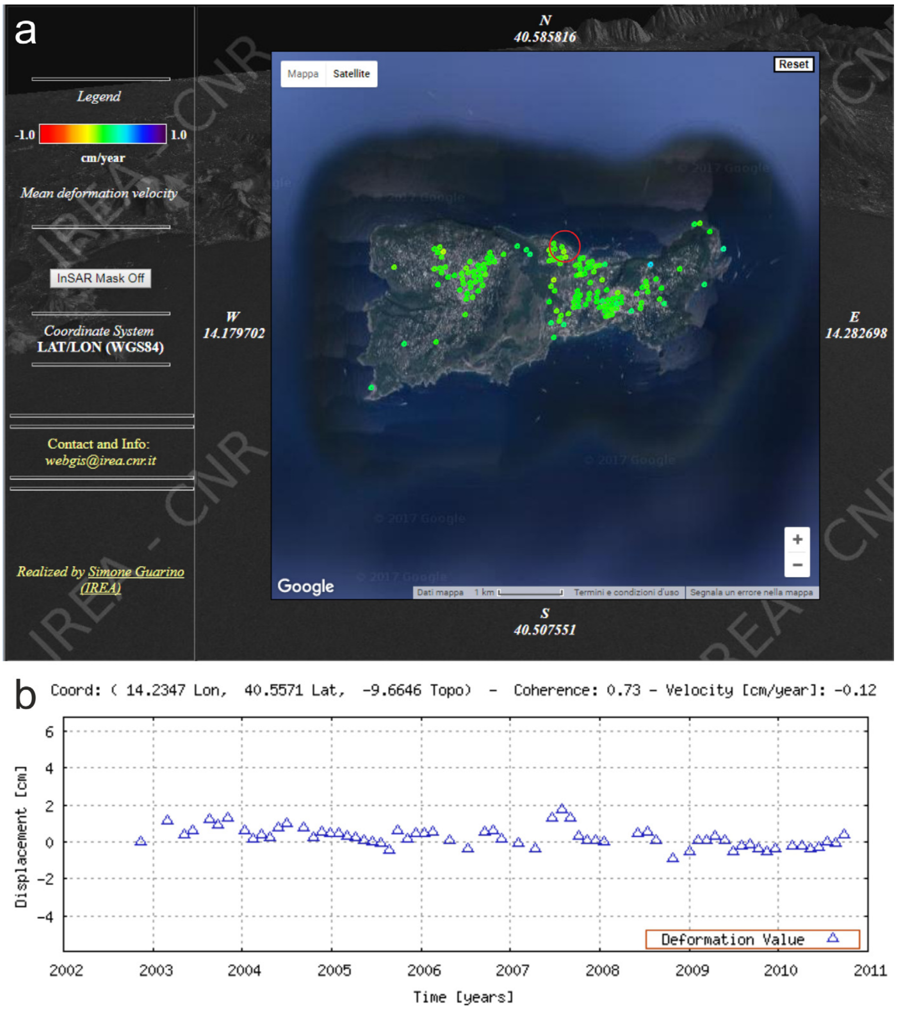

Figure 7 – a, ERS images of Capri Island, from Irea (Istituto per il rilevamento eletromagnetico dell'ambiente); red open circle is the study area; b, InSAR deformation-timeseries.

and to consider also a morpho-structural and morpho-evolutionary models derived from geoarchaeological and geomorphological evidences. Finally, these models must be set on a local scale since multiple causes simultaneously act along the territory in different ways and intensity, leading to great modification of the coastland.

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