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Nature Based Solutions on the river environment: an example of cross-disciplinary sustainable management, with local community active participation and visual art as science transfer tool

Andrea Conte[a], Patrizia Brunetti[b]*, Enrica Allevato[c], Silvia Rita Stazi[c], Maria Luisa Antenozio[b], Laura Passatore[d]* and Maura Cardarelli[b]

[a]*Climate Art Project, Andreco Studio, Rome, Italy;* [b]*CNR, Institute of Molecular Biology and Pathology (IBPM), Roma, Italy;* [c]*Department of Innovation in Biology, Agri-food and Forest systems (DIBAF), University of Tuscia, Viterbo, Italy;* [d]*CNR, Institute of Research on Terrestrial Ecosystems, Monterotondo, Italy*

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An attempt to link phytomanagement, art and social involvement is presented. The "Remediation" Project started up from the search of sustainable solutions for the management of a riparian area in the city of Rome. With the participation of citizens, researchers carried out a preliminary survey on the presence of metals within the target ecosystem and a demonstrative experiment on phytoremediation. Several social and cultural events have been organized in connection with the scientific part of the project: a public debate, an art exposition, a performance and two workshops at the experimental field. The Project demonstrated that through art it is possible to raise curiosity on scientific issues; the participated survey on metal pollution highlighted the strict interconnection among environmental matrices (soil/water/bioma) and thus the risk of contamination transfer; the demonstrative experiment, even if very basic in order to be easily approached by citizens, showed the great potential of Nature Based Solutions.

Keywords: Nature Based Solutions; environmental art; citizen science; phytoremediation; art and science

1. Introduction

1.1. Nature Based Solutions

Riparian zones are key interfaces between stream and terrestrial ecosystems. Several studies have highlighted their role in biogeochemically linking aquatic and terrestrial habitats. Nitrogen, Phosphorous and contaminant fluxes between soil and water are heavily influenced by the management of land-facing watercourses (Larson, Dodds, and Veach 2019; Wang *et al*. 2018). Not only do riparian vegetation species and agricultural practices have strong implications for the surface water quality and flooding (Surian *et al*. 2015; Melland, Fenton, and Jordan 2018), but also stream water pollution can heavily affect the quality of the soil through irrigation practices with freshwater or shallow groundwater.

The connection between different cycles and processes within a river ecosystem is so tight that is not possible to act only on a single component such as water quality or

*Corresponding authors. Email: laura.passatore@cnr.it; patrizia.brunetti@uniroma1.it

the survival of an endangered species. River management and restoration cannot be but a holistic process, which tackles multiple problems simultaneously (hydrological risk, water quality, biodiversity, landscape, soil erosion, water provision, social governance, climate regulation). Among the strategies developed for river management and restoration, Nature Based Solutions (NBS) are a category of interventions that target the holistic character described above (Hanson, Nordin, and Lazarova 2017*;* Keesstra *et al*. 2018). The European Commission defines NBS as "actions which are inspired by, supported by or copied from nature" (Bauduceau *et al.* 2015, 4). NBS offers great potential for application in the field for contaminated land remediation and brownfield redevelopment (Song *et al*. 2019; Bouzouidja *et al*. 2019). Nature based remediation technologies such as phytoremediation or, according to a wider definition inclusive of the concept of site use profitability, phytomanagement, can be an opportunity from a variety of viewpoints, ranging from energy efficiency and soil fertility, to environmental resilience and aesthetics of the site (Evangelou *et al*. 2015; Cundy *et al*. 2016; Burges *et al*. 2018).

The present work focuses on the management of a riparian natural area within an urban context and aims to highlight the risk of pollution migration between different environmental compartments. Heavy metal pollution has been investigated in different environmental matrices (soil, water and biomass) for the target area and a pilot representative experiment on phytomanagement has been conducted with the involvement of citizens.

To realize their full potential, NBS must be developed through an inclusive and participatory approach, involving local communities and relevant stakeholders such that "solutions" contribute to achieving all dimensions of sustainability (Esteves 2017; Nesshöver *et al*. 2017; Keesstra *et al.* 2018). Especially when applied in urban and suburban contexts, the phytomanagement actions should be planned and implemented in connection with local communities in order to inform about problems and opportunities of the site and tailor the project to the needs of citizens (Cundy *et al*. 2016; Keesstra *et al.* 2018).

1.2. Art and science

The project illustrated here makes use of visual art as the vector and language to raise citizens' awareness on scientific findings about the environment and about the state and potentialities of their own territory.

There has been a long debate on the nexus between art and science; in the present paper we can just sketch the main traits of these studies. From Snow's lecture on The Two Cultures (1959, published in 2012) a new concept of socially distributed knowledge, opposed to the old paradigm of scientific discovery, has been raised triggering a "(multi) cultural" practice of science communication (Nowotny, Scott, and Gibbons 2001; Van Dijck 2003; Born and Barry 2010; Snow 2012). Art has long offered empirical objects through which to theorize nature and society–environment relationships, such as paintings, installations, land-art and art–science collaborations (Hawkins *et al.* 2015). In recent years, we have assisted in a rapid growth of hugely varied forms of the art-environment-science relationship.

During the sixties and seventies, environmental themes were very present in the visual arts. Movements such as "Land Art" and "Environmental Art" brought the theme of nature and landscape into the center of their poetics, especially in the UK and the United States. Artists such as Richard Long, Robert Morris, Dennis Oppenheim, Robert Smithson, started to use natural material and landscapes to build their artworks. Among the most well-known works, are the path in the landscape and the circle of stone made by Richard Long. Another famous Land Art Artwork is the "Spiral Jetty," a spiral made of stone clay and algae, 460 meters long and 4.6 meters wide, made by Robert Smithson in the Great Salt Lake (April 1970, Utah). The land Art Movement was also inspired by the German artist Joseph Beuys, founder of the German Green Party, that conceptualized the "Social Sculpture" to embody art's potential to transform society. One of his best known works is "7000 Eichen" the seven thousand oak trees planted, each accompanied by a basalt rock, for the exhibition Documenta 7 (1982, Kassel). In Italy, the artists Giseppe Penone and Gianfranco Baruchello also worked on nature and agriculture as their main artistic themes (Baruchello 1981). SLOW clean-up, convened by the artist Frances Whitehead is, to the best of our knowledge, the first project joining phytoremediation and aesthetic, going beyond manuals and guides of urban brownfield remediation. This artwork has been used as a key study by Hawkins and her coauthors in order to explore how the arts can enable forms of socioecological transformation (Hawkins *et al*. 2015). Most recently, some Street Artists have also been influenced by environmental issues, as described by Bengtsen (2018). These artworks pretend to have an effect on society and in many ways they have by creating bridges between art, ecological and social engagement (Brady 2007; Ingram 2012). Environmental themes are coming back in contemporary artworks, but with different urgency. The climatic and environmental crisis affects contemporary art production. Artists from all over the world have taken on climate change as the subject matter of their work, inspired by the latest scientific research. Art as a representation of climate change has been widely theorized and speculated about (Cant and Morris 2006; Miles 2010); much progress has been made in appropriating climate change art as essentially artistic, rather than propagandistic or activist practice (Nurmis 2016). Artists such as Olafur Elliason, Tomas Saraceno and Andreco are addressing major environmental issues in Europe and worldwide. In Paris, during the UN conference on Climate Change Cop21, Olafur Eliason installed "ice watch," an installation made from ice blocks harvested in the arctic to underline the problem of polar ice melting. At the same time, in another area of Paris, Andreco realized a big wall painting featuring the causes and consequences of climate change and a sculpture made from wood and climbing plants as a symbol of Nature Based Solutions for Climate change mitigation and adaptation. This intervention marks, for Andreco, the beginning of the Climate Art Project, a cross-disciplinary project, between art, science and actions for the environment. Andreco has also led other projects related to art, science, urban planning and the environment, contributing to the local debate on urban sustainability and resiliency (Conte 2019). Andreco, for almost ten years, has used plants for the realization of his installations, with the aim of celebrating their remediation properties on soil, air and water pollution. "Nature As Art" is Andreco's artist practice founded in 2011 which elects the physical-chemical-biological reactions occurring in the ecosystem as the artwork itself. The artist individuates the properties of nature, such as plants' ability to treat pollutants, as a work of art. Andreco's activity, inspired by Donna J. Haraway and Ana Tsing's writings (Haraway 2016; Tsing *et al*. 2017), is carried out in close collaboration with research groups in order to understand chemical-physical transformations active in plants and bring them to the general public through visual art.

According to the idea of considering the complexity of ecosystems and experimenting with other, non-anthropogenic, views, Andreco overlaps artistic research with scientific research in the field of Nature Based Solutions to develop symbiotic projects such as the one presented in this paper.

1.3. The REMEDIATION project and the "River Contract"

The "REMEDIATION" project is a transdisciplinary initiative between art and science, conceived by the visual artist Andreco, realized in partnership with representatives from the protected area "Valle dell'Aniene," researchers from the University and Italian National Research Council, art professionals from the association Climate Art Project and local institutions. The project comes from the idea of merging contemporary art practices with Nature Based Solutions. In particular, the project seeks to put the focus on the environmental condition of the Aniene river and the riparian green spaces and on the possible solution of decontamination using phytomanagement. Through contemporary art installation, seminars, workshops and participatory practice, the project seeks to bring to a wide public the environmental issues related to the riparian urban area and the potentiality of NBS to improve the actual conditions. The aim is to raise the environmental awareness of citizens and to contribute to the public debate about the environmental and climatic crisis.

In the frame of the present work, art, science and social participation have also been linked together by the "River Contract" tool. The River Contract is an instrument based on an interdisciplinary and participatory approach, that is essential to effectively facing the complexity of a river system. It is defined by an agreement signed by citizens, local and regional authorities, industries and research institutions, leading to the development of a concerted path for the management of the river basin of reference. This kind of agreement, applied for the first time in France and then successfully replicated in different regions of Europe in accordance with the guidelines of the EU Water Framework Directive (2000/60/EC), has been the framework for the collaboration described in the present manuscript. Several actors in the province of Rome, joined forces to draft a common document (Contratto di Fiume Tevere, da Castel Giubileo alla foce) for a more efficient and participatory management of the final section of the Tiber basin.

The present manuscript describes the Remediation project, illustrating all the transdisciplinary actions carried out by some of the partners from the abovementioned river contract; the management of a natural protected area in proximity to the confluence between the Tiber and the Aniene has been the focus of the described work.

2. Materials and methods

The project focused on heavy metals as one of the most representative contaminants of urban areas. Two plant species have been chosen as "model plants" in order to illustrate to the community the basis of phytoremediation: *Pteris vittata* and *Cannabis sativa*. The first species is representative of the phytoaccumulation process, the ability of some plants to concentrate heavy metals in the aboveground biomass. *P. vittata* is known for its extremely high accumulation potential toward As and Cd (Yan *et al.* 2019). The second selected species, *C. sativa*, represents a different plant behavior toward toxic metals: it tends to accumulate them in roots, restricting their transfer to the stem and leaves (Citterio *et al.* 2003; Pietrini *et al.* 2019). This last species is suitable for phytostabilisation interventions, offering the opportunity to couple soil remediation with industrial crop cultivation, obtaining fibers, energy from biomass or oil from seeds.

The project addressed the Rome district "Municipio IV," located on the eastern part of the city, on the right side of the river Aniene, just before the confluence with the Tiber. The Aniene river is a tributary of the Tiber and is one of the most relevant vectors of pollution. This area falls within the territory of "Riserva Naturale dell'Aniene," a regional protected area within the city of Rome. The social commitment in this zone is very strong and 20 years ago, local citizen committees joined up to create an association called "Amici per l'Aniene" aimed at the preservation of the historical and environmental resources along the urban section of the Aniene river. This association, which is partner to the "Remediation" project, is still very active in the territory and manages, on behalf of the regional body, the dissemination activities in the protected area. Among its initiatives, in 2011, "Amici dell'Aniene" organized a system of Urban Gardens; this currently includes 100 cultivable plots, that are assigned to citizens, associations and cooperatives. Over the years, urban gardens have become a social gathering space, and a reference point for people living in a very dense urban area.

The Remediation Project comprises a theoretical part and a practical pilot study. It is possible to summarize the project development in five points strictly interconnected, as follows.

1) Performance

A performance directed by Andreco took place in the Cavea of the Auditorium of Rome, a multi-functional complex designed by Renzo Piano. Citizens and environmental activists from the local group "Extinction Rebellion Rome," joined the performance. It consisted of the realization of a big sand clock made by plant species used in phytoremediation. A circle made from people surrounded the plant installation forming a big circle (Figure 1). The sand clock in a circle is the symbol of Human Extinction. After the performance, the plants were used for the main installation of the exhibition.

2) Future Landscape Exhibition

The exhibition Future Landscape, curated by Sara Alberani, took place in Auditorium Arte, a space within the Auditorium complex, during April and May 2019. The exhibition's intention was to address critical points related to the landscape and to envision possible future scenarios. A further description of the exhibition is provided in Section 2.1.

3) Public Debate

In the same location of the exhibition a public debate took place with the curator and some of the scientific partners of the project. The event was introduced by lecturers who presented the preliminary results from the demonstrative pilot experiment (point n.5) and the ongoing artistic and scientific research.

4) Workshops

Two workshops, open to the public, where organized at the Natural Reserve of Aniene in collaboration with "Insieme per l'Aniene" association and the scientific partners of the project. During the first event, citizens were invited to approach the basic knowledge on NBS for pollution management and to attend the planting activity by researchers who planted *C. sativa* and *P. Vittata* plants in selected areas of the Reserve (first step of the demonstrative pilot experiment, point n.5). 30 people, mainly adults, took part in this workshop.

Figure 1. Andreco – XR Roma – performance – Cavea Auditorium, Rome.

A second workshop was organized especially for 20 children, aged between 6 to 12, in collaboration with “Contemporary Art Foundation Smart.” The workshop focused on the relationship between humans and the environment. The events included a theoretical session, held by Andreco, and a practical part carried out at the Natural Reserve of Aniene where children explored the experimental site and planted additional plants of *C. sativa* and *P. vittata* within the urban gardens.

5) Demonstrative Pilot Experiment

A field experiment on phytoremediation was carried out within the Natural Reserve of Aniene, along the edges of the river. This activity is described in Sections 2.2, 2.3 and 2.4. The sampling and planting steps were attended by local communities during the first project workshop (point n.4). The preliminary results of the experiment were presented and discussed during the public debate in the auditorium (point n.3).

2.1. Future landscape exhibition

The main room of the exhibition hosted a big installation with plants, *N. exaltata* (Boston Fern), *P. Vittata* and *C. Sativa,* chosen as species representing the phytoremediation action. The plants were disposed as trenches to symbolically represent an act of resistance against anthropic pollution and a tribute to the natural processes (NBS). A metal sculpture was integrated within the plant installation as a symbol of hearth geology (Figures 2 and 3). This installation was made by the artist Andreco following

Figure 2. Andreco – installation view – future landscape. Fondazione Musica per Roma. Photo: Musacchio Iannelli Pasqualini.

his artist practice "Nature as Art" where the chemical-physical-biological reaction of the natural elements, in this case the plants and the exchanges with the soil and the air, become the artwork itself. The installation was surrounded by sculptures, flags and some photography from the latest project related to art and environmental and social change. In fact, the flags were made for the project "Climate 05 Reclaiming Air and Water" in Delhi, India, an art and science project produced by the Start India Foundation and the Italian Institute of culture in New Delhi in collaboration with the Asian Paint and Air-Ink Organisations, on the basis of data from he IPCC (Intergovernmental Panel on Climate Change), NEERI (National environmental Engineer Institute) and CSE (Centre for Science and Environment). The artist realized a wall painting and directed a collective performance to address the environmental problems after Delhi was recognized as the most polluted city in the world because of fine dust and greenhouse gas emissions. Knives and leaves of Indian plants are represented on the flags. The idea of the artist behind this work is a reflection on the ability of the plants to contrast anthropogenic pollutants, mainly made by vehicles, small fires, heating systems, factories and construction sites. In fact, the artist considers the leaves as symbolic of nature's weapons. The video screened in a second room of the exhibition, showed the performance "Climate 05" in New Delhi (India) and the "Anthropocene Parade" at the Centro Pecci in Prato (Italy), strictly connected to the topic of the show and the artist's practice. The artist reflects on the relationship between humans and ecosystems and desires to underline the importance of ecosystem services, Nature Based Solutions and natural capital, are values to preserve and implement for a healthy and sustainable future (Figure 4).

Figure 3. Andreco – installation view – future landscape. Fondazione Musica per Roma, Photo: Musacchio Iannelli Pasqualini.

Figure 4. Andreco – workshop – Clima Futuro –smART, polo per l'Arte Riserva Valle dell'Aniene, 2019. Photo: Giorgia Rissone.

Figure 5. Satellite image of the Natural Reserve of Aniene. Soil samples were collected from different areas: urban garden (A), grazing field (B) and river banks (C and D).

2.2. Demonstrative pilot experiment: survey on the presence of heavy metals

A preliminary survey on the presence of heavy metals in the target area of the Aniene Natural Reserve was carried out during spring 2019. Three potentially contaminated environmental matrices were investigated: topsoil, water and biomass from cultivated plants.

The soil samples were collected from four different plots (20 cm depth) characterized by different soil management (Figure 5): urban garden (A), grazing field (B) and riverbanks (C and D). Two representative areas were identified for each plot and two samples were taken from each area. The samples were processed in duplicate. Below are the coordinates of the central point of each plot area.

Urban garden (A): 41°55'46.9"N, 12°33'17.2"E
Grazing field (B): 41°55'46.2"N, 12°33'05.5"E
River banks (C): 41°55'53.7"N, 12°32'47.9"E
River banks (D): 41°55'43.2"N, 12°33'14.6"E

A physic-chemical characterization was carried out on soil from plot A, where the pilot experiment took place. Soil samples were sieved (<2 mm) and oven dried (40 °C, 7–15 days). Active and exchangeable acidity were measured on sieved soil suspended in a solution of deionized water (active) or in 1 N KCl (exchangeable) in 1:2.5 ratio (w/v). The pH was measured in the supernatant with a pH meter (pH 211, Hanna Instruments). All analyses were performed on the original samples. The total organic carbon (TOC) was determined using a Shimadzu TOC VCSH analyzer. 1 g of soil was analyzed using the TC/IC method, where TOC is the result of the difference between total carbon and inorganic carbon. Cation exchange capacity (CEC) was determined after extraction with 10 percent BaCl2 solution pH 8.1, according to Gillman (1979). Results were expressed as $cmol^{+}\ kg^{-1}$ of soil. All the results about soil are presented on a dry mass basis.

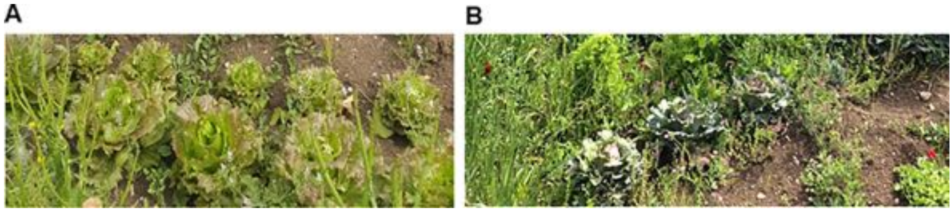

Figure 6. *Lactuca* (6A) and *Brassica* (6B) plants grown during six weeks in the urban garden (plot A). Photo: Patrizia Brunetti.

Water samples were collected from the river Aniene, in the proximity of plot C, and from the well used for urban garden irrigation. Three samples were collected from the river and well respectively. Samples were filtered and acidified to preserve most trace metals and reduce precipitation, microbial activity and absorption losses to container walls.

The concentration of metals and metalloids was measured in the water samples as described in Section 2.3. Each sample was processed in duplicate.

Leaf samples from *Lactuca sativa* and *Brassica oleracea* were taken from the urban garden plot in order to evaluate the presence of heavy metal(loid)s in the edible parts of the plants. The plants had been planted six weeks before sample collection. Plants were sampled in each area of plot A (Figure 6). A representative sample was taken from each plant, harvesting leaves homogeneously distributed within the plant. The sampled material was thoroughly washed under running deionized water, weighed and dried in an oven before the analysis. Each sample was processed in duplicate.

2.3. Demonstrative pilot experiment: experimental design

The demonstrative experiment on the phytoremediation potential of *P. vittata* and *C. sativa* was carried out in plot A, where the topsoil was found to be contaminated by heavy metal(loid)s following the preliminary survey. The experimental design was very basic to be easily accessible by local communities attending the project events. Six plants of *Pteris vittata* and six plants of *Cannabis sativa* (cv. Eletta Campana, Italian cultivar) were grown in plot A for six weeks (Figure 6A,B). A shade cloth was placed over the ferns in site A, where direct sunlight could be harmful for the plants (Figure 6C). After six weeks, plants were harvested collecting root and leaf samples. Representative samples were collected from each plant, sampling homogeneously leaves of different ages. Root and leaf samples were thoroughly washed under running deionized water, weighed and dried in an oven before the analysis. Each sample was processed in duplicate.

2.4. Demonstrative pilot experiment: heavy metal and metalloid quantification in soil, water and plant tissues

Total concentration of Zn, Cd, Cu, Cr, Ni, Pb, Co, As, V, Be, Hg was measured in water, in soil samples and in plant biomass.

For soil, 0.3 g of samples were placed in 100 ml PFA HP-500 Plus digestion vessels; 8 ml of concentrated HNO_3 and 2 ml di H_2O_2were added. Samples and reagents were mixed, sealed, and digested in a microwave oven, using a commercial highpressure laboratory microwave (Mars plus CEM, Italy) operating at an energy output of 1800 W. The heating program was performed in two steps: the temperature was increased from 25 to 165 °C in 10 min, it was held at 165 °C for 2 min, then it was increased from 165 °C to 180 °C in 6 min, and held at 180 °C for 10 min.

For plant tissues, all root and plant samples were chopped into small pieces, washed with water and then dried at 65 °C for 72 h. Approximately 300 mg of each vegetable dry sample was inserted directly into a microwave-closed vessel. Two milliliters of 30% (m/m) H_2O_2, 0.5 ml of 37% HCl and 7.5 ml of HNO_3 69% solution were added to each vessel. The heating program was performed in one step: temperature was increased linearly from 25 to 180 °C in 37 min; at the end, the temperature was held at 180 °C for 15 min.

After the digestion procedure and subsequent cooling, the samples were transferred into a Teflon beaker and the total volume was made up to 25 mL with Milli-Q water. The digest solution was then filtered (DISMIC 25HP PTFE syringe filter (pore size = 0.45 mm, Toyo Roshi Kaisha, Ltd., Japan) and stored in a screw cap plastic tube. Blanks were prepared in each lot of samples. The reagents of super-pure grade, used for the microwave-assisted digestion, were hydrochloric acid (36% HCl), nitric acid (69% HNO_3) and hydrogen peroxide (30% H_2O_2) (Merck, Darmstadt, Germany). High-purity water (18 $M\Omega\,cm^{-1}$) from a Milli-Q water purification system (Millipore, Bedford, USA) was used for the dilution of the standards, for preparing samples throughout the chemical process, and for final rinsing of the acid-cleaned vessels, glasses, and plastic utensils.

The accuracy of the measurements was assessed using standard reference material trace metals (SRM 1573a; (CRM034). Determination of total elements in soil samples, plant biomass and water were carried out using the ICP-OES technique (Perkin-Elmer 8000 DV, Perkin-Elmer Corp., Norwalk, CT, USA) equipped with a Scott nebulizer system for soil and with an ultrasonic nebulizer (Perkine Elmer) for plant tissues and water samples.

In all analytical determinations, blanks and duplicate samples were used, each sample was given spectrophotometric readings in duplicate.

3. Results and discussion

3.1. Soil and water analysis

As shown in Table 1, a higher concentration of all tested elements was found in the urban garden (A) compared to the other plots. Notably Cd significantly exceeds the Italian legal limits for green areas in all sampled plots. In addition, Hg content is high in all sites and slightly exceeds the permitted limit only in plot D, while Be exceeds the permitted limit only in plot A.

In order to establish whether the presence of heavy metals is related to irrigation practices or flooding, we analyzed Zn, Cd, Cu, Cr, Ni, Pb, Co, As, V, Be and Hg content in the water from the well used for irrigation and in the water from the river. As shown in Table 2, in water from the well, Cd content was just near, while Hg resulted 15 times above, the reference limits (according to WHO/FAO 2007, Lenntech.NL). Notably, in water samples from the river, the content of all the following metals was above the Italian limits. (D.Lgs. 152/2006, Annex 2 – Sect. B, Tab. 1/B): Cd, 43 fold; Cu 14 fold; Pb 5 fold; Hg 78 fold; Ni 1,4 fold; Cr, 2 fold.

Table 1. Heavy metal concentration in soil (mg/Kg).

Heavy metal(loid)s	Urban Garden A	Grazing fields B	River banks C,D		Italian limits*
Zn	102.69 ± 5.23	46.99 ± 2.17	41.37 ± 1.54	57.67 ± 0.72	150.00
Cu	69.79 ± 4.06	25.61 ± 2.61	23.57 ± 1.56	27.03 ± 0.30	120.00
Cr	16.02 ± 0.92	12.95 ± 1.41	7.79 ± 0.38	8.90 ± 0.12	150.00
Ni	13.68 ± 0.78	11.65 ± 1.28	6.26 ± 0.29	7.89 ± 0.06	120.00
Pb	55.32 ± 2.58	19.91 ± 2.53	19.84 ± 1.85	26.21 ± 0.91	100.00
Co	6.78 ± 0.42	5.46 ± 0.56	3.45 ± 0.14	4.75 ± 0.2	20.00
As	8.67 ± 0.43	6.79 ± 0.74	7.46 ± 0.46	7.74 ± 0.19	20.00
V	40.33 ± 1.97	28.45 ± 3.08	19.41 ± 0.80	24.64 ± 0.41	90.00
Cd	**15.39 ± 1.00**	**10.92 ± 1.25**	**6.86 ± 2.11**	**7.49 ± 0.12**	2.00
Hg	0.83 ± 0.04	0.41 ± 0.05	0.77 ± 0.07	**1.00 ± 0.03**	1.00
Be	**2.55 ± 0.14**	1.39 ± 0.15	0.93 ± 0.06	0.95 ± 0.01	2.00

Note: The reported data represent the average value and the Standard Error ($N = 8$). Values exceeding Italian limits are highlighted in bold
*D.Lgs. 152/2006, limits for green areas.

Table 2. Heavy metal concentration in water (μg/L).

Heavy metal(loid)s	Water river	Italian limits*	Water wells	WHO/FAO 2007 Lenntech.NL
Zn	<D.L.	300–400	<D.L.	/
Cu	**579.5 ± 4.35**	40	33.06 ± 0.1	/
Cr	**207.00 ± 1.08**	20–100	13.25 ± 0.03	/
Ni	**106.75 ± 1.49**	**75**	<D.L.	10-20
Pb	**255.25 ± 2.75**	10–50	8.17 ± 0.03	/
Co	107.35 ± 4.17	/	16.16 ± 0.05	/
As	42.00 ± 2.12	50	14.03 ± 0.05	/
V	95.75 ± 5.36	/	41.19 ± 0.1	/
Cd	**107.50 ± 4.17**	0.2–2.5	**10.19 ± 0.05**	10
Hg	**39.50 ± 0.65**	0.5	**15.13 ± 0.14**	1
Be	48.00 ± 1.08	**/**	<D.L.	/

Note: The reported data represent the average value and the Standard Error ($N = 4$). Values exceeding Italian limits are highlighted in bold
*D.Lgs. 152/2006, All. 2 – Sez. B, Tabella 1/B.

As a whole, these data indicate contamination mainly by Cd in all plots, and a higher content of all metals in urban garden plots. The Hg concentration was slightly below the legal limit in the urban garden and significantly above the limit in the river-bank plot D. Both Cd and Hg contamination are possibly related to the high concentration of these metals in the river water and in the water used for irrigation.

As reported in Table 3, the analyses of physic-chemical parameters on plot A (Urban Garden) revealed a clay-loam soil, slightly alkaline and poor in Nitrogen, with a medium-high content of organic matter.

3.2. Heavy metal uptake by edible plant and by phytoremediation model plants

In order to establish whether the plants cultivated in the urban garden accumulated toxic concentrations of metals in the edible parts, we analyzed metal(loid) content in leaves of *Lactuca* and *Brassica* plants. As shown in Table 4, the Cd content, as well

Table 3. Physico-chemical characterization of soil from plot A.

Texture	Clay loam
Conducibility μS $(cm)^{-1}$	1212.5 ± 62.5
pH H_2O	7.65 ± 0.05
pH KCl	6.9 ± 0
CEC meq $(100g)^{-1}$	25.9 ± 3.9
Total carbonate%	8 ± 0.01
TOC %	2.461 ± 0.23
Organic matter%	4.2 ± 0.4
Total N%	0.243 ± 0.011
C/N	10.1 ± 0.5
P available μg $(g)^{-1}$	14.95 ± 0.9

Note: The reported data represent the average value and the Standard Error (*N* = 2). TOC: total organic carbon. CEC: cation exchange capacity.

Table 4. Heavy metals content in edible plants (mg/Kg FW).

Heavy metal(oid)s	*Brassica*	*Lactuca*	Italian limits
Zn	0.12 ± 1.13E-02	0.12 ± 4.67E-03	
Cd	0.03 ± 2.40E-04	0.02 ± 3.38E-06	0.2 (Reg CE 1881/2006)
Cu	0.54 ± 6.83E-03	0.9 ± 1.51E-02	
Cr	<D.L.	<D.L.	
Ni	0.0 ± 1.47E-03	<D.L.	
Pb	0.02 ± 1.53E-03	0.03 ± 4.39E-04	
Co	0.03 ± 1.20E-04	0.03 ± 4.51E-06	
As	0.04 ± 9.41E-04	0.03 ± 1.63E-03	
V	0.02 ± 6.14E-04	0.02 ± 7.86E-04	
Be	<D.L.	<D.L.	
Hg	D.L.	D.L.	0.01 (Reg. (UE) 2018/73)

Note: The reported data represent the average value and Standard Error (*N* = 4).

as that of other heavy metals, was within the limits (Reg UE 1881/2006) suggesting that Cd is not efficiently translocated from the roots to the edible leaves of these plants. In addition, as expected, Cd level was higher in *Brassica* than in *Lactuca* leaves due to the higher heavy metal accumulating capacity of plants belonging to the *Brassicaceae* family (Broadley *et al*. 2001). Interestingly, Hg content, although found in relevant concentrations in soil, was not detected in the plant tissues.

In order to test the behavior of different plant species toward heavy metal(loid)s, *P. vittata* and *C. sativa* biomass was analyzed after the experimental trial in plot A (urban garden). Data on Cd, As and Hg concentrations in roots and leaves are shown in Figures 7 and 8; the concentration of the other tested metal(loid)s was under the instrument detection limit.

Both species accumulated a comparable amount of Cd. Cd content in *Pteris* was significantly higher in roots, while As was mainly translocated to the frond (Figure 7). In contrast, both Cd and As in *Cannabis* were similarly accumulated in roots and leaves (Figure 8). Hg concentration was similar in aboveground parts and in roots of *Pteris* plants, while, in *Cannabis,* Hg was present mainly in aboveground tissues (Figures 7 and 8).

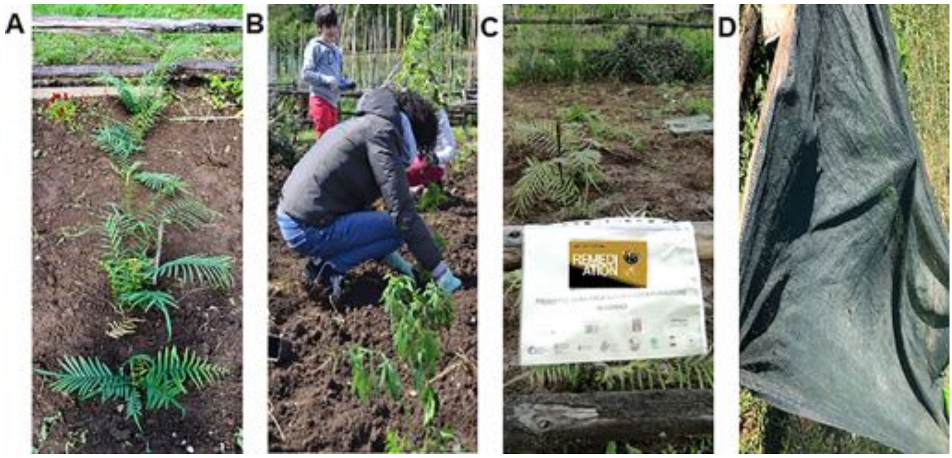

Figure 7. *Pteris* and *Cannabis* plants grown in urban garden soil (A–C). Shade cloth placed over the ferns (D). Photo: Patrizia Brunetti and Laura Passatore.

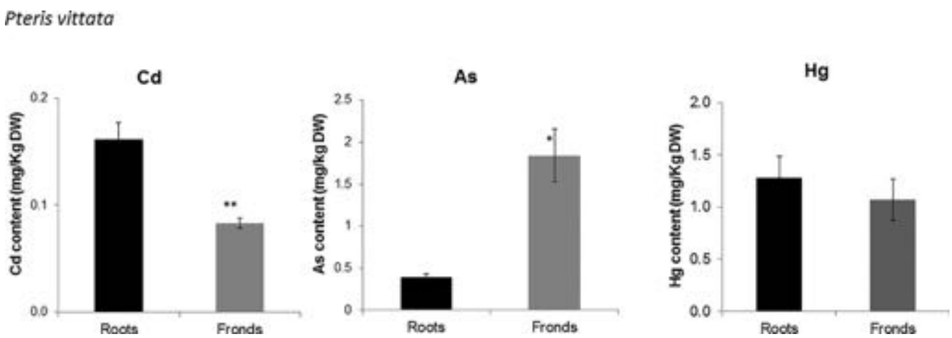

Figure 8. Cd, As and Hg concentration in root and frond biomass of Pterisvittata plants grown during 9 weeks on urban garden soil (plot A). The reported data represent the average values and standard error. Significant differences are indicated with asterisks (*$p < 0.05$; **$p < 0.001$, $N = 6$), as determined by two-tailed unpaired Student's test.

These data suggest that both *Pteris* and *Cannabis* are able to extract Cd and Hg from the soil, translocating these metals to the aerial parts with different efficiency. More data are required to confirm the distribution of Cd and Hg in these plants; the present study was mainly focused on showing to the local community the potentiality of phytoremediation techniques and the simplified procedures of a phytomanagement project (Figure 9).

3.3. *Art as a tool to raise public awareness about nature-based solutions*

Citizens participated in the project thanks to the involvement of local associations and the echo of the project on the media. Art magazine, newspapers and national television spread information about the project events.

The garden owners of the Natural Reserve of Aniene were also involved in the project activities. Considering that we are facing a widespread "phenomenon" of Urban Gardening, it is important to raise awareness on the possible risks of urban

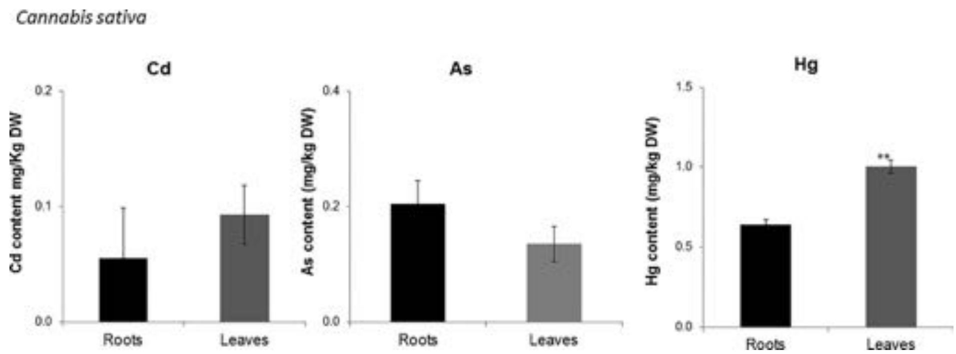

Figure 9. Cd, As and Hg concentration in root and leaf biomass of Cannabis sativa plants grown during 9 weeks on urban garden soil (plot A). The reported data represent the average values and standard error. Significant differences are indicated with asterisks (*$p < 0.05$; **$p < 0.001$, $N = 6$), as determined by two-tailed unpaired Student's test.

agriculture, spreading the best practices about it (Calvet-Mir *et al*. 2016; He and Zhu 2018). Environmental activists from the "Fridays for Future" and "Extinction Rebellion" movement were also involved in the project with the aim of putting scientists, artists, activists and citizens in contact with each other.

The people attending the workshops and the debates were informed about the environmental conditions of the studied area, the NBS and the best practices to improve the current environmental quality. The artistic and scientific approach of the project was also illustrated to the participants. The public exchanged doubts and opinions with the experts. More than 2,500 people visited the Future Landscape Exposition during March and April 2019.

The exhibition visitors, at the first approach, showed curiosity, looking at the plant installation, then, after reading the related information, interest and empathy with the project. Some of the visitors asked questions and wanted to know more about the project. Some people decided to join the workshop at the Natural Reserve of Aniene.

Art involved the perception and the emotions of the public, touching the deepest cord of the soul and interacting in a personal way with the public. The reaction of the exhibition visitors demonstrated that Contemporary Art is a language, different from the scientific and political language, less direct, more abstract but able to touch people's sensibility. An artwork does not inform, does not give numbers or solutions, but highlights question marks about a contemporary urgency. As the environmental crisis and the climate crisis are urgencies for contemporary society, an art piece about these issues can give to the collectivity a new key for reflection, a new point of view for thinking about them.

4. Conclusions

The present study attempted to investigate, with the involvement of citizens, the complex interconnections between different environmental matrices within an urban riparian ecosystem. Preliminary analysis of topsoil in the study area revealed slight contamination by Cd and Hg, probably due to water pollution. Our data suggest that the water used for irrigation in the urban garden contributed to Cd contamination, even if we cannot exclude the use of Cd-containing pesticides. The Hg contamination of riverbanks is probably related to the pollution of the river. Notably, the leaves of the tested edible plants in the polluted urban garden do not contain toxic amounts of heavy metals, while a more extensive analysis would be necessary to exclude the risk of heavy metal-contamination in cultivated plants. The demonstrative pilot experiment with *Pteris* and *Cannabis* highlighted the different behavior of the two species toward the presence of metal(loid)s in the soil. All the results about soil, water and biomass contamination have been shared with local communities in an effective way, involving a huge number of citizens.

This interdisciplinary study contributed to strengthen social awareness about the direct interconnection between soil, water and plants within an ecosystem: the survey on heavy metal distribution highlighted the risk of pollution migration; the demonstrative pilot experiment and the related meetings informed citizens about sustainable solutions for the management of their own territory; visual art raised curiosity and contributed to spreading scientific concepts, making them readily understandable. Art can contribute in raising critical thinking, a fundamental factor for a healthy, sustainable and democratic environment.

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Author contributions

A.C. conceived and coordinated the project "Remediation," created and organized the performance and the installations at Auditorium Complex; L.P. supervised and performed the experimental work on plant growth and coordinated the manuscript redaction and submission; S.R. and E.A. organized the soil sampling procedures and carried out chemical analysis; M.C. and P.B. coordinated and realized the pilot experiment on phytoremediation and performed the data elaboration; all authors wrote the paper as regards their part.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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