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Keywords: dredged sediment; waste soil; geopolymer; leaching

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Dear Editor,
thank you for your message with comments of the reviewers on the above paper.
Here are our responses on the observations, made by the reviewers. The related changes in the text are indicated by the red colour.
Looking forward to hearing from you about acceptance, I thank you very much and send you my best regards,
Barbara Liguori

*Response to Reviewers

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Revision notes
(i) The potential viability of the industrial flyash "as composite" towards changing leaching behaviour & its environmental compliance should be included in the text and in the research highlights.

According to the above suggestion, the following part was added in the manuscript:
"As reported in the current literature, the use of geopolymer technology in waste management represents a promising practice. In particular, fly-ash based geopolymer resulted an efficient matrix for the immobilization of contaminants (Van Jaarsveld et al.,1999). Moreover, the low permeability, resistance to acid attack and inherent durability of the geopolymeric binder makes it an ideal solution in both landfill-based and non-landfill-based immobilization methods. In the present paper, the fly ash was employed to produce a geopolymer-based building materials."

The research highlights was updated with the following point:

- *The fly ash was employed to produce a geopolymer-based building material.*

(ii) A summary of findings on the specific chemical constituent (of the flyash) that increases the leaching rate under worst scenario of sediment ecosystem is to be included.

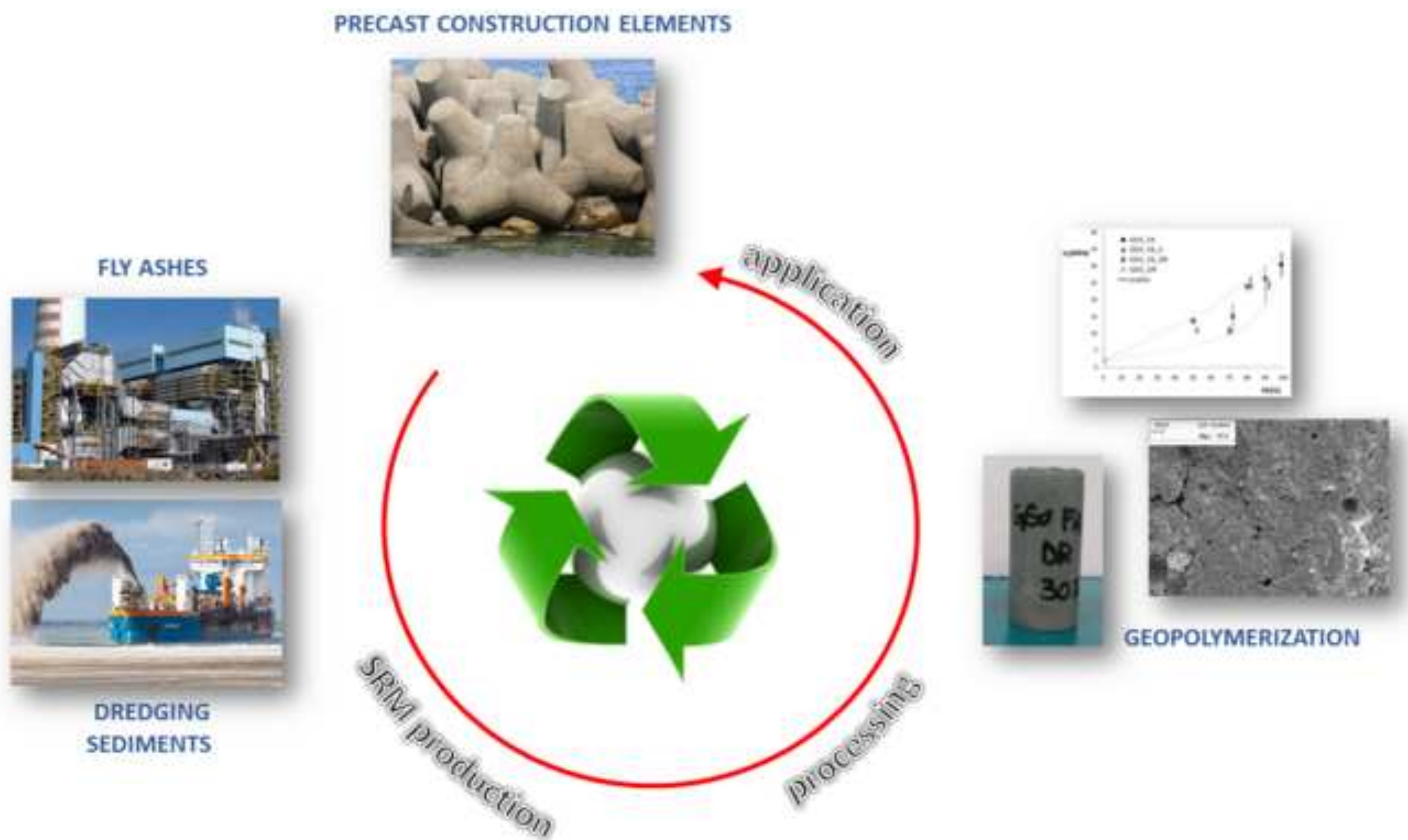
Inspecting literature data (Van Jaarsveld et al. 1999, Izquierdo et al.,2009, 2010), fly ash based geopolymers inhibit the metal mobility either in alkaline or acid conditions. A large number of pollutants can be retained within this kind of geopolymeric structure or remain physically encapsulated in it. Accordingly, the increase of the leaching rate, even in the worst scenario, can be excluded.

(iii) A comparative summary of leaching compliance and standards available under European Directives and US EPA current formulations & enforcements applicable to composites on sediment ecosystem.

Following the above suggestion, the text was changed as follows:

"Each country has developed individual guidelines, mainly based on a chemical approach, for characterizing dredged material referring to different regulatory agencies (e.g. US EPA and European agencies) (Del Valls et al., 2004). In particular, US EPA recommend the toxicity characteristic leaching procedure (TCLP, US EPA Method 1311, 1992) used to evaluate the potential environmental impact in terms of leachability of heavy metals from the contaminated sediment, waste materials, and sediment blocks. The European Commission, as reported in the Directive 1999/31/EC for the landfill of waste, recommends leaching test for granular materials, in order to verify the compliance of the waste destined for landfill."

Graphical Abstracts



Highlights

- The management of dredged sediments is an environmental problem for many countries.
- Geopolymers were prepared by mixing harbour's sediments and industrial fly ashes.
- The fly ash was employed to produce a geopolymer-based building material.
- The stress-strain behaviour is typical of an artificially structured soil.
- Leaching compliance test classify the geocomposite as a non-dangerous material.

MECHANICAL AND CHEMICAL PROPERTIES OF COMPOSITE MATERIALS MADE OF DREDGED SEDIMENTS IN A FLY-ASH BASED GEOPOLYMER

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ABSTRACT: Dredging activity in harbours and channels produces huge quantities of sediments, generally considered as waste soil (WS) to be disposed: the management of such sediments is a great environmental problem for many countries worldwide. Among the recycling possibilities, the use of dredged sediments for the manufacture of geopolymer-based materials seems to be an interesting alternative to disposal, due to their low cost and easy availability. In order to analyse the possibility to use these geopolymer materials as building materials, – for instance as precast construction elements in maritime projects - a multi-disciplinary research activity has been developed at the Federico II University of Napoli (Italy). Some experimental tests have been carried out on different geopolymeric specimens made by mixing sediments from Napoli 'harbour and industrial fly ashes produced by a power plant in the South of Italy. A siliceous sand was used for comparison as an inert reference material. Chemical, morphological and mechanical properties of different specimens have been studied by X-ray diffraction, Scanning Electron Microscopy (SEM), Fourier transformed infrared spectroscopy (FTIR) and finally unconfined compression tests. The experimental results highlight that the use of dredged sediments in combination with fly ash can lead to geopolymeric matrices with interesting mechanical performances. Some differences in the microstructure of the geocomposite built with the siliceous sand or the dredged materials were found. In terms of environmental impacts, on the basis of standard leaching tests and according to Italian thresholds, the adopted dredged mixtures satisfy the prescribed limit for inert or non hazardous waste.

Keywords: dredged sediment; waste soil; geopolymer; leaching

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1. INTRODUCTION

The management of huge amount of sediments coming from dredged activities in harbours or channels is an important issue to be solved in many countries worldwide (Bates et al., 2015; Onorati et al., 2013). To maintain the navigability of the waterways, each year several 100 millions of tons of sediments are dredged around the world. Dredged material is a slurry composed by solid grains (from fine to coarse) and a large amount of water (whose chemical characteristics depend on the dredging environment).

For many years, dredged sediments were considered waste materials and, consequently, they were mainly landfilled as a slurry. Because of the shortage of disposal capacity, nowadays in many countries, a reuse strategy (Fig.1) has been adopted and dredged materials are increasingly seen as a resource (Apitz, 2010). Despite of in the last decades many approaches and methodologies for their beneficial reuse are being developed throughout the world (Collins, 1980; Hamer and Karius, 2002, Bianchi et al., 2019; Akcil et al., 2015), a low amount of dredged sediments is currently recycled and reused (Fig. 1).

The chemical and mechanical properties of the dredged soils, as well as the types of contaminants, rule the beneficial reuse of these materials in upland, wetland or aquatic environments.

The typical treatment processes for dredged sediments, for either reuse or disposal, are:

- dewatering (natural or mechanical);
- particle separation (sorting and washing);
- contaminant removal (thermal, chemical, and biological treatments);
- contaminant immobilization (chemical oxidation, stabilization and thermal immobilization).

Clean dredged materials can be used for construction fill (highway, road, airport), for manufactured products (additives in brick or asphalt manufacturing), topsoil (landscaping/agricultural soil), marine projects (filling in-water mining sites; construction of artificial islands, beach nourishment, coastal defence structures).

One possible application for the recycled dredged materials is as raw material for manufacturing building materials such as bricks (Hamer and Karius, 2002; Zhang, 2013; Wang et al., 2013), compressed blocks, lightweight aggregate or cement filler: in these technologies, dredged material is used as a replacement of common standard raw materials. Another attractive field of application of the dredged sediments is their use in the manufacture of geopolymer-based materials.

It is well known that geopolymer based materials have a wide range of applications in the civil engineering market (Duxson et al., 2007). Great attention has been given to their use because geopolymers have very low porosity, excellent mechanical properties, durability and thermal stability. Furthermore, and most interestingly from an environmental point of view, geopolymers can provide significant reduction in energy requirement for their manufacture and, consequently, reducing emissions by 80% compared to Portland cement (Davidovits, 1993a).

Geopolymers are hydraulic binders produced starting from the activation in an alkaline environment (silicate solution and sodium and / or potassium hydroxide) of natural or synthetic silico-aluminate powders, often resulting from industrial waste (Davidovits, 1991; Cioffi et al., 2003; Ferone et al., 2011). The prefix "geo" symbolizes the constitutive relationship of the binders to geological materials, natural stone and/or minerals. In contact with a high pH alkaline solution, the starting materials dissolve, and geopolymer polycondensation takes place. Because of this reason, geopolymers are also considered as inorganic polymers based on aluminosilicates (Davidovits, 1993b).

The use of secondary resources such as fly ashes, slags and reservoir sediments as aluminosilicate source material to form geopolymers has been widely proven (Buchwald, 2006; Duxson et al., 2007; Palomo et al., 1999; Ferone et al., 2013, 2015). As reported in the current literature, the use of geopolymer technology in waste management represents a promising practice. In particular, fly-ash based geopolymer resulted an efficient matrix for the immobilization of contaminants (Van Jaarsveld et al.,1999; Izquierdo et al.,2009, 2010). Moreover, the low permeability, resistance to acid attack and inherent durability of the geopolymeric binder makes it an ideal solution in both landfill-based and non-landfill-based immobilization methods. In the present paper, the fly ash was employed to produce a geopolymer-based building materials. In the framework of the activities of the European Commitment on raw materials ROSE (www.rosecommitment.eu), which includes 35 partners coming from both the research world and the industry world, recently at the Federico II University of Napoli (Italy) a multidisciplinary research activity is going on to get an insight on the possible reuse of dredged sediments in manufacturing geopolymers.

The aim of the research is to propose dredged sediments in combination with fly ashes in the production of geopolymer-based building materials. A siliceous sand was used in the same condition for comparison as an inert reference material. For such a reason, an experimental programme has been developed in order to identify the amount of fly ashes and dredged sediments that can optimize the building of the geopolymeric structure.

In the paper the physical, chemical and mineralogical properties of all the adopted materials (dredged sediments, fly ashes and silica sand) are first analysed; then, a chemical, morphological and mechanical characterization of the treated specimens is carried out in order to quantify the positive effect of geopolymerization. Moreover, the environmental impact of the designed geopolymers is investigated by performing standard leaching tests.

2. MATERIALS

2.1 Dredged sediments

2.1.1 Physical characterization

Same samples of dredged marine sediments have been taken from the bottom of the harbour of Napoli (South of Italy), and used in the experimental programme. The marine sediment can be classified as a sandy and gravelly silt (Fig. 2) and have a specific gravity G_s equal to 2.62.

Even though the fine content is rather large (about 43% by weight passing at ASTM sieve #200), the material shows no plastic activity. Therefore, according to the Unified Soil Classification System (ASTM D2487), the dredged sediments can be classified as a coarse grained soil, sand SM.

2.1.2 Chemical and mineralogical characterization

The chemical composition of the dredged sediments (DR) was obtained, according to the following procedure. Each sample was first calcined at 550°C for two hour, then a weighted amount of the dry samples was subjected to digestion, under microwave-induced heating (Perkin-ElmerMultiwave 3000 oven) in a standard solution prepared by mixing 1 ml of HCl (37%, w/w), 1 ml of HNO_3 (65%, w/w) and 4 ml of HF (39.5%, w/w). After addition of 24 ml of a 8M H_3BO_3 solution to attain fluoride complexation, the resulting solution was analyzed by ICP atomic emission spectroscopy (ICP-OES, Perkin-Elmer Optima 2100 DV). The chemical composition of the sediments is presented in Table 1. The mineralogical composition of the sediments was obtained performing XRD diffractometry (PANalytical X'Pert Pro). The XRD spectrum, reported in Figure 3(a), showed a large number of reflection phenomena, which suggests the presence of numerous crystalline phases. The main phases present are analcime, calcite, quartz, halite with presence of clay phases.

2.2 Siliceous sand

2.2.1 Physical and mineralogical characterization

A siliceous sand (S) was used for comparison as an inert reference material. In particular, some fly ash based geo-composites have been prepared with a siliceous sand instead of the dredged sediment. The adopted sand has a specific gravity Gs equal to 2.74: its grain size distribution is plotted in Fig. 2. According to the Unified Soil Classification System (ASTM D2487), the siliceous sand can be classified as a poorly graded sand with silt. The XRD spectrum of the sand (Figure 3(b)) confirmed its siliceous nature. In fact, the main crystalline phases present are quartz and albite with presence of clay phases and calcite.

2.3 Fly ashes

2.3.1 Physical, chemical and mineralogical characterization

Fly ashes (FA) supplied by ENEL (Brindisi, Italy) have been used as raw materials to produce the geopolymer based specimens. The chemical composition is reported in Table 1. They can be classified as Class F fly ashes (ASTM C618-12a). The grain size distribution is reported in Figure 2, along with that of the other granular materials used in the preparation of the specimens.

The XRD spectrum of the fly ashes (Figure 3(c)) confirmed the amorphous nature of the sample, having quartz and mullite as main crystalline phases.

3. EXPERIMENTAL ACTIVITY ON GEOPOLYMER BASED COMPOSITIES

3.1 Specimens preparation and experimental programme

The fly ashes based geopolymers have been prepared mixing fly ashes (FA) and dredged sediments (DR) or siliceous sand (S): the goal of the experimental programme is to investigate the role of each component in the chemical and mechanical behaviour of the final geocomposite. The specimens named GEO_FA have been chosen as a reference mixture: in this case, the geopolymer made only of FA (DR = 0, S=0) is expected to show the best mechanical properties.

All the geopolymer specimens have been prepared as follows: powdered materials were previously dry mixed and homogenized, and then the alkaline solution was added to the dry mixture. The alkaline activator solution has been prepared mixing a sodium silicate solution (SS) (Na_2O 8.15%, SiO_2 27.40%) provided by Prochin Italia S.r.L. (Caserta, Italy) with 10 M sodium hydroxide solution (N) prepared starting from NaOH in pellets (NaOH 98%, J.T. Baker) and bi-distilled water. The weight ratio SS/N/binder was 1: 1: 3 for all the geopolymer specimens. The binder was composed by mixture of FA and DR (or S) with a percentage of FA ranging between 0 to 100% of the total binder. The activator/binder ratio (0.66) was kept constant for all the mixtures.

Finally, three samples were prepared for each mixture. The mixtures were placed in cylindrical polyethylene molds (diameter 30 mm; height 70 mm, see Figure 4), and cured for 3 days at 60 °C in an oven, in sealed vessels in order to ensure 100% relative humidity conditions. At the end of the curing, all the specimens were removed from the molds and stored at room temperature.

3.2 Experimental results

3.2.1. Uniaxial compression tests

The mechanical behaviour of all the cylindrical specimens (whose average diameter and height are respectively: d=28 mm and h=60 mm) has been analysed by means of uniaxial compression tests, in which the specimens are loaded along their axis of symmetry at zero confining stress.

Due to the lack in standard specification for geopolymer paste or mortars, the mechanical characterization was carried out following the prescription for cement materials. The tests were carried out after a curing time of 28 days.

In Figure 5, the results pertaining to the two extremes (only fly ash, no fly ash) are plotted in terms of uniaxial strength (σ_f) versus axial strain (ε), in order to present some features of the mechanical behaviour of the different materials. As expected and known in literature (Temuujin et al., 2010), the GEO_FA uniaxial strength σ_f ranges between 25-33 MPa (Fig. 5.a), with an average Young's modulus before failure in the range 1400 MPa<E_{50}<4600 MPa, calculated at 50% of σ_f. The scatter in Young's modulus may be attributed to sub-experimental errors (one for all: possible lack of parallelism between the top and bottom of the specimens) whose relevance is amplified for stiff materials as the GEO_FA are. The scatter of strength may also be linked to the very brittle behaviour of the specimens, which – even though the tests were obviously carried out at a strain controlled rate - literally exploded upon failure. In Figure 5.b, the much lower geopolymerization effect of GEO_DR is observed: the specimens have a more ductile behaviour, with a much lower scatter in both uniaxial strength (1.2 MPa<σ_f<2.2 MPa), and Young's modulus (250 MPa<E_{50}<690 MPa, calculated at 50% of σ_f).

Also for the GEO_FA_DR and GEO_FA_S specimens, the stress-strain behaviour is typical of artificially structured soils (Lirer et al. 2006, 2011 and 2012): the uniaxial strength is attained at medium axial strain levels (ε<2%), and a brittle behaviour is systematically observed. In each category (GEO_FA_DR and GEO_FA_S), the uniaxial strength σ_f decreases as the content in fly ashes decreases (Table 2). The reason why is that when an amount of fly ashes is replaced with an equivalent amount by weight of sand or dredged sediment, the structure of the final geo-composite becomes weaker.

While the influence of fly ash content is extremely relevant, the use of sand or dredged material does not play a significant role: the uniaxial strength at a given fly ash content is roughly the same (Table 2). As far as the Young's modulus is concerned, on the contrary, it seems that – at least for the higher contents in inert component (either sand or dredged material) – the GEO_FA_DR specimens are stiffer (Table 2). This seems to indicate that when the content in sand or dredged material is low (10%), the overall structure and therefore the mechanical behaviour of the composite material is ruled by fly ash, and therefore no difference is found between GEO_FA_DR_10 and GEO_FA_S_10. Some considerations on the microstructure of the specimens will be presented in § 3.2.3, which are consistent with these mechanical evidences.

A synthesis of the overall results in terms of σ_f is shown in Figure 6, in terms of average values and scatter ranges. Since it seems that a very clear relationship exists between fly ash content and σ_f, in the figure two close bounding curves (upper and lower limits) are reported as well.

3.2.2. Chemical characterization of the geopolymers

FTIR was used to verify the degree of geopolymerization of the geocomposites (Fernandez-Jimenez and Palomo, 2006; Rees et al., 2007). Geocomposites produced starting from aluminosilicate powders are amorphous aluminosilicates themselves, so that they show FTIR spectra characterized by the typical absorption bands of Si-O-Si and Si-O-Al bonds (absorption range 600-800 cm^{-1}). The band at 3450 cm^{-1} is correlated to the "chemically bonded water" and it can provide information about the degree of geopolymerization (Verdolotti et al., 2008).

All the FTIR spectra (see Fig. 7), with the exception of dredged sediments, showed significant broad bands at approximately 3450 cm^{-1} and 1647 cm^{-1} associated with the O-H stretching and bending, respectively. These bands are connected to the bound water molecules which are surface absorbed or entrapped in the large cavities of the molecular structure (Fernandez-Jimenez and Palomo, 2005; Swanepoel and Strydom, 2002). The intensity of these bands was greater in FTIR spectra of geopolymers, indicating both a higher degree of water molecules adsorption in their mass and the occurrence of a geopolymerization reaction of the raw materials into geopolymer pastes (Verdolotti et al., 2008).

In the spectrum of GEO_DR, the presence of the peak at 875 cm^{-1}, already visible in the spectrum of dry dredged sediments (DR), confirms that calcite is also present in geopolymeric sample (Shahraki et al., 2011). Moreover, the peak at 1454cm^{-1} represents the sodium carbonate resulting from the atmospheric carbonation of the unreacted sodium silicate and/or sodium hydroxide. This peak is more evident for GEO_DR as a consequence of a reactivity of dredged sediments lower than that of fly ashes.

3.2.3 Morphological characterization

Further information about the degree of geopolymerization can lead from the microstructure of each geopolymer, by means of scanning electron microscopy (SEM, Cambridge S440) (Fig. 8). The substitution of fly ashes, either with dredged sediments or natural sand, gives rise to a less compact structure of the final product. Even if the activator/binder ratio was kept constant in all the mixture, the different reactivity of each binder component (FA, DR or S) influenced the microstructure of the final geocomposite, as reported in the following morphological characterization. So, more is the FA content (the more reactive component) higher is cohesion of the sample. In fact, the lack of fly ashes in the system causes an incomplete geopolymerization, due to the lower reactivity of the dredged sediments and/or silica sand, as also confirmed by the uniaxial test results commented in § 3.2.1. From a mechanical point of view, at a given fly ash content, sand and dredged sediments showed very similar behaviour, whereas the influence of fly ash content is extremely relevant. Nevertheless, Fig. 8 indicates that the GEO_DR_50 specimen has a more compact structure than the GEO_S_50 one: the latter has a much more porous microstructure with a large number of interconnected pores and cracks.

Again, this is consistent with the experimental findings reported in § 3.2.1, showing a higher Young's modulus of GEO_FA_DR specimens. This difference may depend on either the mineralogical composition of the substitutions (sediment or sand) (Xu and van Deventer, 2000) or their particle size distribution (see Fig. 2).

3.2.3. Leaching behavior

Each country has developed specific guidelines, mainly based on a chemical approach, for characterizing dredged material referring to different regulatory agencies (e.g. US EPA and European agencies) (Del Valls et al., 2004). In particular, US EPA recommend the toxicity characteristic leaching procedure (TCLP, US EPA Method 1311, 1992) used to evaluate the potential environmental impact in terms of leachability of heavy metals from the contaminated sediment, waste materials, and sediment blocks. The European Commission, as reported in the Directive 1999/31/EC for the landfill of waste, recommends leaching test for granular materials, in order to verify the compliance of the waste destined for landfill.

In order to characterize the environmental impacts of the geocomposites obtained with dredged sediments, European standard leaching tests were performed. Leaching tests on original sediment and geocomposites, previously ground to a fineness <4 mm, were performed according to the International Standards recommendations leaching test for granular materials aimed at compliance testing of waste destined for landfill (UNI EN 12457-2).

Accordingly, a 5 g amount of dry weight was placed into 50 ml flasks; water was then added to obtain liquid to solid ratio (L/S) of 10 l/kg. The mixture was stirred at 10 rpm for 24 h at room temperature. After filtration, the concentration of the most relevant toxic element released were evaluated by means of ICP spectofotometry (ISO 17294-2:2003.Water quality - Application of inductively coupled plasma mass spectrometry (ICP-MS) - Part 2)

Table 3 summarizes the leaching concentration in all the geocomposites. The leaching compliance were verified comparing all data were compared with the Italian law limits (D.M. 27th September

2010, which recognizes the European Directive 1999/31/CE), in order to classify the kind of waste. All the geocomposites satisfy the prescribed limit for inert or non hazardous waste.

4. CONCLUDING REMARKS

A more sustainable management of dredged materials constitutes a strategic requirement to maintain navigability of the water ways and to promote sustainable development.

The experimental research activity described in this paper was aimed to get some insight on the possibility to use dredged sediments in combination with fly ash in the production of geopolymer-based building materials. Some geocomposites were prepared using a siliceous sand - considered as inert reference material - in substitution of the dredged sediment, in order to investigate the possible existence of a chemical activity of the used dredged soil.

The experimental results highlighted that the use of fly ashes can improve the mechanical properties of the dredged sediments, leading to geopolymeric matrices with interesting mechanical performances. The composite materials made with the dredged soil show a more compact microstructure than the composite materials made with sand, thus having better mechanical properties. The main difference is observed far from failure, being the Young's modulus of the geocomposite with sand higher than the Young's modulus of those with the dredged material.

In terms of environmental impact, the values of hazardous elements classify the geocomposite as a non-dangerous material. Based on these preliminary results, the proposed methodology could represent a starting point for the investigation of possible beneficial uses of polluted sediments in geopolymeric matrices.

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Figures

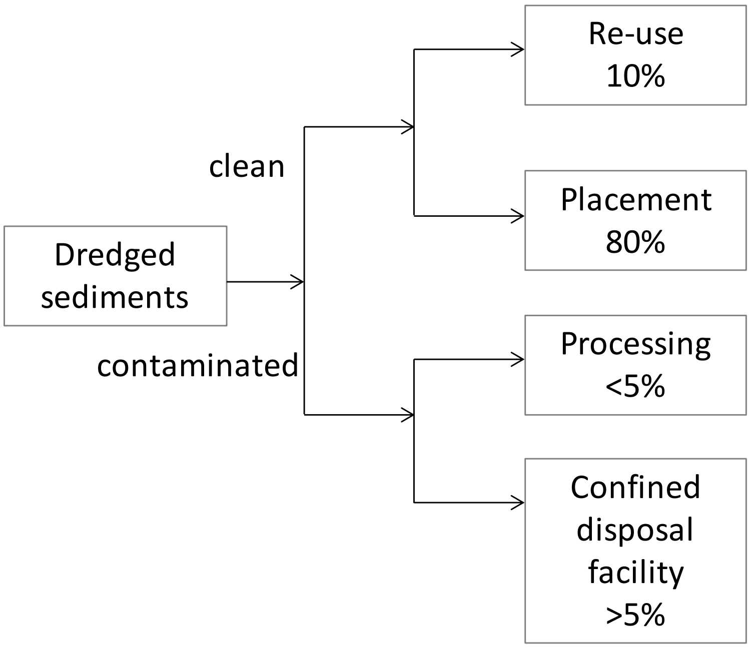


Figure 1. Dredged Material Management in a Marine environment (after European Dredging Association EuDA report, 2005).

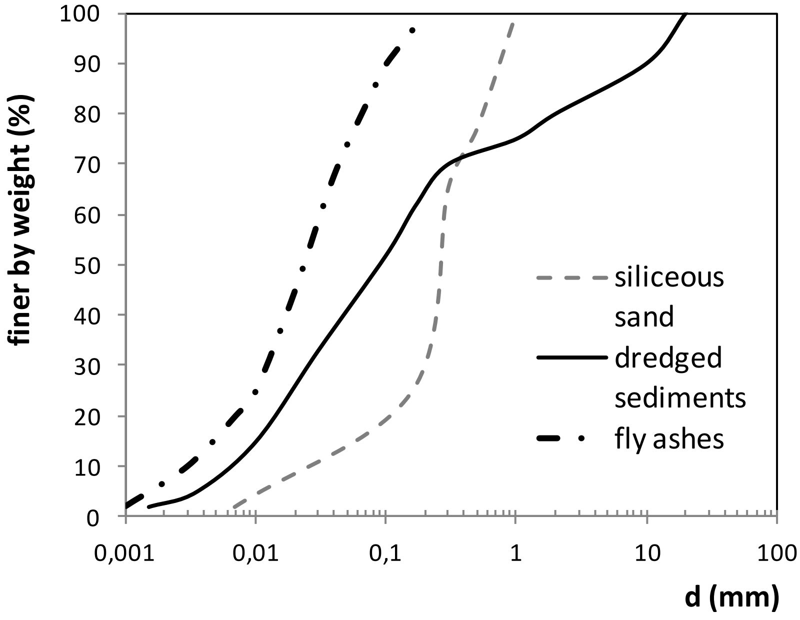


Figure 2. Grain size distribution of the tested materials: siliceous sand, dredged sediments and fly ashes.

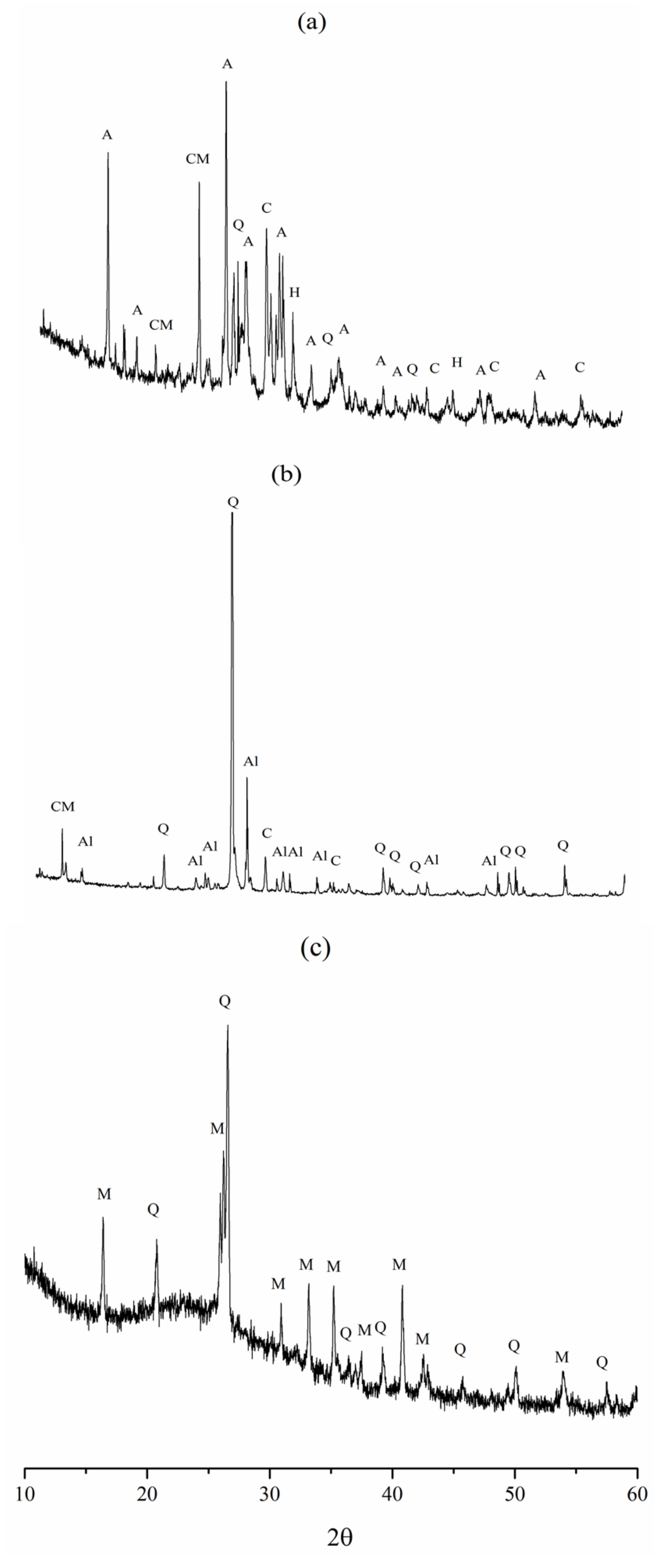


Figure 3. XRD spectra of (a) dredged sediments, (b) siliceous sand and (c) fly ash. A = Analcime, Q = Quartz, CM = Clay Minerals, C = Calcite, H = Halite, Al = Albite, M = Mullite

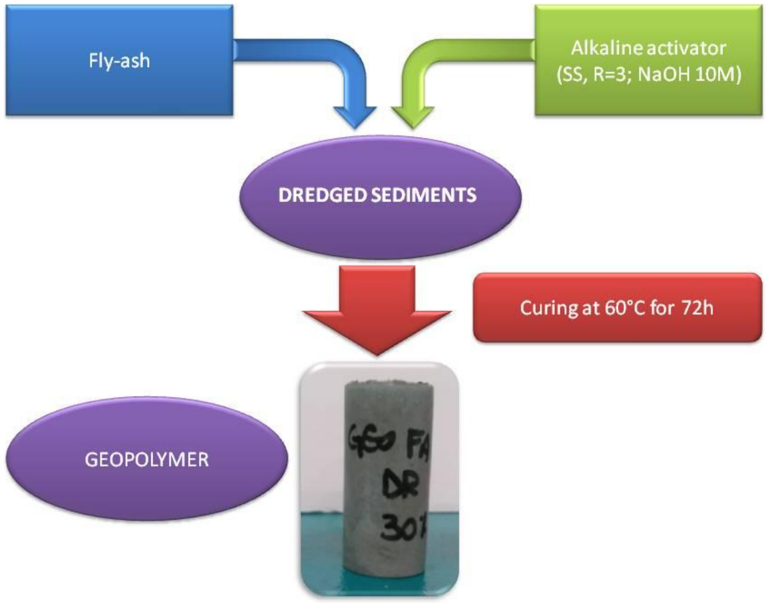
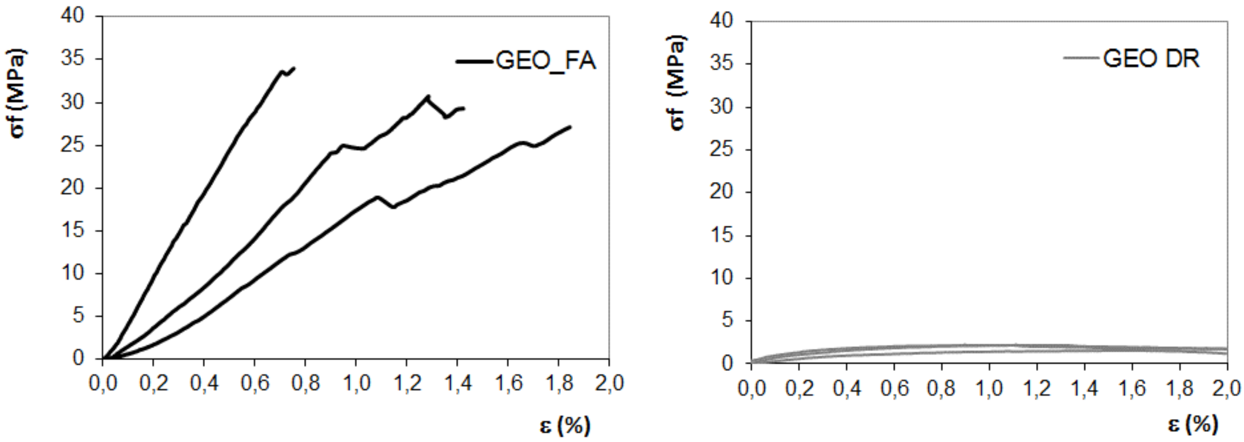


Figure.4. Procedure used for the preparation of the geopolymer specimens.



(a) (b)

Figure 5. Results of the uniaxial compression tests carried out on: a) GEO_FA specimens, b) GEO_DR specimens.

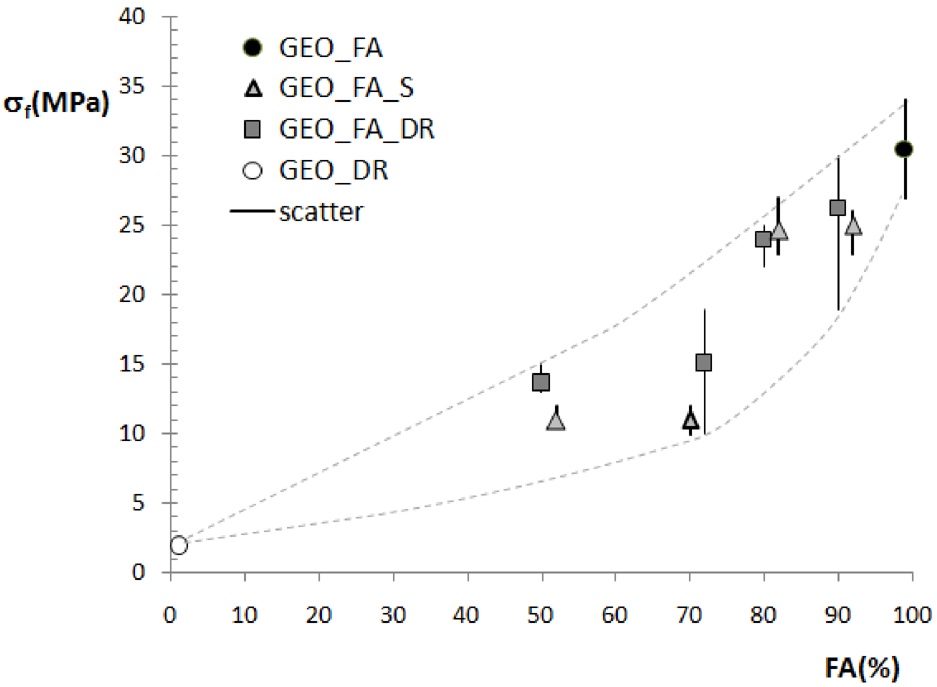


Figure 6. Overall results of all the uniaxial compression tests: uniaxial strength σ_f (average value) versus the fly ashes content FA (the FA values on the x axis have been slightly shifted to make the graphic more readable).

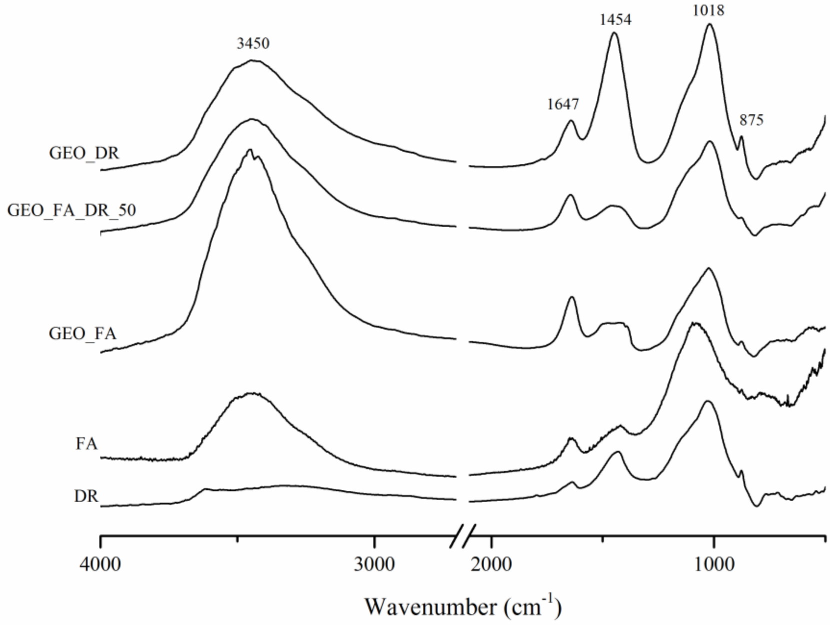


Figure 7. FTIR spectra of dredged sediments, unreacted fly ashes and of geopolymeric samples

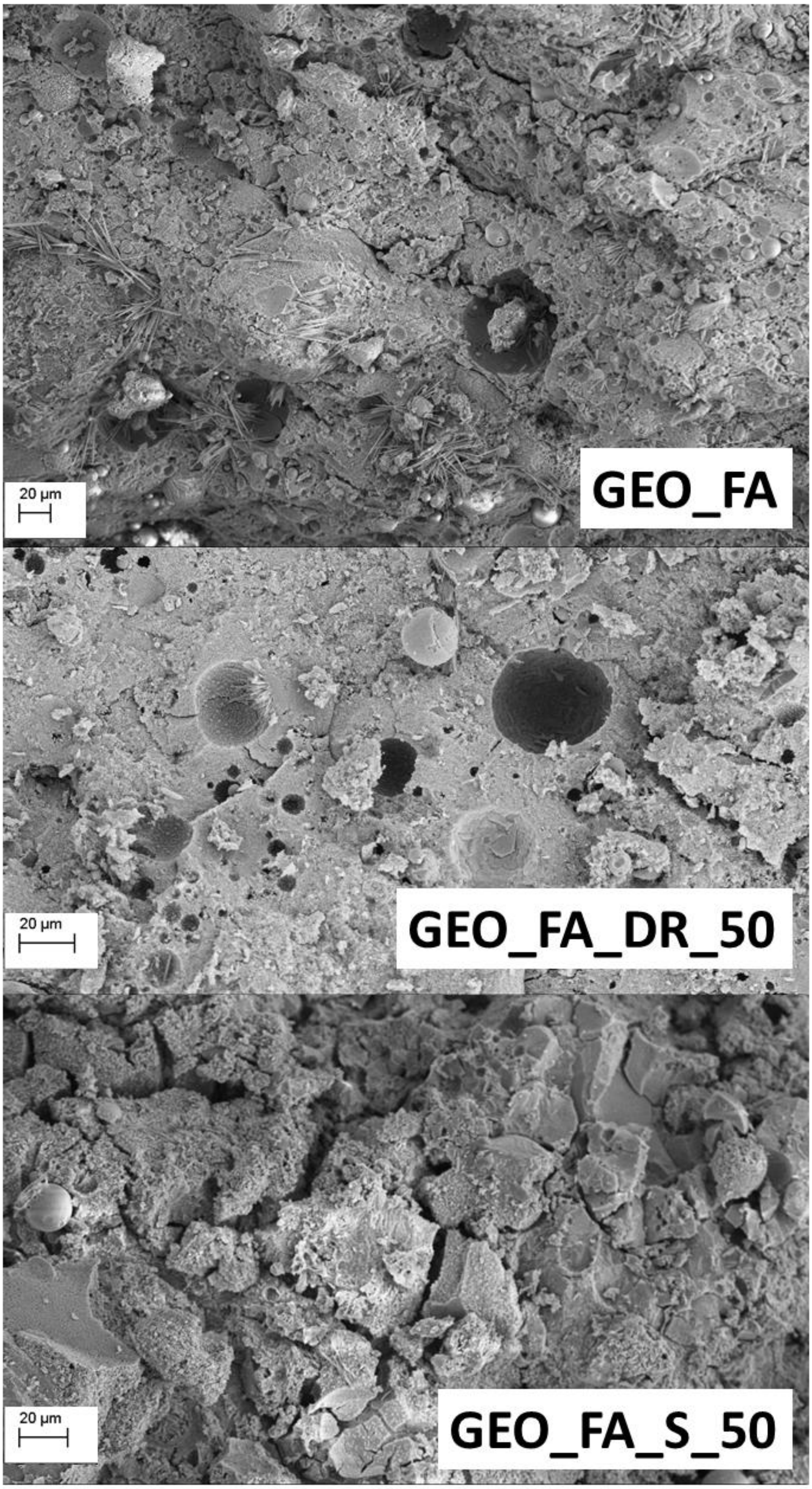


Figure 8. SEM analysis of selected specimens

Tables

Table 1. Chemical composition of dredged sediments.

Oxide, %.	**SiO_2**	**Al_2O_3**	**CaO**	**Fe_2O3**	**Na_2O**	**K_2O**	**MgO**	**MnO**	**TiO_2**
DR	44.17	14.18	12.17	4.72	4.70	3.84	2.617	0.08	0.50
Fly ashes	53.7	28.1	4.32	6.99	0.87	1.89	1.59	-	-

Table 2. Results of the uniaxial compression tests.

Specimens	σ_f (MPa)	E_{50} (MPa)	γ_d (kN/m^3)
GEO_FA_DR 10	26.2±0.13	2561±0.2	13,3
GEO_FA_DR 20	24±0.06	1940±0.10	12,9
GEO_FA_DR 30	15.1±0.23	1600±0.23	13,5
GEO_FA_DR 50	13.7±0.07	1952±0.07	13,8
GEO_FA_S 10	25±0.05	2737±0.23	13,6
GEO_FA_S 20	24.7±0.07	2700±0.18	14,4
GEO_FA_S 30	11±0.09	837±0.12	14,4
GEO_FA_S 50	10.7±0.02	1137±0.20	14,6
GEO_FA	30.5±0.09	2810±0.45	14,3
GEO_DR	1.9±0.16	483±0.16	13,5

Table 3. Leaching features of the geo-composites

After leaching, mg/l						
		GEO_FA_DR				
Element	GEO_FA	10	20	30	50	GEO_DR
Cd	[0,003]	[0,003]	[0,002]	[0,003]	[0,001]	{0,017}
Co	[<0,001]	[0,004]	[0,006]	[0,017]	[0,018]	[0,031]
Ni	[0,003]	[0,025]	{0,120}	{0,171}	{0,141}	{0,144}
Pb	[0,005]	[0,010]	[0,009]	[0,018]	{0,066}	{0,073}
Zn	[<0,001]	[0,082]	[0,017]	[0,023]	[0,001]	[0,100]
Cr	{0,058}	{0,065}	{0,059}	[0,0365]	[0,037]	[0,034]
Cu	[0,007]	[0,055]	{0,338}	{0,518}	{1,087}	{2,864}
Reference	POLLUTION LEVEL					
D.M.27/09/2010	Inert waste		Non-dangerous waste		Dangerous waste	
	[]		{}		$	