Bio-pedo-depuration of wastewater
A pedological approach

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Soil is the environmental sphere designated to purify water. Soil is organized in horizons, each one with its composition. Microbial communities, humic substances, 2:1 clay minerals, and Fe-oxy-hydroxides are key components of the soil ecosystem.
Soil solution

Inorganic cations (heavy metals) and anions

Organic compounds (hydrophilic and hydrophobic)

Processes

- Ionic exchange
- Selective adsorption
- Precipitation
- Oxidation/reduction

- Mineral surface acidification
- Adsorption by shrinking/swelling

- Adsorption
- Abiotic transformation
- Rhizospheric processes
- Plant absorption

Soil components
Soil adsorption and degrading capacity is maintained thanks to rooting plants, which extract what the exchangeable complex has adsorbed. Because of this, components designated to adsorption do not reach saturation.

Plants act as a biological pump: they convert solar energy in chemical energy and carry on $O_2$ from leaves to roots, so allowing microrganisms colonizing the rhizosphere.
Thanks to all the processes and reactions occurring in soil, soils of different nature are used to dispose wastewaters of civil and agricultural origin.

Constructed wetlands is an example of soil use for treating wastewaters.
There is a branch of research devoted to finding plants or genotypes able to accumulate high concentrations of heavy metals per mass of biomass.
Based on the idea of constructed wetlands, our approach consists of two major challenges:

- to reconstruct soils (Technosols) suitable for different types of wastewater;
- to improve depurating capacity by using the minerals that in nature are more involved in water depuration so to allow reducing the surface to be used;
- to use *waste materials* containing useful minerals.

Let’s go shortly to get a look on the materials we refer to and on the activity of their components...
Waste materials forming carbonates

Action: heavy metals and phosphates co-precipitate at the surface of limestone particles because of $CO_3^{2-}$. 

Limestone particle (CaCO$_3$; Ca,MgCO$_3$) + Pb$^{2+}$, Cd$^{2+}$, Zn$^{2+}$, PO$_4^{3-}$ → Limestone particle (CaCO$_3$; Ca,MgCO$_3$)
Waste materials forming Fe-oxy-hydroxides

- bricks
- tiles
- waste iron
action:

FeO + PO$_4^{3-}$ \[\rightarrow\] ligands exchange

FeO$^-$ (alkaline pH)

+ Pb$^{2+}$, Cd$^{2+}$, Zn$^{2+}$, Cu$^{2+}$, Ni$^{2+}$ \[\rightarrow\] Ionic adsorption

2Fe + 1/2O$_2$ + 2H$_2$O + 3CO$_2$ \[\rightarrow\] Fe$_2$(CO$_3$)$_3$ + 4H$^+$

2Fe + 1/2O$_2$ + 5H$_2$O \[\rightarrow\] 2Fe(OH)$_3$ + 4H$^+$
Waste materials forming kaolinite

usually landfilled

action:

Si-O\(^-\) and Al-O\(^-\) (at alkaline pH)

+ Pb\(^{2+}\), Cd\(^{2+}\), Zn\(^{2+}\), Cu\(^{2+}\), Ni\(^{2+}\)
Waste materials forming clay minerals

Action: the interlayer of clay minerals is able to selectively adsorb $K^+$, $NH_4^+$, $Cu^{2+}$, $Zn^{2+}$, $Cs^+$, $Ba^{2+}$, $Pb^{2+}$, $Cd^{2+}$, $Ag^+$, $Al^{3+}$ and other ions.
At acid (pH < 5.2-5.5), Fe-oxy-hydroxides, kaolinite, and clay minerals can adsorb $\text{AsO}_4^{3-}$, $\text{VO}_4^{3-}$, phosphates, and other anions on the variable charges.
Other useful waste materials

Residues of limestone rocks deriving from mines operations: marble, marl, shale, flinstone;

Mine waste materials with a physiological acid pH (pyrite, ...), can be used to adsorb anions (PO$_4^{3-}$, AsO$_4^{3-}$, NO$_3^-$, ...).

Copper mine at Touro, Galicia, Spain.

Amphibolite with pyrite, pyrrhotite, chalcopyrite. (JSSS, 2011. 11:221-230)
Scheme of a bio-pedo-treatment plant

Wastewater, sludge or water coming from pre-treatment plants (decanting, imhoff tank)

Decontaminated water
As in the constructed wetlands, in each segment there are processes such as:

- **evapotranspiration**
- **plant absorption**
- **increase of temperature due to fermentation**
- **humification of SOM**, which help water to be depurated.
Bio-pedo treatment plant differentiates from other depurating systems for:
• use of waste lithic (and local) materials
• sequence of waste materials on the basis of their mineral composition and pH of the medium

Because of this, other things being equal, a water with a given polluting load can be treated in a smaller plant, contributing to save natural soil and landscape.

Olive trees grove or water treatment plant?

Bio-pedo-depuration plant in Tuscany, Italy.
The plant has been devised for a small village of 20 inhabitants
Villa garden or water treatment plant?

Bio-pedo-depuration plant in Tuscany, Italy. The plant has been devised for a wine cellar producing 100 tons of wine.

Major problems of cellar sludge:
- tannins
- lignified particles
The plant for cow rearing at Saint Christophe (Italy), in a cold area: 70 cows, about 200 m$^3$ per year, amounting to 175 equivalent inhabitants*. Surface of the plant: 207 m$^2$ (9x23 m) for a depth of 105 cm. Material treated: sludge.

**Major problems of the sludge:**
- High organic load
- High microbial load

*equivalent inhabitant: biological organic load requiring a biochemical demand of oxygen at 5 days ($BOD_5$) equal to 60 g of oxygen per day. Roughly: the amount of biodegradable organics produced by an user in one day, or a volume of wastewater of 200 L per day per person.
The plant at the Champagne cooperative cheese factory at Chambave (Aosta, Italy) – 486 m a.s.l., 45° parallel

Surface of the plant: 270 m² (10x27 m); mean depth: 1 m.

Material treated: water from a decanting plant with a diameter of 6 m.

Major problems:
• Proteins
• Fat
• Soap
Plant of the Champagne cooperative cheese factory

350 Equivalent Inhabitant (70 m³/day), 270 m² = ~0.8 m²/EI

Roughly: considering porosity (~30%) and evapotranspiration (few), contact time of daily wastewater is 28 hours.
### Chemical and biological parameters of cheese factory wastewater before and after bio-pedo-treatment (Chambave, Aosta, Italy).

<table>
<thead>
<tr>
<th></th>
<th>Water in</th>
<th>Water out</th>
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</thead>
<tbody>
<tr>
<td>BOD-5*</td>
<td>667.2 mg O$_2$ L$^{-1}$</td>
<td>129.4 mg O$_2$ L$^{-1}$</td>
</tr>
<tr>
<td>pH</td>
<td>5.56</td>
<td>6.86</td>
</tr>
<tr>
<td>Total bacteria load</td>
<td>$8.8 \times 10^6$ CUF § mL$^{-1}$</td>
<td>$1.4 \times 10^6$ CUF mL$^{-1}$</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>$3.2 \times 10^6$ CUF mL$^{-1}$</td>
<td>$1.2 \times 10^6$ CUF mL$^{-1}$</td>
</tr>
<tr>
<td>Fecal Streptococcus</td>
<td>$2.6 \times 10^6$ CUF mL$^{-1}$</td>
<td>0 CUF mL$^{-1}$</td>
</tr>
<tr>
<td>Total N</td>
<td>169.2 mg L$^{-1}$</td>
<td>89.4 mg L$^{-1}$</td>
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The system was not so efficient in this case, and we are now making longer the plant so to reach 360 m$^2$: 10x36 m.

**Contact time of daily wastewater will be 37.5 hours.**

*BOD-5*: biochemical Oxigen Demand at 5 days; it is an indirect determination of the organic matter content in the water, and it measures the consume of oxigen due to microrganisms in a given time. The water of a non-polluted river has a BOD-5 < 1 mg L$^{-1}$ di O$_2$.

§CUF (Colony-Forming Units): number of living microrganisms, each one able to form a visible colony on a suitable solid nutritive substrate.
Based on the rate on mineral weathering calculated for five years of use, with no managing of the filling materials, the plant should maintain its functionality for about a century.
We may use the same approach in cases like flowerbeds, roundabouts, kennels, areas surrounding car-washing or parking lots, and in all situations where water flow can not be collected, so contributing to reduce air pollution too.

In urban area, when particulate matter (PM10 and PM2.5) is trapped into a Technosol, its re-suspension in air due to wind blowing is really unlikely: organics are degraded, heavy metals are selectively adsorbed.
What we have learned with our experiments:

• Bio-pedo-treatment of wastewater with the use of waste materials is feasible and allows us reducing occupying surface so to preserve soil and landscape

• Waste materials to be used must be characterized for their physical, mineralogical and geo-chemical properties

• Needed contact times and fluxes inside the treating plants must be calculated more carefully

• Each wastewater requires its own Technosol, so much research on this aspect is needed.

Important message to be addressed:

let’s save soil and let’s use local waste materials
World Health Organization 2005 motto:  
Clean Care is Safer Care

ASEM 2014 motto could be:  
Cleaner World is a Safer and Nicer World
Thanks for your attention