SJSS
SPANISH JOURNAL OF SOIL SCIENCE

First results of Technosols constructed from municipal waste in Vitoria-Gasteiz (Spain)

Primeros resultados de la elaboración de Tecnosoles a partir de residuos municipales en Vitoria-Gasteiz (España)
Primeiros resultados da produção de Tecnosolos a partir de resíduos urbanos em Vitoria-Gasteiz (Espanha)

AUTHORS

Herrán Fernández A.[1]

Lacalle R. G.[2]

Iturritxa Vélez del Burgo M. J.[1]

Martínez Azkuenaga M.[1]

Vilela Lozano J. [@,3]
jvilela@vitoria-gasteiz.org

[@] Corresponding Author

[1] Department of Environment and Public Health, Vitoria-Gasteiz City Council. Pintor Teodoro Dubland, 25. 01008 Vitoria-Gasteiz, Spain.

[2] Department of Plant Biology and Ecology, University of the Basque Country. Bº Sarriena w/n. 48490 Leioa, Vizcaya, Spain.

[3] Department of Mayoralty and Institutional Relationships, Vitoria-Gasteiz City Council. Pintor Teodoro Dubland, 25. 01008 Vitoria-Gasteiz, Spain.
.

Received: 04.11.2015 | **Revised:** 13.02.2016 | **Accepted:** 15.02.2016

ABSTRACT

Construction of Technosols offers interesting alternatives to two current problems in the city of Vitoria-Gasteiz (Spain): waste recycling and degraded plot recovery. To evaluate the viability of their use, 6 types of Technosols were created by mixing four different byproducts from municipal waste treatment plants. The less than 40 mm size fraction material from the municipal construction and demolition waste treatment plant was used as the main ingredient, bio-stabilized material from the solid urban waste treatment plant mixed with triturated pruning was used as organic matter input, recycled bentonites and topsoil from the public plots of Vitoria-Gasteiz (Spain) completed the mixture. Mixes were prepared in triplicate and installed in 48 m^2 cells along with another 4 control cells containing only one of the ingredients at the municipal landfill of Gardelegui. A monitoring program for different parameters on soil, eluates and natural leachates was established to test the Technosols' capacity to sustain vegetation without negative impacts on the environment. The final objective is to test their ability to restore unused municipal plots. Results from the first year show that Technosols are a suitable option for degraded sites restoration and green infrastructure support. All controlled parameters on soil are within the limits set by autonomic legislation for land use as public park. The eluate analysis concludes for all studied parameters that all mixes would be classified by legislation as inert waste, except for the sulphate concentration (which exceeds the inert waste limit of 1 000 ppm), that currently would label the soil as non-hazardous. In the natural leachate analysis strongly basic pH values were present above 9.5, the limit allowed in Royal Decreet 849/1986, but acidified throughout the year moving towards neutrality, with final values between 7.31 and 7.51. Leachate from CDW30, TS15 and RB30 Technosols showed not allowed values with respect to sulfates and Fe during the last sampling, surpassing the limits of 2 mg/l and 2 000 mg/l respectively. All studied Technosols presented a low ecological potential risk (RI < 150) for heavy metals in soil and eluates.

RESUMEN

La elaboración de Tecnosoles plantea interesantes alternativas a dos problemáticas actuales que aparecen en el municipio de Vitoria-Gasteiz: la gestión de residuos y la recuperación de parcelas degradadas. Para evaluar la viabilidad de su aplicación se planteó la realización de 6 tipos de Tecnosoles mediante la combinación de diferentes subproductos de plantas de tratamiento de residuos. Se empleó material de la fracción menor de 40 mm de la planta municipal de residuos de construcción y demolición (RCD´s) como ingrediente base, material bioestabilizado de una planta de residuos sólidos urbanos (RSU´s) mezclado con poda triturada como aporte de materia orgánica, bentonitas recicladas y tierra vegetal de parcelas públicas de Vitoria-Gasteiz. Se prepararon las mezclas por triplicado y se instalaron en celdas de 24 m^2 junto con 4 celdas control para cada uno de los ingredientes en el vertedero municipal de Gardelegui. Se planificó un seguimiento controlando diferentes parámetros en el suelo bruto, eluatos y

DOI: 10.3232/SJSS.2016.V6.N1.06

lixiviados naturales para comprobar su capacidad de sostener cobertura vegetal sin afección al medio ambiente. El objetivo final sería su aplicación en la recuperación de parcelas públicas degradadas. Los resultados del primer año muestran que el uso de Tecnosoles es una opción viable para la restauración de zonas degradadas y para el soporte de infraestructura verde. Todos los parámetros controlados en el suelo bruto están dentro de los umbrales que marca la legislación autonómica de suelos contaminados para el uso de "parque público". El estudio de los eluatos concluye que los parámetros estudiados en todas las mezclas se clasificarían como residuo inerte, a excepción de la concentración en sulfatos que supera el límite como residuo inerte de 1 000 ppm, que hasta la fecha los señalaría como residuos no peligrosos. En el análisis de lixiviados naturales inicialmente se presentaron valores fuertemente básicos de pH por encima de 9,5, el límite permitido por el Real Decreto 849/1986, pero se fueron acidificando a lo largo del año y evolucionando hacia la neutralidad, con valores finales entre 7,31 y 7,51. Los lixiviados de los Tecnosoles CDW30, TS15 y RB30 muestran cifras no permitidas para sulfatos y Fe durante el último muestreo superando los límites de 2 mg/l y 2 000 mg/l respectivamente. Todos los Tecnosoles estudiados presentaron un riesgo ecológico potencial bajo (RI < 150) para metales pesados en suelo bruto y eluatos, por lo que no manifestaron toxicidad para estos parámetros.

RESUMO

A produção de Tecnosolos oferece uma interessante alternativa para dois problemas atuais na cidade de Vitória – Gasteiz (Espanha): reciclagem de resíduos e recuperação de parcelas de solo degradadas. Para avaliar a viabilidade da sua utilização produziram-se 6 tipos de Tecnosolos misturando 4 subprodutos diferentes das estações de tratamento de resíduos urbanos. Como componente principal usou-se a fração fina do material de construção e demolição das estações de tratamento, enquanto o material bioestabilizado estação de tratamento de resíduos sólidos urbanos misturado com materiais de poda triturados constituíram o input orgânico, sendo a mistura completada com bentonites recicladas e com a camada superior dos solos das parcelas públicas de Vitória-Gasteiz (Espanha). As misturas prepararam-se em triplicado e foram instaladas em células de 48 m² simultaneamente com 4 células controlo contendo apenas um dos componentes do aterro municipal de Gardelegui. Estabeleceu-se um programa de monitorização para os parâmetros do solo, eluatos, e lixiviados naturais para testar a capacidade dos Tecnosolos em manter o coberto vegetal sem produzir impactos negativos no ambiente. O objetivo final é testar a sua capacidade para recuperar parcelas urbanas não utilizadas. Os resultados do primeiro ano mostraram que os Tecnosolos são uma opção adequada para a recuperação de locais degradados e como suporte de infraestruturas verdes. Todos os parâmetros do solo controlados respeitaram os limites estabelecidos pela legislação local para a utilização do solo em parques públicos. A análise dos eluados permitiu concluir que para todos os parâmetros estudados todas as misturas podem ser classificadas pela legislação como resíduos inertes, com exceção da concentração em sulfatos (ultrapassa o limite de resíduo inerte 1000 ppm) sendo atualmente classificados como resíduos não perigosos. A análise dos lixiviados naturais revelou valores fortemente básicos de pH, acima de 9,5, o limite permitido pelo Decreto Real 849/1986, mas foram sofrendo acidificação ao longo do ano aproximando-se da neutralidade, com valores finais variando entre 7,31 e 7,51. Os lixiviados dos Tecnosolos CDW30, TS15 e RB30 apresentaram valores acima dos permitidos quanto aos teores de sulfatos e ferro na última amostragem ultrapasando os limites de 2 mg/l e 2 000 mg/l, respetivamente. Todos os Tecnosolos estudados revelaram um baixo potencial de risco ecológico (RI < 150) n que se refere aos teoresde metais pesados no solo e eluatos, pelo que não se manifestou toxicidade para estes parâmetros.

KEY WORDS
Restoration, heavy metals, physicochemical parameters, leachates

PALABRAS CLAVE
Restauración, metales pesados, parámetros fisicoquímicos, lixiviados

PALAVRAS-CHAVE
Restauração, metais pesados, parâmetros fisicoquímicos, lixiviados

1. Introduction

The presence of soils with high risk of degradation produced by humans has been a problem in the last years in several zones, for example, a tentative assessment for the soil degradation status in South America revealed that about 14% of the total land areas of South America was affected by human-induced soil degradation (Oldeman et al. 1991). In Vitoria-Gasteiz (Spain), 215 public plots with degradation risk were recorded in 2013. Nowadays urban soil is considered a fundamental ecologic resource in a city (Lehmann and Stahr 2007) and it can play a beneficial role by affecting directly a large amount of people (Lehmann 2006). Restoration of degraded plots or plots under the risk of degradation is necessary to avoid loss of the soil´s beneficial functions: hazard prevention, provision of renewable sources of water and food, contributions to urban infrastructure and to environmental quality and cultural heritage (Lehmann 2006). One approach to urban soil remediation is the use of Technosols: soils whose characteristics and pedogenesis are dominated by their technical origin (IUSS Working Group WRB 2015). These Technosols are based in the application of technology and scientific knowledge to create soil mixes depending on the characteristics of a particular problem (Ibarrola 2015). Technosols are part of the reference groups of the World Reference Base for Soil Resources (IUSS Working Group WRB 2015) and are considered as a mechanism against the greenhouse effect, being an interesting carbon sequestration alternative (Macías Vázquez 2004; Lorenz 2009).

When designing a Technosol it is essential to know its future use and many different ingredient mixes have been proposed. Several remediation projects have been successfully performed using the method "Technosols á la carte" (Macías Vázquez 2004), a technical design of Technosols using waste mixes for the improvement of the soil capacities or the pollution attenuation. Amendment of soils with certain waste products can improve characteristics of the Technosol as the capacity of developing certain kind of vegetation, of retaining water or working as an impermeable barrier (Wassemiller and Hoddinott 1997).

The remarkable improvement of the management in waste treatment plants allows re-using many of the non-hazardous byproducts, in this case for the creation of Technosols. Making Technosols out of byproducts of municipal wastes is a feasible method for the recovery of degraded lands, according to previous experiences like the degraded areas restoration projects in Laminoria sand mine (Maeztu, Spain) and Touro (A Coruña, Spain) (Asensio et al. 2013). Those projects presented good soil and ecosystem recovery results.

Organic matter concentration is an essential factor when formulating Technosols, existing different wastes usable as organic amendment. A common method to add organic matter is using sewage sludge (Arbestain et al. 2009; Yao et al. 2009b), which has shown good soil restoration results. Nevertheless, its effectiveness has been questioned because of the high heavy metal content found occasionally in this ingredient, which could provoke an aggravation in the degradation conditions (Asensio et al. 2013). In addition, the decomposition of the organic matter and the nitrification reactions can acidify the soil (Yao et al. 2009a). Another kind of organic amendment is the use of compost from the waste treatment plants (Clemente et al. 2010), which has been the selected option for this project.

The future use of the Technosol entails the selection of an appropriate kind of vegetation for the planned use of a site. A possible option is the utilization of artificial soils for energetic crops. In previous experiences good results were obtained in the *Salix spp*. plantation in degraded or polluted soils (Aronsson and Dimitriou 2005) and there are studies in which sewage sludge has been used in agriculture and fodder plantations like *Agropyron elongatum (Host)* (Wong et al. 1997).

The purpose of this study is to create different Technosol mixes by the combination of different byproducts from waste treatment plants and to test their viability to support vegetation and recover degraded lands without environmental impacts. For that several parameters taken from specific legislation will be controlled to evaluate soil pollution, and the possible risks for the environment and human health.

2. Materials and Methods

In this paper the results of the first year are shown, from December 20, 2013 to December 9, 2014.

2.1. Technosol creation and experimental design

To test the viability of the Technosols the Gardelegi municipal landfill in Vitoria-Gasteiz (Spain, 42°48'1.92" N, 2°41'22.87" W) was chosen, as it is a prepared site where non-hazardous wastes are admitted.

Technosols were made by mixing the following materials: construction and demolition dirt composed of the less than 40 mm size fraction of the construction and demolition waste processed in the treatment plant of Gardélegui as the main ingredient; bio-stabilized material from the "Biocompost de Álava" plant of mechanic-biologic treatment of urban wastes mixed with crushed prunings from the public garden maintenance as organic matter source; recycled bentonite from the ECOFOND sand foundry in Salvatierra-Agurain as a clayey component; and finally topsoil from municipal plots ("Vitoria's topsoils") stored in the Municipal Vivarium.

A total of 22 cells of 48 m^2 were created: 18 for the 6 mixes described in **Table 1** (3 cells for each mix), which were arranged one next to the other following this pattern: CDW15, CDW30, TS15, TS30, RB15, RB30 (repeating this sequence 3 times) and 4 control cells, one for each ingredient: construction and demolition dirt, bio-stabilized material with triturated prunings, bentonite and topsoil. Before filling the cells the mixes were matured for a month and homogenized every two weeks. Maturation consisted of exposing the mixes to the environmental conditions (Climograhp in Figure A3 in Supplementary Information). Material from each cell was laid over an impermeable plastic and, because of its volume, an intermediate mechanic flip was performed using a backhoe after 2 weeks, in order to aereate and homogenize the mix.

Table 1. Composition of the Technosol mixes

	Construction and demolition dirt	Bio-stabilized material	Triturated pruning	Bentonite	Topsoil
CDW15	85%	10%	5%	0%	0%
CDW30	70%	20%	10%	0%	0%
TS15	65%	10%	5%	0%	20%
TS30	50%	20%	10%	0%	20%
RB15	70%	10%	5%	15%	0%
RB30	55%	20%	10%	15%	0%

Each cell had an outer structure made of construction and demolition dirt, covered by an impermeable sheet and a tap for the leachate collection (**Figure 1**). The inner structure was formed by three layers: a 20 cm thick drainage

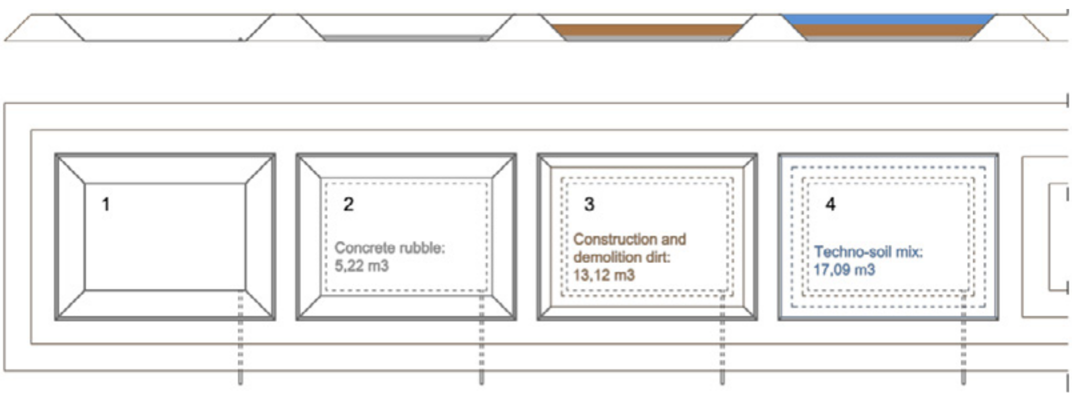


Figure 1. Creation of the cells: impermeable sheet and draining tap (1), draining layer (2), intermediate layer (3) and top layer with the Technosol mix (4).

layer made of concrete rubble (40-80 mm particle diameter), an intermediate layer 40 cm thick of construction and demolition dirt over a geotextile layer, and a top layer 40 cm thick with the Technosol mix.

In our project 4 types of plantations were installed in each of the Technosol cells: meadow area, forest area, agricultural area with rapeseed and biomass area with planted willows.

2.2. Legislation checking and analytical determinations

The program included periodic soil and natural leachate sampling from the cells. The analytical results were compared with the current legislation: Basque Law 4/2015 for the soil parameters to check that Technosols were under the VIE-B limits (Table A1 and A2) for the land use "public park", Decree 49/2009 for the eluates, considering the Technosols as inert products, and the Royal Decree 849/1986 of the public waters domain that the natural leachates could drain to natural streams without treatment.

First analyses were executed in September 2013 on the mix ingredients. A month later, in October 2013, analyses were done on the mixes before being taken to fill the cells. Soil sampling was performed once every two months during 2014.

Stratified random sampling was performed, obtaining complex samples from each cell. The stratification divided each cell in 4 quadrants. In each quadrant a random sampling was performed, selecting the sampling points randomly and non-systematically. Each of the subsamples were collected using a soil probe, marked each 10 cm, which was introduced slightly under the 40 cm mark, to avoid crossing the Technosol limit and accidentally collecting from the CDW layer.

In order to obtain a 2 kg-sample, 20 or 28 subsamples were collected, collecting the same number of subsamples in each quadrant. Each subsample was deposited in a plastic plate until the expected amount was collected. Sample was homogenized using a plastic shovel and stored in two plastic bags, one for each aliquot. Once prepared, samples were moved to laboratory to be processed following the leachate assay (UNE-EN 12457/4).

Leachates are collected from the draining taps every two months or right after reaching 150 mm of precipitation. The chronogram is shown in **Table 2.**

Table 2. Initial monitoring chronogram (Ing: ingredients; Mix: mixes in maturation; Cel: mixes in cells).

	2013				2014								
	SEP	OCT	NOV	DEC	JAN	FEB	APR	MAY	JUN	JUL	AUG	OCT	DEC
Ingredient accumulation	Ing												
Creation of mixes	Mix												
Maturation		Mix											
Cell construction	■	■											
Cell filling			Cel										
Planting					■								
Sowing							■					■	
Harvesting										■		■	
Sampling	Ing	Mix		Cel		Cel	Cel		Cel		Cel	Cel	Cel
Natural leachates					■	■	■		■		■	■	■

To analyze soil parameters, previous preparation of the samples is required. For eluates a leachate essay was performed (UNE-EN 12457/4) in which the liquid/solid proportion is 10 L/kg for material with a particle size less than 10 mm, and for the soil a digestion was performed using aqua regia (ISO 15586 2003).

Metals from the eluate, soil and natural leachates were determined by using Inductively Coupled Plasma (ICP) with cyclonic chamber and ultrasonic nebulizer (ISO 11885 1996). Electrical conductivity (UNE 77308 2001) and pH (UNE EN ISO 10523 2012) of eluates and natural leachates were determined by using a pH meter and conductivity meter with their respective selective electrodes. Chemical Oxygen Demand (COD) (EPA 410.4 1993), Total Organic Carbon (TOC), Dissolved Organic Carbon (DOC), cyanide, phosphorus and phenols were analyzed using commercial kits specific for each parameter and visible spectrophotometry spectrum (with a wavelength range of 340 to 900 nm). Sulphates, fluoride, chloride and nitrate (UNE-EN ISO 10304-1 2009) were analyzed by liquid phase ion chromatography. For C10-C40 hydrocarbons (UNE-EN 14039 2005) gas chromatography was used.

The statistical analysis was made with a Student's t distribution was performed at 95% confidence interval (0.05 statistical significance) of the arithmetic mean of the measured parameters on eluates, soil and natural leachates.

2.3. Soil pollution indexes

The evolution of the status of the mixes was evaluated using soil pollution indexes, specifically the potential Ecological Risk Index (RI) (Hakanson 1980). This index is used to evaluate the risk of heavy metals in sediments (Asrari 2014), and has also been used to evaluate heavy metals in different soils as necrosoils (Amuno 2013) or coal mining áreas (Pandey et al. 2015). Four levels of RI have been set:

- *RI < 150 → Low ecological risk*
- *150 ≤ RI < 300 → Moderate ecological risk.*
- *300 ≤ RI < 600 → High ecological risk.*
- *RI ≥ 600 → Very high ecological risk.*

Ecological risk is calculated by the combination of two simple indexes: Pollution factor (C^i_f), that relates the concentration of a metal (C^i_{0-1}) with the limit set by the legislation (C^i_n). Ecological risk factor (Er^i) (Quingjie et al. 2008), which is the product of the pollution factor (C^i_f) and the toxic response factor for each metal (Tr^i).

3. Results

3.1. Initial analysis

An initial characterization of the parameters was performed by the analysis of eluates and soil of the 4 ingredients and the 6 mixes. Results and limits are shown in **Tables A1** and **A2** in the Supplementary Information. In the leachate the Decree 49/2009 establishes three categories: inert, non-hazardous and dangerous. In the assay performed on the CDW, concentrations over the limit for inert waste were found for fluorides, Sb and Se. Those results would classify this ingredient as a non-hazardous product. The bio-stabilized material contents Cu, Ni, Sb and Se, and would also be classified as non-hazardous, as their concentration surpasses the limit established for inert wastes. However, bio-stabilized material also presents high concentration of dissolved organic carbon (DOC reaching 10 500 mg/kg), that would classify it as a hazardous waste (limit 1 000 mg/kg), because of the higher organic matter content of this ingredient. The results of the crushed prunings were similar to the bio-stabilized material: the Sb surpasses the inert waste limit, but it would be classified as hazardous because of the high DOC levels. In bentonite a concentration of 74.3 mg/kg of fluoride was found, over the limit of 10 mg/kg set for inert wastes, and it would be considered as non-hazardous. Finally, Vitoria's topsoils were classified as inert waste, as it didn't surpass any of the values of evaluation for the protection of human health VIE-B (limits in **Tables A1 and A2**) (IHOBE 1998) of the law (Law 4/2015).

In the initial characterization of the mixes (**Table A2** in the attachments), the results are more attenuated than in the sole ingredients. For the heavy metal concentrations, all the mixes were under the inert waste limit and the VIE-B. The DOC and TOC (inert limit 30 000 mg/kg) are still high, reaching the DOC the range of hazardous waste in CDW30, TS30 and RB30 mixes, because of their higher bio-stabilized material and prunings contents. After consulting the public organism "Sociedad Pública de Gestión Ambiental" (IHOBE), it was concluded that these values show no hazard and are not an inconvenience for the planned future uses of the Technosols (vegetation support), as they are a consequence of the organic matter necessary for those uses.

Physicochemical parameters from soil mixes are shown in **Figures 2, 3, 4 and 5**. Only organic matter related data and parameters in conflict with current legislation were selected for the discussion. It has to be noted that these are the average values of the three replica values for each mix.

3.2. Organic matter, TOC and COD evolution

TCDW30, TS30 and RB30 mixes (**Figure 2a**) showed significantly ($p < 0.05$) higher values of organic matter than CDW15, TS15 and RB15 mixes (**Figure 2a**). These mixes reached values over 4% the first 7 months, which finally decreased to around 4%. RB30 mix, containing bentonite, was the one with higher organic matter value, surpassing 5% during the 3rd and 7th month. On the other hand, mixes CDW15, TS15 and RB15, as they had lower bio-stabilized material and pruning content, presented significantly lower organic matter percentage. The lowest values were found in the CDW15 mix, about 2.20% by the end of the year. In CDW15, TS15 and RB15 an increase was perceived in the organic matter percentage during the first months following a slight decrease after that.

Regarding TOC in eluates (**Figure 2b**), RB30 sampling presented values significantly over the limits for inert wastes during the 3rd and 7th months. After that, the TOC decreased, reaching values under the limits by the end of the year. The rest of mixes were constant and under the 30 000 mg/kg in all samplings. Chemical Oxygen Demand (COD) values of the natural leachates from the mixes with higher organic matter content (CDW30, TS30, RB30) were over the allowed limit (160 ppm), even surpassing 300 ppm during the third month (**Figure 2c**). Initially, COD increases for all the mixes until the second sampling. From that point, values decrease for

Figure 2. Average and standard deviation of the organic matter content (a), TOC (b) and COD (c) in Technosol mixes. Statistical analysis: Confidence interval of the arithmetic mean (n = 3) by Student's t distribution (95% confidence).

all the studied mixes, even that TS15 and RB15 were almost constant during the whole year. At the end of the year, the COD values of the all Technosol mixes were under the limits, except for the CDW30 mix, with 168 ppm.

3.3. Characteristics and parameter evolution of eluates

The pH values have been significatively ($p < 0.05$) similar in all mixes (**Figure 3a**), with initial levels of 8.02 and 7.82, except for the CDW15 Technosol, which presented a slightly more basic pH values. During the first three months a slight acidification of the eluates was observed, followed by a return to the initial levels. After that, pH was constant during the last 4 samplings, never aproaching to the limit for non-hazardous wastes (pH 6).

For most of the selected parameters, results at a confidence interval of 95% do not surpass the limits for inert wastes, according to the Decree 49/2009. Only sulphates surpassed that limit (**Figure 3b**) during the 12 months, as is explained below. Sulphate (**Figure 3b**) values were similar for all mixes in the first sampling, close to 15 000 mg/kg. This would initially classify the Technosol as non-hazardous, according to the current legislation (inert limit 1 000 mg/kg and non hazardous limit 20 000 mg/kg). During the 3rd and the 5th months sulphate content was reduced, to slightly rise again in the following samplings, and finally descending again by the end of the year, even if the concentration is still clearly over the inert waste limit (1 000 mg/kg), finding significatively ($p < 0.05$) lower concentrations in CDW15, RB15 and RB30 cells than in the others.

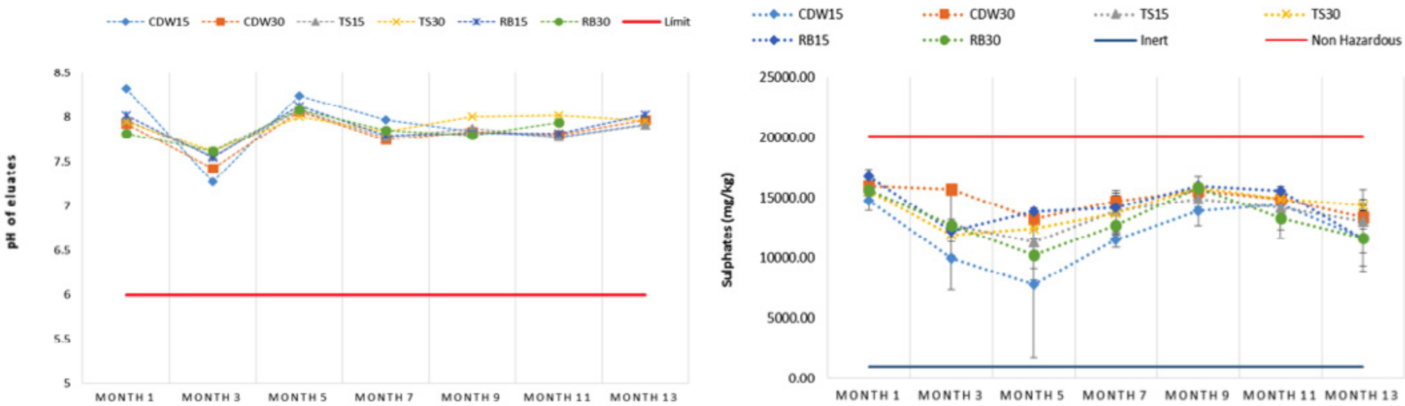


Figure 3. Average and standard deviation of pH (a) and sulphate (b) evolution in leachate assays. Statistical analysis: Confidence interval of the arithmetic mean (n=3) by Student's t distribution (95% confidence).

3.4. Characteristics and parameter evolution of natural leachates

It should be noted that the collected natural leachate not only comes from the Technosol mix, it traspasses the construction and demolition dirt middle layer and the draining layer.

During the first year different parameters surpassed the established limits from the RD 849/1986. First of all, pH presented very basic initial values (**Figure 4a**), reaching 11.43 and 11.50 for TS15 and RB30 mixes, respectively. Only the TS30 mix was under the allowed limit, with 9.27. During the following months a rapid acidification was observed until the 9th month, when all the mixes presented allowed pH values. During the last two samplings the values of all the mixes converged and showed significatively similar values. By the 11th month, all the samples were between pH 6.67 and 7.06. By the end of the first year the pH of all the different Technosols were under the limits established by the public waters legislation.

Unlike pH, inital sulphate concentrations were under the established limit (**Figure 4b**), but they rose during the last months of the year, except for TS30 mix, which descended from the 9th month, ending the year as the significatively lowest one.

In the last sampling month, the RB30 Technosol exceptionally surpassed the legislation limit of 2 000 ppm, reaching a concentration of 2 168.67 ppm. The RB15 and RB30 mixes, containing bentonite, were significantly richer in sulphate than the rest.

From all the different heavy metals analyzed, only Al, Cu and Fe showed concentrations over the established limits (**Figures 4c, 4d and 4e**). During the year, aluminum concentrations were very low in all Technosol types, until the 7th month, when they rose, to descend again and maintaining constant the rest of the year, under the limit, except for TS15 mix, that presented values clearly over the limit (1 mg/l). Cu concentrations presented a similar evolution, being constant during the first months, rising during the 7th over the limit (0.2 mg/l), and descending and finishing the year with values allowed by the RD 849/1986. The third metal which concentration was problematic according to the law was Fe. During the first months Fe concentration was constant, clearly under the limits, but by the end of the year it began to sharply rise, being significantly higher for CDW30, TS15 and TS30 mixes, surpassing the limit (2.00 mg/l) during the 11th and 13th months. There was no clear relationship between the presence of heavy metals and the composition of the Technosol.

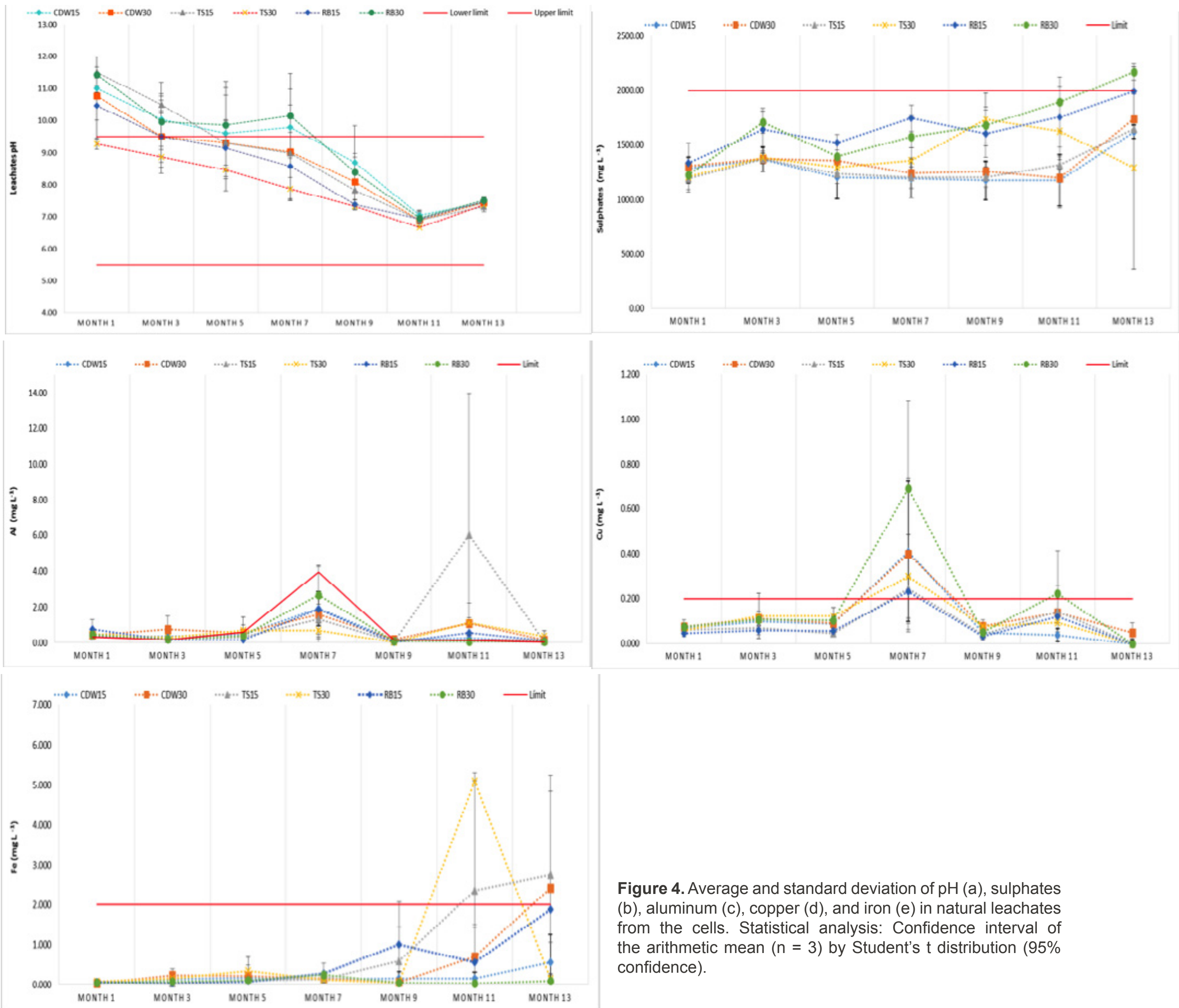


Figure 4. Average and standard deviation of pH (a), sulphates (b), aluminum (c), copper (d), and iron (e) in natural leachates from the cells. Statistical analysis: Confidence interval of the arithmetic mean (n = 3) by Student's t distribution (95% confidence).

3.5. Soil pollution indexes

In this study a group of metals was selected (As, Cd, Cu, Cr, Ni, Pb, Zn) in the eluate and soil analysis to calculate those indexes. In both cases there was a low ecological risk (RI) for all studied mixes, according to Hakanson's (1980) classification (RI < 150).

In the RI of the soil there's a variation along the year (**Figure 5a**). During the first two samplings the ecological risk fell, and increased in the 5th and 7th months. By the end of the year the risk descended again, with a higher risk in the CDW15 (RI = 1.7) and TS15 (RI = 3.9) samplings.

Eluates presented higher ecological risk values than the soil (**Figure 5b**). During the first months of the year all the mixes showed similar and constant values, but from the 7th month they started to differ and presented occasional peaks of RI. The risk value highly increased in the TS15 mix during the 7th, 11th and 13th months, and the RB15 and RB30 mixes presented higher concentrations in the last two samplings of the year, reaching values of 21.9 and 21.7, respectively. The TS30 mix showed an increase on the 11th month, but it fell markedly by the end of the year. All these variations were due to the Cd and Ni concentration in the eluates. On the contrary, mixes with greater presence of construction and demolition dirt, CDW15 and CDW30, had low and constant values, ending the year with RI values of 1.9 and 1.7 respectively.

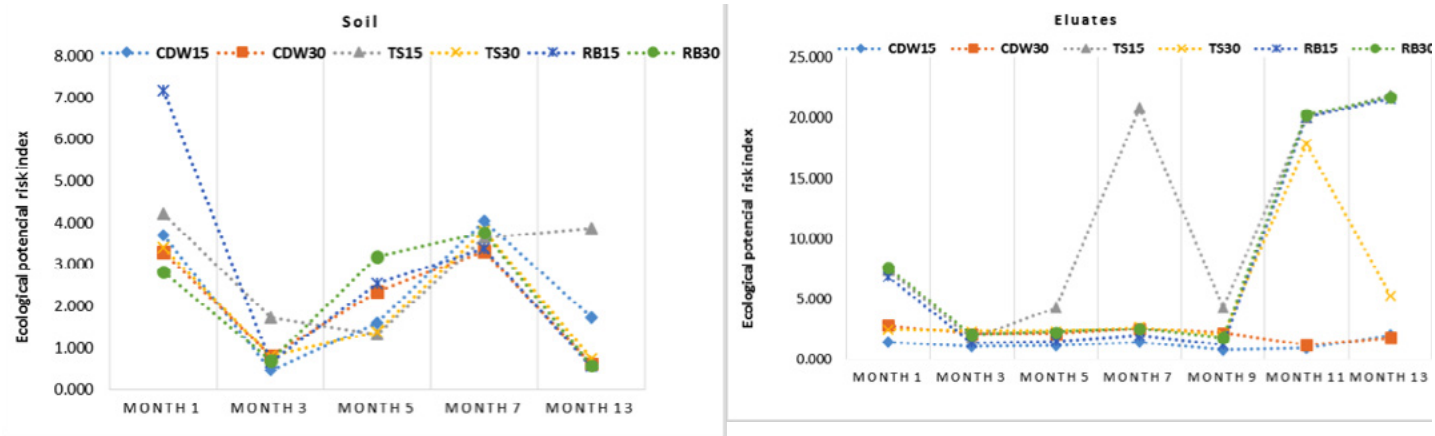


Figure 5. Evolution of the ecological risk indexes for soil (a) and eluates (b).

4. Discussion

4.1. Parameter evolution

The project's purpose is to test the Technosols' suitability as plant support and compliance with the law. The organic matter content is a necessary factor for that suitability. In soil, eluates and leachates organic matter content, TOC and COD were controlled. Higher values for those three parameters were reached by the mixes with higher bio-stabilized matter and pruning content, CDW30, TS30 and RB30.

According to the legislation for natural leachates, the CDW30 mix is over the established limits for DOC. However, these values are not considered a problem by the experts of the environmental service, given that the planned use for these Technosols (agronomic use) requires a sufficient organic matter content in the soils, similar to the content found in this study (3-6%), which is directly related to the values of TOC and COD.

To determine future agronomic use, the following nutrients were measured: total nitrogen (total Kjeldahl nitrogen, nitrite and nitrate) in the soil, total phosphorus, total potassium and total carbon. The presence of high concentrations of nitrogen in the soil indicates a possible biological activity of the upper layers (Huot et al. 2015). Over time, the water-soluble compounds such as these nutrients, will be phased out due to leaching, vegetation cover and dynamics recharge the soil solution. Offsetting these losses and maintaining soil fertility will be achieved by atmospheric inputs, decreased drainage and own contribution of nutrients from the mulch (Ranger and Turpault 1999). The fertility is dependant on the availability of nutrients and potentially toxic compounds, therefore soil acidification may adversely affect, to promote the mobility of heavy metals.

Although vegetation cover is directly related to the physicochemical evolution of the soil, the results of the first year did not demonstrate this relationship - the organic matter was not affected despite the Technosol mowings being returned to the Technosols. The only parameter that presents a relationship between the concentration and the presence of vegetation are metals. In the study of heavy metals we observed a decrease of ecological risk as well as the metal concentrations, this event can be directly related to the presence of vegetation cover in the mixtures. It has been proven that willow plantations are used for heavy metal phytostabilization (Sylvain et al. 2016), a fraction of the vegetation cover of the mixtures were willows, which could directly contribute to the downward trend of these metals.

Our results confirm that Technosols are young, evolving soils (Seré et al. 2010). Variation of different parameters such as pH and COD in natural leachates or organic matter in soil was evident through the study period, with the decrease in COD and organic matter content being directly related. The pH of leachates presented initially very basic values (reaching pH 11.5 in RB30 mix) and neutralized over time. This acidification could be attributed to phenomena such as rainfall-induced leaching, nitrification, carbonation of the system, organic matter mineralization and establishing a charge balance (Yao et al. 2009a). Acidification of the pH can directly affect in heavy metal availability (Arbestain 2009), which promotes the mobility of metal. The pH plays an important role in the bioavailability of a heavy metal and potential environmental risks posed by the metal (Briki et al. 2015). Several processes contribute to the acidity of soil, including the use of fertilizers, root activity of the plant, and mineral weathering of primary and secondary soil components. The organic matter content and pH distribution are the two most important factors influencing the distribution of a metal on the floor (Li 2004). Sulphates, unlike pH, organic matter and COD, rose throughout the year until surpassing the limits in the last sampling.

In some samplings an abnormally high metal content in soil was observed (non-included data). This fact is attributed to the high heterogeneity of the ingredients, even if the samples come from non-systematic random samplings. The small sample size, plus the heterogeneity of the mix ingredients, causes high uncertainty in some of the analysis results.

4.2. Suitability of the Technosols

Looking at the first year´s data, an initial assessment of the suitability of the Technosols can be done. At a 95% confidence interval it can be affirmed that, according to the Law 4/2015, all mixes were suitable for the land use of public park, according to the indicative evaluation value VIE-B. Attending only to the soil analysis during the first year, Technosols do not present any inconvenience for that use. Eluate analysis supports also the viability of Technosols. The main objective was that Technosols would classify as an inert product, according to the Decree 49/2009, and this was achieved in all parameters except for the sulphate concentration and corresponds to the non-hazardous waste group. The public organism “Sociedad Pública de Gestión Ambiental” (IHOBE) was consulted about this, and it was considered that it is not a problem for their use as plant support, because similar or higher sulphate concentrations are found in natural soil.

On the contrary, natural leachates analysis from some mixes reveals that by the end of the first year parameters as sulphates and iron slightly surpass the limits set by the RD 849/986. Only mixes CDW15 and RB15 fully comply with the current legislation. High sulphate concentration is attributed to two main reasons: as the natural leachate sampling was performed once every two months, or after 150 mm of precipitation, leachates could be stagnant in the lower cell layers; and, that the collected natural leachate not only comes from the Technosol mix, it traspasses the construction and demolition dirt middle layer and the draining layer. According to the environmental service, these levels were not considered dangerous or pollutants (there are natural soils such as Gypsisols that present higher sulphate values), and their origin is probably gypsum enriched material from construction and demolition dirt. According to the legislation (Law 4/2015), Technosols are suitable for their use as public park and vegetation support.

Finally, pollution indexes were very useful when checking the viability of the Technosols for their application to specific situations and, in addition, they were useful to evaluate their evolution over the time and to compare the toxicity grade of different Technosol mixes. As the finale values were lower than the initial in all mixes, it could be concluded that the IR has decreased during 2014. Furthermore, there seems not to be a relation between the ecological risk and the bio-stabilized material, rejecting the ecotoxicity effects these materials occasionally provoke (Smith 2009). During the calculation of the ecological risk index, the metal with the highest value was cadmium. Cd contamination poses a problem for human health and the ecosystem (Maanan et al. 2015), however the ecological risk value is lower than 150 as in the rest of the metals studied. According to the metal content, it could be affirmed that these soils are not toxic.

5. Conclusions

Results of the first year are considered positive. A substrate was created, admissible by the autonomic basque legislation for its use as public park, and the ecological risk study shows no harm to humans or the environment. Its use is appropriate for polluted land restoration, altered soils or in soil-less plots. Because of that, Technosols are presented as a good solution for the problem of municipal vacant land management, and the lack of adequate soil for planting. Nevertheless, before stronger and longer-termed conclusions can be drawn, the three-year monitoring must be completed. This monitoring during the next two years will be useful to observe the evolution of the soil to natural soil parameters.

6. Supplementary information

A1. Average of initial analysis of the control cells with the ingredients

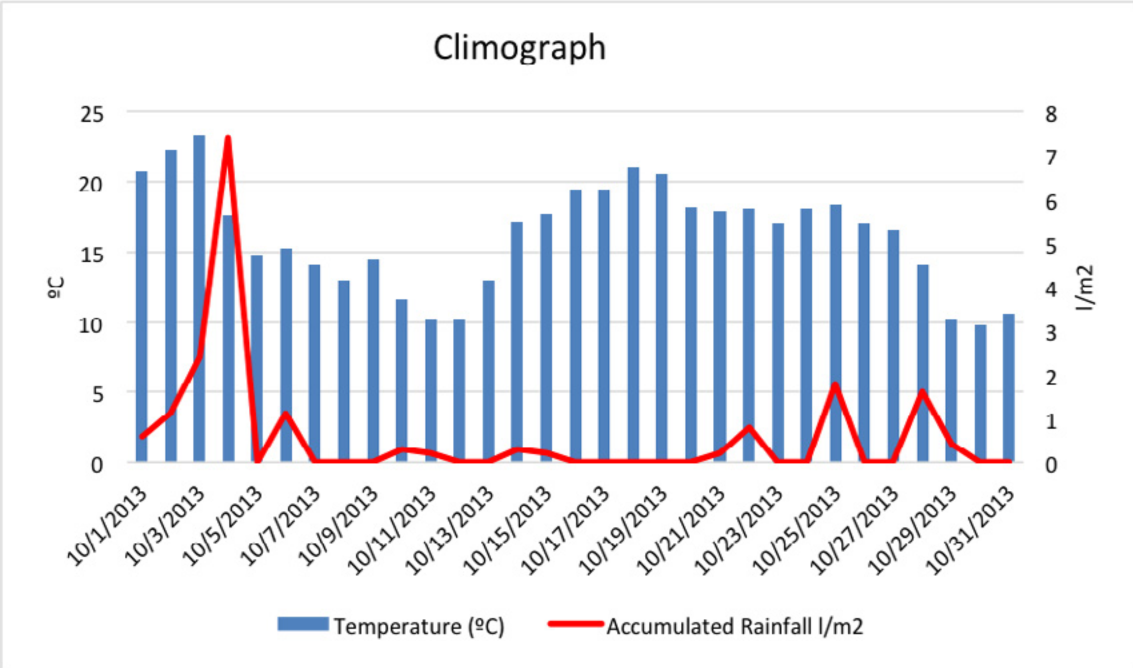
REGISTER No.				157 951	157 948	158 286	157 949	157 950
LEGISLATION 49/2009	LIMITS			Construction and demolition dirt	Bio-stabilized material	Pruning	Recycled bentonite	Vitoria's lands
	Inert	Non-hazardous	Hazardous					
Component (mg/kg of dry matter)								
As	0.5	2	25	0.096	0.2	0	0.1	0.03
Cd	0.04	1	5	0.04	0	0	0.02	0.02
Cr (total)	0.5	10	70	0.18	0	0	0.04	0.03
Cu	2	50	100	0.47	8.2	0	0	0.08
Mo	0.5	10	30	0.27	0.3	0	0.26	0.04
Ni	0.4	10	40	0.09	0.9	0	0.05	0.02
Pb	0.5	10	50	0	0.3	0	0.05	0.02
Sb	0.06	0.7	5	0.07	0.4	0.1	0.02	0.01
Se	0.1	0.5	7	0.12	0.5	0	0.04	0.03
Zn	4	50	200	0.22	13.2	0	0.36	0.16
Ba	20	100	300	0.52	0	0	0.18	0.84
Fluoride	10	150	500	44,8	1	1	74.3	6.5
DOC	500	800	1 000	80.2	10 500	6 875	155	63.4
Parameters (mg/kg)								
BTEX	6			<0.1	<0.1	<0.1	<0.1	<0.1
pH		<6		8.65	8.26	7.11	9.55	8.51
4/2015 - VIE-B LIMIT								
Heavy metals (ppm)								
As	30			0.0	0.0	0.0	0.0	3.8
Cd	25			1.9	2.0	0.0	1.9	1.9
Cu	10 000			5.8	181.5	5.8	11.3	7.7
Cr (total)	400			53.8	21.9	3.9	18.9	26.9
Mo	250			0.0	0.0	0.0	0.0	0.0
Ni	500			23.1	21.9	3.9	18.9	13.4
Pb	450			17.3	39.9	40.7	20.8	26.9
Zn	10 000			192.2	265.2	255.8	94.4	53.8
Other inorganic compounds (ppm)								
Cyanide	5			0.6	0.6	0.6	0.6	0.6
Organic volatile compounds (ppm)								
Benzene	5			<0.1	<0.1	<0.1	<0.1	<0.1
Ethylbenzene	20			<0.1	<0.1	<0.1	<0.1	<0.1
Toluene	40			<0.1	<0.1	<0.1	<0.1	<0.1
Xilene	40			<0.1	<0.1	<0.1	<0.1	<0.1
Phenol	25							

Polycyclic aromatic hydrocarbon (ppm)						
Anthracene	500	<0.1	<0.1	<0.1	<0.1	<0.1
Benzo(a)pyrene	2	<0.1	<0.1	<0.1	<0.1	<0.1
Fluoranthene	60	<0.1	<0.1	<0.1	<0.1	<0.1
Naphthalene	10	<0.1	<0.1	<0.1	<0.1	<0.1
Pesticides (ppm)						
a-HCH	1	<0.1	<0.1	<0.1	<0.1	<0.1
b-HCH	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
c-HCH	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Physical parameters						
Density(g/ml)		1.67	0.7	0.41	1.05	1.36
Humidity		7.46	20.25		20.91	8.46
Electrical conductivity(μS/cm)		2 100	9 200	1 100	1 150	88
O.M. (%)		4.1	79.2	100	8.7	8.3
Total N		510.78	16 549.2		2 154.06	1 107.79
Total K		3 171.2	5 583.3	2 325.1	1 453.1	4 530.6
Total P		301	7 272.2	1 015.5	160	606.1

A2. Average of initial analysis of the Technosol mixtures

REGISTER No.				159 183	159 184	159 185	159 186	159 187	159 188
LEGISLATION 49/2009	LIMITS			**CDW15**	**CDW30**	**TS15**	**TS30**	**RB15**	**RB30**
	Inert	Non-hazardous	Hazardous						
Component (mg/kg of dry matter)									
As	0.5	2	25	0.08	0.09	0.07	0.1	0.07	0.08
Cd	0.04	1	5	0.01	0.02	0.01	0.01	0.01	0.02
Total Cr	0.5	10	70	0.03	0.05	0.02	0.04	0.02	0.04
Cu	2	50	100	0.39	0.26	0.15	0.17	0.14	0.13
Mo	0.5	10	30	0.14	0.18	0.13	0.16	0.16	0.21
Ni	0.4	10	40	0.1	0.17	0.1	0.17	0.14	0.22
Sb	0.06	0.7	5	0.03	0.03	0.02	0.02	0.02	0.02
Se	0.1	0.5	7	0.02	0.03	0.03	0.02	0.02	0.03
Zn	4	50	200	0.14	0.37	0.15	0.4	0.18	0.53
Ba	20	100	300	0.34	0.33	0.61	0.58	0.37	0.3
Fluoride	10	150	500	2.8	2.2	2.7	2.5	4	4.6
DOC	500	800	1 000	579	1 272	459.8	1 108	610.8	1 328
Parameters (mg/kg)									
TOC	30 000	50 000	60 000	19 000	32 700	15 300	20 000	17 900	34 800
BTEX	6			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
PCB	1			0.05	0	0	0	0	0
pH		<6		7.8	7.7	7.69	7.72	7.63	7.7

4/2015 VIE-B LIMIT							
Heavy metals (ppm)							
As	30	3.6	13.7	1.6	0.0	3.6	0.0
Cd	2,5	0.0	2.0	1.6	0.0	1.8	1.5
Cu	10 000	16.3	66.4	20.9	39.8	64.7	74.6
Cr (total)	400	21.7	21.5	35.4	39.8	46.7	26.8
Mo	250	1.8	3.9	1.6	1.9	3.6	1.5
Ni	500	10.8	29.3	16.1	18.9	28.8	19.4
Pb	450	19.9	27.3	16.1	24.6	71.9	38.8
Zn	10 000	75.9	117.2	72.5	134.4	152.8	147.7
Other inorganic compounds (ppm)							
Cyanide	5	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Organic volatile compounds (ppm)							
Benzene	5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ethylbenzene	20	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Toluene	40	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Xilene	40	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Polycyclic aromatic hydrocarbon (ppm)							
Anthracene	500	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Benzo(a)pyrene	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Fluoranthene	60	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Naphthalene	10	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Pesticides (ppm)							
a-HCH	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
b-HCH	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
c-HCH	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Other inorganic compounds (ppm)							
PCB	0.8	0.05	0	0	0	0	0
Physical parameters							
Thick sand (%)		7.49	22.47	41.31	45.66	30.79	27.63
Fine sand (%)		28.32	30.81	19.27	20.72	28.24	29.95
Silt (%)		46.35	34.73	27.19	24.64	29.77	32.31
Clay (%)		17.84	11.99	12.23	8.98	11.20	10.11
Density(g/ml)		1.45	1.16	1.26	1.20	1.23	1.05
Humidity		8.43	-	9.65	9.56	9.63	11.40
Electrical conductivity (µS/cm)		2 350	3 300	2 550	3 200	3 100	3 600
O.M. (%)		3.27	5.63	2.64	3.44	3.08	5.98
Total N		2 021.00	3 628.00	1 587.30	3 204.60	2 380.00	4 162.00
Total C		92 800	10 7000	87 700	95 100	103 000	115 000
Total K		305.40	2 715.40	2 914.70	3 464.60	2 606.50	2 908.30
Total P		713.72	1 502.25	839.29	1 601.86	1 489.30	2 444.44



A3. October 2013 Climograph (http://www.euskalmet.euskadi.eus/s07-5853x/es/meteorologia/climatologia.apl?e=5).

REFERENCES

• Amuno SA. 2013. Potential ecological risk of heavy metal distribution in cementery soils. Water, Air and Soil Pollution 224(2):1-12.

• Arbestain MC, Ibargoitia ML, Madinabeitia Z, Gil MV, Virgel S, Morán A, Macías F. 2009. Laboratory appraisal of organic carbon changes in mixtures made with different inorganic wastes. Waste Management 29(12):2931-2938.

• Aronsson P, Dimitriou I. 2005. Sauces para energía y fitorremediación en Suecia. Unasylva 221(56):47-50.

• Asensio V, Vega FA, Andrade ML, Covelo EF. 2013. Technosols made of wastes to improve physico-chemical characteristics of a copper mine soil. Pedosphere 23(1):1-9

• Asrari E. 2014. Heavy metal contamination of water and soil. Oakvill (Canada): Apple Academic Press.

• BOE. 1986. Reglamento Público Hidráulico. Real Decreto 849/1986 de 11 de abril. Boletín Oficial del Estado, nº103, 30 de abril de 1986.

• BOPV. 2015. Prevención y corrección de la contaminación del suelo. Ley 4/2015 de 25 de junio. Boletín Oficial del País Vasco, nº 32, 24 de julio de 2015.

• BOPV. 2009. Regulación de la eliminación de residuos mediante depósito en vertedero y la ejecución de los rellenos. Decreto 49/2009 de 24 de Febrero. Boletín Oficial del País Vasco, nº 54, 18 de marzo de 2009.

• Briki M, Ji H, Li C, Ding H, Gao Y. 2015. Characterization, distribution, and risk assessment of heavy metals in agricultural soil and products around mining and smelting areas of Hezhang, China. Environmental monitoring and assessment 187(12);1-21.

• Clemente R, Hartley W, Riby P, Dickinson NM, Lepp NW. 2010. Trace element mobility in a contaminated soil two years after field-amendment with a greenwaste compost mulch. Environ Pollut. 158:1644-1651.

• DOG. 2008. Instrucción técnica de residuos referente a la fabricación de suelos (tecnosoles) derivados de residuos. ITR/01/08 de 8 de enero. Diario Oficial de Galicia, nº 18, 25 de enero de 2008.

• EPA 410.4. 1993. Environmental monitoring systems laboratory office of research and development. Cincinnati, Ohio: U.S. Environmental Protection Agency.

• EUSKALMET: Agencia vasca de meteorología. 2013. Datos de estaciones, octubre 2013. Avaible from: http://www.euskalmet.euskadi.eus/s07-5853x/es/meteorologia/climatologia.apl?e=5.

• Hakanson L. 1980. An ecological risk index for aquatic pollution control: A sedimentological approach. Water Research 14:975-1001.

• Huot H, Séré G, Charbonnier P, Simonnot MO, Morel JL. 2015. Lysimeter monitoring as assessment of the potential for revegetation to manage former iron industry settling ponds. The Science of The Total Environment 526:29-40.

• Ibarrola CV. 2015. Lago Ypacari: aplicación de tecnosoles atieutrofizantes y reducción de cianobacterias. Revista sobre Estudios e Investigaciones del Saber Académico 8:71-74.

• IHOBE. 2013. Efecto acondicionador de bentonitas recicladas sobre la fracción de lodos EDAR: Proyecto de rehabilitación de áreas naturales alteradas. IHOBE, Sociedad Pública de Gestión Ambiental.

• ISO 11885. 1996. Water quality – Determination of 33 elements by inductively coupled plasma atomic emission spectroscopy.

• ISO 15586. 2003. Water quality – Determination of trace elements using atomic absorption spectrometry with graphite furnace.

• IUSS Working Group WRB. 2015. World Reference Base for Soil Resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. Rome: FAO.

• Lehmann A. 2006. Technosols and other proposals on urban soils for the WRB (World Reference Base for Soil Resources). International agrophysics 20(2):129-134.

• Lehmann A, Stahr K. 2007. Nature and significance of anthropogenic urban soils. J Soils Sediments 7(4):247-260.

• Li Y. 2004. Effect of pH and organic matter on the bioavailability Cd and Zn in soil. Journal of Yunnan Agricultural University 20(4):539-543.

• Lorenz K, Lal R. 2009. Biogeochemical C and N cycles in urban soils. Environment International 35(1):1-8.

• Macías Vázquez F. 2004. Recuperación de suelos degradados, reutilización de residuos y secuestro de carbono. Una alternativa integral de mejora de la calidad ambiental. Recursos Rurais 1:49-56.

• Maanan M, Saddik M, Maanan M, Chaibi M, Assobhei O, Zourarah B. 2015. Environmental and ecological risk assessment of heavy metals in sediments of Nador lagoon, Morocco. Ecological Indicators 48:616-626.

• Oldeman L, Hakkeling R, Sombroek W. 1991. Global assessment of soil degradation, world map of the status of human-induced soil degradation. [Modified 1991 Oct]. Wageningen (Netherlands): ISRIC.

• Pandey B, Agrawal M, Singh S. 2016. Ecological risk assessment of soil contamination by trace elements around coal mining area. Journal of Soils and Sediments 16(1):159-168.

• Quingjie G, Jun D, Yunchuan X, Qingfei W, Liqiang Y. 2008. Calculating pollution indices by heavy metals in ecological geochemistry assessment and a case study in parks of Beijing. Journal of China University of Geosciences 19:230-241.

• Ranger J, Turpault MP. 1999. Input–output nutrient budgets as a diagnostic tool for sustainable forest management. Forest Ecology and Management 122(1):139-154.

• Seré G, Schwartz C, Ouvrard S, Renat JC, Watteau F, Villemin G, Morel JL. 2010. Early pedogenic evolution of constructed Technosols. Journal of Soils and Sediments 10(7):1246-1254.

• Smith SR, 2009. A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge. Environment International 35(1):142-156.

• Sylvain B, Mikael MH, Florie M, Emmanuel J, Marilyne S, Sylvain B, Domenico M. 2016. Phytostabilization of As, Sb and Pb by two willow species (*S. viminalis and S. purpurea*) on former mine Technosols. Catena 136:44-52.

• UNE 77308. 2001. Calidad de suelo. Determinación de conductividad eléctrica específica.

• UNE-EN 12457-4. 2003. Caracterización de residuos. Lixiviación. Ensayo de conformidad para la lixiviación de residuos granulares y lodos. Parte 4: Ensayo por lotes de una etapa con una relación líquido-sólido de 10 l/kg para materiales con un tamaño de partícula inferior a 10 mm (con o sin reducción de tamaño).

• UNE-EN 14039. 2005. Caracterización de residuos. Determinación del contenido de hidrocarburos en el rango de C10 a C40 por cromatografía de gases.

• UNE-EN ISO 10304-1. 2009. Calidad del agua. Determinación de aniones disueltos por cromatografía de iones en fase líquida. Parte 1. Determinación de bromuro, cloruro, fluoruro, nitrato, nitrito, fosfato y sulfato.

• UNE-EN ISO 10523. 2012. Calidad del agua. Determinación del pH.

• Wassemiller MA, Hoddinott KB. 1997. Testing Soil Mixed with Waste or Recycled Materials. Rosewood: STP 1275.

• Wong JWC, Su DC. 1997. The growth of Agropyron elongatum in an artificial soil mix from coal fly ash and sewage sludge. Bioresource Technology 59(1):57-62.

• Yao FX, Macías F, Santesteban A, Virgel S, Blanco F, Jiang X, Arbestain MC. 2009a. Influence of the acid buffering capacity of different types of Technosols on the chemistry of their leachates. Chemosphere 74(2):250-258.

• Yao FX, Macías F, Virgel S, Blanco F, Jiang X, Arbestain MC. 2009b. Chemical changes in heavy metals in the leachates from Technosols. Chemosphere 77(1):29-35.