Spatial Modeling of Industrial Windfall on Soils to Detect Woody Species with Potential for Bioremediation

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Abstract—*A spatial model is presented to explain the concentration of heavy metals (Fe, Cu, Zn, Ni, Cr, Co and Pb), in the soils around the industrial complex near the Port of Veracruz, Mexico. Unexpected low concentration sites where then tested to detect woody plant species that may have the capability to hiperacumulate these contaminants, hence having a potential for dendroremediation.*

The study case circumstances are conducive to test this hypothesis because of the radial nature of the industrial sprawl, and the rural surroundings, where low presence of heavy metals is expected. Contaminants selected are common in the sort of industrial outfits in the region, most of which are involved in metal manufacturing.

Results show levels of Cu, Zn, Cr, Co, and Pb in soils exceeding the reference threshold concentration in a fanshaped pattern downwind, with peak values for Fe. At least four species had no damage symptoms: guácimo, Guazuma ulmifolia*; roble,* Tadelobuia pentaphylla L.*, cocuite,* Gliricidia sepium *and* palo mulato, Bursela simaruba L. *This suggests these materials are resistant to metal pollution at the concentration levels seen in the region.*

Analysis of woody and bark tissue is underway, and it is expected to confirm the potential of the four species as pollutant accumulators suitable for bioremediation. If such were the case, they should they be propagated and placed all through out the downwind side of the industrial complex in a large scale trial. The up wind concentrations were not a concern from the point of view of environmental regulations, and the effect of accumulator species already present resulted not statistically significant, except cocuite.

Introduction

Spatial modeling of airborne contaminants on soils is an approach capable of identifying woody species with potential capability for remediation and reclaiming. There are two direct benefits from this type of result, a) assess the soil health condition, and b) identify native species suitable for clean up.

In the Mexican scene, 21 out of 32 states comprises 166 illegal toxic dump sites abandoned. An assessment in 1995-1997 reported: heavy metals, dust, smelter residues (scum), mining debris, oils, hydrocarbons, organoclorides, muds, Pb, cadmium, niquel, cianure, silic sand (EMA 1999). Consider in addition that industry continuously disposes this and other contaminants.

Nowadays there is a recent body of regulatory legislation concerning toxic emissions into the atmosphere, and heavy metals are a matter of concern in this regard. Tools to locate and spatially analyze hot spots are therefore urgently needed. Screening up locations where contaminants represent a hazard to population is an activity of major priority. In a similar fashion, modeling the fallout patterns creates the opportunity to detect species with potential capability to accumulate these metallic contaminants.

The municipality of Veracruz (latitude 19º 16´ y 19º 06´ N, longitude 96º 07´ y 96º 20´ W) includes the city of Veracruz (pop. 457 377), and a considerable industrial infrastructure including the Port of Veracruz, and Bruno Pagliai industrial park (FIBP), (INEGI 2000).

Climate in the study region is tropical semidry, with summer rains. Weather is strongly influenced by trade winds. Natural vegetation cover in Veracruz has declined historically, temperate forests dropped from 18 percent to 4 percent, and tropical forests from 66 percent to 24 percent, in the 1800 to 1900 time span (INEGI 2000). The main cover type is low tropical forest, which involves wooded areas of up to 15 m in height, growing in a climate with 25.3 ºC mean temperature, and 1669.2 mm annual rainfall (SEFIPLAN 2002). This vegetation responds to xeric site conditions imposed by the sandy, poorly developed soils usually found in coastal dunes such as in the study region. Local species are well adapted to these environments produced by the fast drainage, occasional gusty winds, heavy showers, and high salt content in the water.

This research has an appeal and relevance given by the evolving conditions of reduced tree cover, loss of natural landscape, increasing population and industrial development, and rising emission levels (EMV 1998).

Materials and Methods

The study area is defined by a 5 km radius centered at FIBP, at 16 km west from the city and port of Veracruz. FIBP began with the first facility, Tenaris Tamsa, opening in 1958. Tenaris is a steel mill and pipe manufacturer that is the largest (185 ha) and dominant tenant in the park. Today there are 157 industrial outfits in FIBP, 48 of them are metal-mechanic manufacturers, and 44 are chemical industries. Other businesses in FIBP involve food and beverages, electric and electronic components, glass, construction materials, and some other products (CFBP 2002).

The federal highway Veracruz-Jalapa divides by half the study area. This road is used by over 2000 vehicles, many of which are heavy trucks.

Industrial facilities are surrounded by farms with cropping and grazing plots, though these activities are declining because of new housing developments. The largest of these housing projects is Valente Díaz (pop. 13765), which is the second largest population in Veracruz municipality, just surpassed by Veracruz city itself. One more factor of relevance for Valente Díaz is that it borders with the Tenaris steel mill (SEFIPLAN 2002).

A network of sampling points were subjectively chosen to supply information from different distances and orientation respect the center point of the study area. Sampling points necessarily must be near a native tree of sufficient age as to expect to have received the effect of pollutants and reacted to it. From this tree, a sample of bark and wood was taken at 1.3 m in heigth. Two soil samples from the tree crown cover area were also taken, one at 10 cm in depth, and another one at 20 cm. For each soil sample, total concentration of Fe, Cu, Zn, Mn, Ni, Cr, Co, Cd, Pb, and extractable concentration of Fe, Cu, Zn and Mn were determined with procedures indicated in the official Mexican norm about sampling and analysis of soils NOM-021-RECNAT-2000 (SEMARNAT 2002). Tissue analysis was done through atomic absorption using a solution of ashes from tissue sample incinerated at 550 ºC.

Complementary soil data sought included pH, electric conductivity, cation exchange capacity organic mater, total nitrogen, assimilable phosphorous, exchangeable bases, and texture.

Climate data was provided by Centro de Previsión del Golfo de México. Wind speed and direction, temperature, relative humidity, global solar radiation, cloud cover, and barometric pressure were variables selected to model atmospheric dispersal. The local cartography was digitized, and fed to software Archie (FEMA/USEPA 1993), and Surfer (Golden Software, Inc). Isoconcentration digital maps for each contaminant were produced with the ground and atmosphere modeled features, plus contaminant values recorded in field samples of soil, bark and wood. Scenarios of interest to model included:

- the annual cycle, represented by weather and contaminant fallout patterns in January, April, July, and October (featuring seasonal conditions for winter, spring, summer, and fall), gusty wind days (synoptic weather systems from higher latitudes descending on to the tropics; also, stormy conditions associated to anticyclonic circulation producing winds over 30 m s-1)
- steady days with high temperature (maximum hourly temperatures each month)

Results

Soils presented an average pH of 5.95 at the 0-10 cm depth, and 5.79 at 10-20 cm (±0.69 and ±0.79 standard deviation, respectively). Mean electric conductivity was 0.142 dS.m-1, a value within acceptable range (United States Salinity Laboratory of Riverside, USA). Organic mater contents in the soil was >3.01 percent at 10-20 cm deep, and still very high at 2.01 percent to 3.0 percent in the top layer, at 0 cm to10 cm. Soils were coarse in texture, ranging from sandy loam to loamy sand. Exchangeable cations were also high, ranking Ca >Mg >K>Na.

Soil total heavy metals (Fe, Cu, Zn, Mn, Ni, Cr, Co, Pb), resulted over the reference tolerance (table 1). Of

Table 1. Average of total heavy metals in soils 0-10 cm, 10-20 cm, mg.kg-1 (dry weight).

	0-10cm	10-20cm				
Fe	This study	This study	(1)	(2)	(3)	(4)
average	45372.9	40411.7	-	-	-	-
range	17520-161590	20740-116550				
Cu						
average	67.3	78.87	100	60	26	100
range	9.7-468.8	11-437.5				
Zn						
average	193.8	163.7	400	70	73.5	300
range	39-1550	38-1240				
Mn						
average	1036	957.5	1500	3000	490	-
range	374-3950	298-3831.5				
Ni						
average	42.9	43.16	100	-	18.5	100
range	20-234	20-204.8				
Cr						
average	112.3	105.7	75	-	50	100
range	18-675	18-675				
Co						
average	35.3	35.3	25	30	10.5	-
range	31.7-63.5	31.7-63.5				
Cd						
average	2	-	8	-	-	5
range	0-2	-				
Pb						
average	105.2	111.9	200	-	26	100
range	26-250	20-440				

particular concer was total and extractable Fe, where records show elevated concentrations >25.0 mg.kg-1, while Cu averaged a high >1.2 mg.kg-1, Zn was also beyond toxic levels (>8.0 mg.kg-1), and so was Mn too (>29 mg.kg-1)

A total of 13 tree species were tested (table 2).

Concentrations of Fe, Cu, Zn, Mn, Ni, Cr, Co, and Pb in bark and wood tissues are presented at table 3.

Cu bioacumulation index by species was oustanding, and statistically significant for cocuite (Gliricidia sepium) and roble (Tadelobuia pentaphylla L). Three other species also displayed a satisfactory bioacumulation potential (index>1).

Table 2. Trees sampled in the study site. FIBP, Veracruz, Mexico.

Nombre común	Nombre científico*
Almendro	*Terminalia catappa L.*
Cedro	*Cedrela odorata*
Cocuite	*Gliricidia sepium*
Ciruelo	*Spondias mombin L.*
Flamboyán	*Delenox regia*
Guácimo	*Guazuma ulmifolia*
Higuera	*Ficus carica*
Mulato	*Bursela simaruba L.*
Jobo	*Spondias purpureas*
Nacastle	*Enterolobium cyclocarpum*
Palo dulce	*Achatacarpus nigricans*
Roble	*Tadelobuia pentaphylla L.*
Uvero	*Coccoloba barbadensis*

(Martínez 1994)

Discussion

This first evaluation assessed heavy metals in the study area soils. The key finding is the expected behavior of sandy and loamy soils. Coarse soils like these have a low retention of heavy metals. Therefore, these contaminants seep through down into the water table. The ample empty spaces inside sandy soils provide fast movement of air and water, and therefore, quick movement of metals carried as particles or dissolved.

Now considering the current trend towards industrial and housing development in the region, significant increase of paved ground and artificial structures (houses, buildings), will make contaminant drift even faster. In this scenario, current environmental regulations might be excessively lenient in protecting public health.

Should any of the species studied turn out as good bioaccumulators, they could be a valuable means to clean up medium level brown soils. Moreover, the spatial model used to identify bioaccumulators is also capable of identify priority areas to be forested with those species found, and the minimum and maximum area and planting density can be calculated too.

Table 3. Heavy metals in bark and wood, study site, Veracruz, México. mg.kg-1 (dry weight).

	Bark								Wood			
	Fe	Cu	Zn	Mn	Ni	Cr	Co	Pb	Fe	Cu	Zn	Mn
Roble	407	28.7	26	56.9	5.9	11.3		7.8	36.8	6.25	8.68	98.7
Cocuite	329	37.5	31	23.7		9			358		6.2	23.7
Jobo	486	18.8	31	134	5.9	18	6.35	5.2	329		18.6	7.9
Ciruelo	408	28.1	31	79	5.9	13.5		5.2	53.6	6.25	6.2	
Nacastle	677	12.5	24.8	120	5.9	18		5.69	52.7	6.25	18.6	43.15
Nopillo	475	24.2	29.5	89.2	5.9	14.6	6.35	5.36	198	6.25	12.4	24.92
Mulato	511	20.9	29.1	106	5.9	16		5.36	158	6.25	13.95	25.32
Almendro	207	18.8	24.8	39.5	5.9	13.5		5.2	28.6	6.25	12.4	
Palo Dulce	129	12.5	49.6	15.8	5.9			5.2	50.1		12.4	
Guácimo	168	15.6	37.2	27.7	5.9			5.2	39.3	6.25	12.4	38.4
Uvero	54.7	6.25	12.8	82.4					34.2	6.25	8.4	53.7
Cedro	78.7	6.25	12.4	92.4					48.2	6.25	12.4	68.6
Higuera	68.5	6.25	12.8	79.8					36.2	6.25	8.78	58.4
Flamboyán	67.3	6.25	12.7	84.9				5.5	39.5	6.25	9.86	60.23

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(1) Linzon, 1978

(2) Kovalskiy, 1974

(3) USEPA, 1995

(4) Kabata-Pendias and Pendias, 1984.