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Characterization of urban waste leachate for better management of the Greater Agadir controlled landfill, Southern Morocco (Caractérisation des déchets urbains pour une meilleure gestion de la décharge contrôlée du Grand Agadir)

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Abstract
In 2010, a controlled landfill started to receive urban waste generated by the Greater Agadir population. As this waste is rich in organic matter, significant quantities of leachate are produced and stored in ponds built for that purpose. Given the pollution load of the leachate it is important to reduce the concentration of pollutants prior to discharge into the urban sewer network. A study was carried out in 2011 to investigate the treatment of the landfill leachate. The results showed that the level of pollution was significantly reduced but the effluent was highly saline (EC: 33.9 dS/m and chlorides concentration: 10,295 mg/L). This high salinity represents a major limiting factor to any kind of subsequent use or disposal. The purpose of this work was to proceed to the characterization of leachate according to the urban neighbourhoods generating the waste with the aim of identifying the origin of salinity. A comparison of the physicochemical parameters (pH, EC, suspended matter, organic matter, dry residues, BOD5, COD, nitrogen, phosphorous, ions and trace elements) between leachates produced by fresh waste originating from different neighbourhoods showed distinct differences. The main differences lay in the concentration of chlorides and EC with the leachate from the fresh waste generated by the port having higher values compared to leachate produced by fresh waste coming from other neighbourhoods. It is recommended that the waste generated by the port's activities should be treated separately so that it does not contaminate relatively less polluted leachate coming from domestic waste.

Keywords: Agadir, landfill, fresh domestic waste, port, leachate, characterization

1. Introduction
Household and similar waste (essentially commercial) often leads to the production of relatively considerable amounts of leachate presenting risks for human and animal health and for the environment. To reduce or avoid the negative impacts of urban waste leachate, regulations for their dumping have been established worldwide [1]. However, the transfer to developing countries of management models of landfills applied in developed countries (waterproofing, recovery and treatment of leachate and biogas ...) began only at the end of the twentieth century. This transfer requires adequate treatment methods of leachate which are often difficult to apply because of landfills receiving big daily tonnage of unsorted household waste. A large number of scientific publications, impact studies and specifications relating to the treatment of leachate from household waste show that the management of leachate is largely confined to leachate storage in ponds with treatment processes that may vary from direct discharge to reverse osmosis as a pre-treatment [2]. However, the composition of leachate varies greatly according to the type of waste from which it is generated, and which itself depends upon its origin. The age of the waste has also an important impact on the composition of the leachate [1; 3; 4].
A previous work on the characterization of the leachate from the controlled landfill of Greater Agadir carried out in 2011 by Koujoute [5] under the supervision of the authors has revealed a very high salinity that can make it difficult to deal with it even after treatment. The purpose of this paper is to investigate the variability of leachate composition and identify the origin of major pollutants. The study was based on the sampling of household and similar waste of Greater Agadir as well as that generated by the port (mainly fish industry). Four periods of sampling were carried out during the months of April and May 2012, taking leachate samples from

the waste of eight neighbourhoods, representative of the Greater Agadir. Each sample was then characterized in terms of physicochemical composition. For comparison, characteristics of the leachate produced by aged waste in the landfill [5] are considered.

1.1. Importance of urban waste generated in the Greater Agadir

The tonnage of waste generated by the different municipalities of the Greater Agadir is distributed as shown in Table 1 [6]. The city of Agadir, with its large population, produces more than half the waste received by the site, followed by the municipality of Aït Melloul [7]**.** The annual amount of waste received by the newly built landfill from the *ca* 800,000 inhabitants of Greater Agadir exceeded 238,000 metric tons in 2012 [6].

Table 1: Waste production by municipalities of the Greater Agadir [6]

Municipality	Agadir	Aït Melloul	Inezgane	Dcheira	Drarga	Aourir	Temsia	Laqliaa
Waste tonnage	52 %	14 %	13 %	7 %	3 %	2 %	2 %	7 %

1.2. Composition of the urban waste in the city of Agadir

Table 2 presents the various components constituting the urban waste of Agadir [8]**.** The average composition of the urban waste of Agadir is characterized by the predominance of the organic fraction (77 %), followed by plastics accounting for 10 %. This is typical of household waste from most areas of Morocco [9; 10]**.**

Table 2: Average composition of the urban waste of Agadir [8]

Matter	Organic matter	Paper and cardboard	Plastics	Metal	Glass	Other
Percentage	77	6	10	1	2	4

2. Materials and methods

2.1. Site location

The new, controlled landfill of Greater Agadir was built to the west of a small village called Tamellast on the hills of the High Atlas Mountain overlooking the city (Figure 1). The site covers a total area of 41 ha. It is situated approximately 6 km from Dakhla neighbourhood of Agadir, and 4.5 km from the former fly tipping site at Bikarrane. This newly built landfill was put into service in April 2010 after completion of the first cell.

The Tamellast site was built according to up-to-date standards for appropriate landfill of household and similar waste. The waste comes from eight municipalities composing the Greater Agadir: Agadir city, Inezgane, Aït Melloul, Dcheira, Drarga, Aourir, Temsia and Laqliaa (Figure 2).

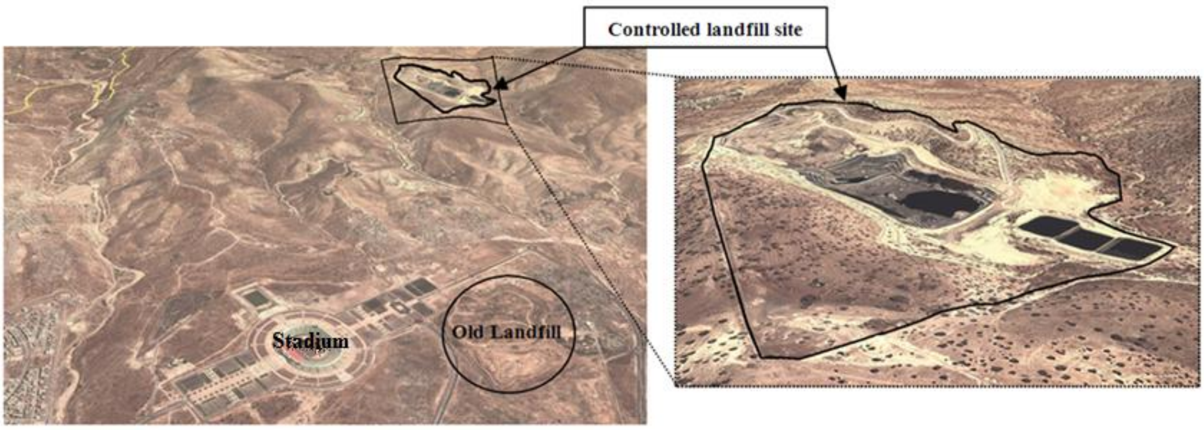

Figure 1: Location of the Tamellast landfill overlooking the city of Agadir (Google satellite image, 2013)

2.2. Sampling methodology

Apart from household waste, the Greater Agadir landfill receives other non-hazardous waste from industrial sources, and in particular waste from the fishing industry located in the port of Agadir. To characterize the leachate according to the origin of waste, eight main neighbourhoods were identified as representative sources of waste production [11] (Table 3).

Samples of leachate were taken from the garbage packer trucks that collect waste from the selected neighbourhoods. As a matter of fact the packing induces leachate sweeping from the waste in the truck. Samples of leachate were taken in contaminant free polyethylene flasks. The sampling flasks were immediately placed in an isothermal case at 4 °C and

transported to the laboratory for analyses. In the laboratory, the samples were placed in isothermal conditions to carry out the physicochemical analyses. Mineral analyses were performed in the laboratory of IAV Hassan II, Agadir and the COD and BOD5 analyses were carried out in the laboratory of the Hydraulic Basin Agency of Souss Massa Draa, Agadir.
Four periods of leachate sampling were carried out in these eight neighbourhoods, during a 3-weeks period (on 23, 24, 28 April and 15 May 2013). Five litres of leachate were taken for each sample. This volume was chosen for practical reasons.

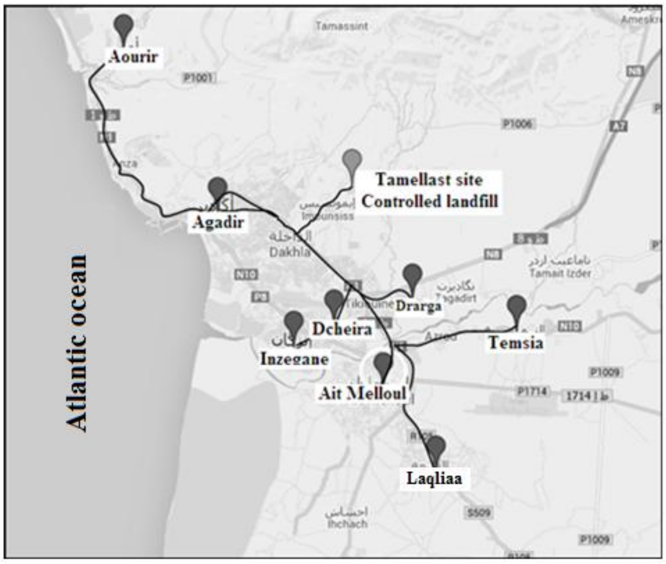

Figure 2: Location map of the eight municipalities composing the Greater Agadir

Table 3: Neighbourhoods sampled for fresh waste leachate

Municipality	Agadir				Aït Melloul		Inezgane	
Neighbourhood or Sector	Talborjt (**Tlb**)	Hassan II Avenue (**Av. H II**)	Charaf (**Char**)	Port **(Port)**	Industrial zone (**IZ**)	Agdal (**Ag**)	Taghzout (**Tgh**)	Bus station (**BS**)

2.3. Methods of analyses
Analysis of each element was repeated at least three times. All analytical methods for analyses were standard or AFNOR (*Association Française de Normalisation*) approved.

- **Physicochemical analyses**

a. The suspended matter was determined by filtration on Wattman filter paper, size 42;
b. The pH was measured by a Jenway pH-meter, model 3310;
c. The electrical conductivity (EC) was measured by a Jenway conductivity meter, model EC 4310;
d. The dry residue was determined by evaporation at 106 °C;
e. Organic matter and mineral substances were determined after calcination at 480 °C.
f. Ammonia, nitrogen and nitrate were determined by distillation using the Kjeldahl method;
g. Nitrites were determined by colorimetric procedure with a wavelength of 540 nm;
h. Chloride ions were determined by the method of Mohr;
i. Phosphorus (Orthophosphates) was determined by the colorimetric dosage method with a wavelength of 882 nm;
j. Minerals (K^+, Na^+, Ca^{2+}, Mg^{2+}) were determined with the emission spectroscopy method;
k. Metallic ions (Zn, Fe, Cu, Mn) were determined by a Perkin Elmer 3110 atomic absorption spectrophotometer;
l. The 5 day Biological Oxygen Demand (BOD5) was determined by an OxiTop IS 6 - BOD manometric method;
m. The Chemical Oxygen Demand (COD) was determined by reflexion followed by titration with Mohr’s salt (5220.C. standard method).

3. Results and discussion

The physicochemical analyses of the leachate sampled during the four sampling periods are grouped in tables 4 to 10. All pH values range between 4 and 5 except that of the port that exceeds 6 making its waste distinct from the other neighbourhoods studied. The electrical conductivity was found in a range of 10.15 to 14.33 dS/m except that of the port that was almost three times higher than the average of the other neighbourhoods (Table 4).

Table 4: Fresh waste leachate pH and EC in different neighbourhoods of Greater Agadir

Neighbourhoods	Agadir city				Aït Melloul		Inezgane	
	Tlb	Av. H II	Char	Port	Ag	IZ	Tgh	BS
pH	4.81 ± 0.14	5.20 ± 0.82	4.54 ± 0.19	6.21 ± 0.23	4.58 ± 0.33	4.59 ± 0.34	4.22 ± 0.24	4.23 ± 0.52
E C at 25 C° (dS/m)	10.15 ±2.51	11.16 ±2.84	11.81 ±2.38	35.83 ±4.89	12.56 ±3.23	14.33 ±5.39	12.56 ±1.74	13.77 ±5.42

Table 5: BOD5 and COD of fresh waste leachate in different neighbourhoods of Greater Agadir

Neighbourhoods	Agadir city				Aït Melloul		Inezgane	
	Tlb	Av.H II	Char	Port	Ag	IZ	Tgh	BS
BOD5 (g O_2/L)	18.63 ± 6.80	16.50 ± 8.09	23.65 ± 16.96	27.43 ± 16.92	28.25 ± 10.47	22.95 ± 4.66	31.34 ± 8.44	26.30 ± 15.81
COD (g O_2/L)	40.58 ±18.63	36.67 ± 19.74	47.48 ± 12.54	54.31 ± 24.60	58.10 ± 13.02	45.43 ± 11.33	52.09 ± 10.05	35.32 ± 20.35

BOD5 values range between 16.50 and 31.34 g/L with high standard deviations making comparable all the sampled sectors. COD values were between 35.32 and 58.10 g/L, following the same pattern as BOD5 (Table 5).
The suspended matter in the leachate ranged between 27.42 and 58.33 g/L except that of the port that exceeded 175 g/L (Table 6). Its shows that port leachate is characterised by significant amounts of suspended matter. The content of organic matter in the leachate of the different neighbourhoods was quite high with values ranging from 25 to 38 g/L (Table 6).

Table 6: Suspended and organic matter in fresh waste leachate from different neighbourhoods of Greater Agadir

Neighbourhoods	Agadir city				Aït Melloul		Inezgane	
	Tlb	Av.H II	Char	Port	Ag	IZ	Tgh	BS
Suspended matter (g/L)	58.33 ±27.23	42.05 ± 13.52	49.97 ± 35.61	175.40 ± 140.76	33.13 ± 26.98	57.8 5 ± 23.62	27.42 ± 13.57	42.19 ± 28.78
Organic matter (g/L)	25.19 ± 9.19	25.05 ± 10.52	32.76 ± 12.24	37.19 ± 16.20	38.21 ± 9.15	30.94 ± 5.73	33.26 ± 5.96	28.31 ± 15.00

Table 7: Total nitrogen, ammonia, nitrite and nitrate content of fresh waste leachate from different neighbourhoods of Greater Agadir

Neighbourhoods		Agadir city				Aït Melloul		Inezgane	
		Tlb	Av.H II	Char	Port	Ag	IZ	Tgh	BS
Total Kjeldahl nitrogen	mg/L	2187.5 ±534.25	1557.50 ±413.63	1676.50 ±516.34	1621.00 ±601.87	1925.00 ±567.24	1564.50 ±410.30	1837.50 ±245.00	1592.50 ±502.75
Ammonia		87.75 ±55.97	72.50 ±75.39	173.75 ±215.05	47.69 ±46.19	108.63 ±115.05	229.50 ±317.22	103.50 ±79.46	79.00 ±56.08
Nitrites		37.00 ±2.94	52.50 ± 9.47	52.25 ± 7.76	29.25 ± 2.99	87.00 ± 6.83	52.00 ± 0.82	43.25 ± 0.96	41.00 ± 6.83
Nitrates		1.68 ±0.03	1.83 ± 0.08	1.84 ± 0.01	2.25 ± 0.12	1.85 ± 0.03	1.93 ± 0.03	1.63 ± 0.03	1.65 ± 0.03

All leachates contain high concentrations of total nitrogen that ranged between 1557.50 and 2187.50 mg/L. The ammonia did not show any clear pattern in terms of concentration. The values ranged from 47.69 to 229.50 mg/L, the port having the lowest. The nitrites did not present any distinct pattern. Some neighbourhoods had high concentrations and others were rather low but it was the port that had the lowest values. The nitrates were low in general for all the sectors sampled (Table 7).

Table 8: Phosphorous and chlorides concentrations in fresh waste leachate of different neighbourhoods of Greater Agadir

Neighbourhoods		Agadir city				Aït Melloul		Inezgane	
		Tlb	Av.H II	Char	Port	Ag	IZ	Tgh	BS
Phosphorus	mg/L	96.44 ±11.74	68.16 ± 40.12	114.50 ± 55.16	75.53 ± 73.39	114.96 ± 17.05	98.47 ± 21.67	92.97 ± 58.74	58.90 ± 35.01
Chlorides		673.35 ±234.48	692.62 ±218.23	674.12 ±188.09	3721.30 ±2627.12	649.47 ±241.78	858.43 ±201.43	611.80 ±177.21	892.45 ±139.37

Phosphorous concentrations varied from 58.90 to 114.96 mg/L without any noticeable difference according to the origin of the leachate (Table 8). The chlorides concentration varied between 611.80 and 892.45 mg/L in all neighbourhoods except that of the port that was almost five times higher than the average of the other neighbourhoods (752 mg/L).
Potassium and sodium were in low concentrations in the leachate sampled from the fresh waste of the different neighbourhoods (Table 9). In contrast, calcium and magnesium showed relatively high concentrations regardless of the sector sampled. The standard deviations were high indicating that the leachate was not consistent in composition.

Table 9: Potassium, sodium, calcium and magnesium concentrations in fresh waste leachate of different neighbourhoods of Greater Agadir

Neighbourhoods		Agadir city				Aït Melloul		Inezgane	
		Tlb	Av.H II	Char	Port	Ag	IZ	Tgh	BS
Potassium	mg/L	20.94 ±4.27	21.71 ± 2.75	16.73 ± 3.29	15.77 ± 3.41	24.80 ± 3.17	20.75 ± 2.93	24.96 ± 1.98	19.42 ± 3.94
Sodium	mg/L	13.94 ± 1.30	16.32 ± 4.30	13.47 ± 3.58	12.07 ± 2.63	16.07 ± 5.67	13.52 ± 3.52	13.35 ± 4.26	11.82 ± 2.68
Calcium	mg/L	364.38 ±211.39	610.12 ± 65.40	554.81 ± 72.11	356.47 ± 175.77	687.30 ±141.79	665.16 ± 77.53	610.09 ±121.21	521.75 ±168.82
Magnesium	mg/L	224.31 ±166.03	202.42 ±137.31	179.84 ±119.76	305.27 ± 293.11	261.33 ±169.05	235.11 ±153.60	246.03 ±160.59	221.83 ±146.64

The trace elements did not show any differences between neighbourhoods but iron was far higher than the other elements investigated (Table 10). Its values were close to that of magnesium. Manganese and zinc had rather comparable values in all leachates. Copper was the lowest component with values below 1 mg/L in all samples.
It is important to stress the high values of standard deviations for all measurements indicating that the composition of leachate and hence of fresh waste was highly variable from one sampling to another.

Table 10: Iron, manganese, zinc and copper concentrations in fresh waste leachate of different neighbourhoods of Greater Agadir

Neighbourhoods		Agadir city				Aït Melloul		Inezgane	
		Tlb	Av.H II	Char	Port	Ag	IZ	Tgh	BS
Iron	mg/L	231.59 ±99.07	113.15 ±9.01	160.65 ±75.58	85.14 ± 30.26	228.50 ±3.42	90.42 ±59.14	297.20 ±10.70	151.33 ±19.99
Manganese	mg/L	5.54 ±0.97	5.27 ± 0.33	8.83 ±0.73	3.46 ± 1.64	7.66 ±2.45	7.64 ±1.14	8.23 ±2.94	6.92 ±1.54
Zinc	mg/L	13.42 ±3.76	17.80 ± 7.77	10.79 ± 3.92	5.35 ± 3.71	14.22 ±2.00	10.84 ±5.78	14.79 ±3.16	16.36 ±9.59
Copper	mg/L	0.18 ± 0.05	0.19 ± 0.06	0.13 ± 0.06	0.23 ± 0.25	0.17 ± 0.08	0.31 ±0.27	0.12 ± 0.08	0.31 ±0.22

This study was undertaken to investigate the origin of the high level of pollution, especially salinity in the leachate that percolated from the waste after 17 months of accumulation in leachate storage reservoirs, following the entry in service of the landfill [5]**.** The colour constitutes the first indicator of the pollution load of a leachate [12; 13]**.** The leachate of the fresh waste from the port and that percolating form the buried waste present a dark colour whereas that of the other neighbourhoods is brown. The dark colour is due to the presence of high amounts of organic matter decomposing in absence of oxygen (anaerobia) [14; 15; 16; 17]**.** Most of the parameter values of these leachates are higher than the legal levels allowed for indirect discharge in the environment [18]**.** Moreover the composition of the leachate varies according to the nature of waste and its age [12; 3]**.**
The results show also a clear difference between the port's fresh waste leachate and that generated by the households of 7 neighbourhoods of the Greater Agadir. The differences lie in remarkably high values in the concentrations of chlorides, suspended matter and electrical conductivity in the port's leachate.
The pH was also high in this leachate compared to that of household waste where the low values (Figure 4) are in the range of a young leachate [20; 21]**.** The acidic pH (4.25 on average) measured in the leachate of the domestic waste from the neighbourhoods (Charaf, Talborjt and Hassan II Avenue of Agadi; Argana and Industrial zone of Aït Melloul; Taghzout and Bus station of Inezgane), suggests an important production of organic acids, in particular free volatile fatty acids (VFAs) [22; 23; 14]**.** According to a large number of authors

who studied the composition of leachate [24; 19; 25; 26; 27; 28; 29; 30], these values correspond to the leachate at the beginning of the acidogenic phase of waste decomposition (Figure 3).

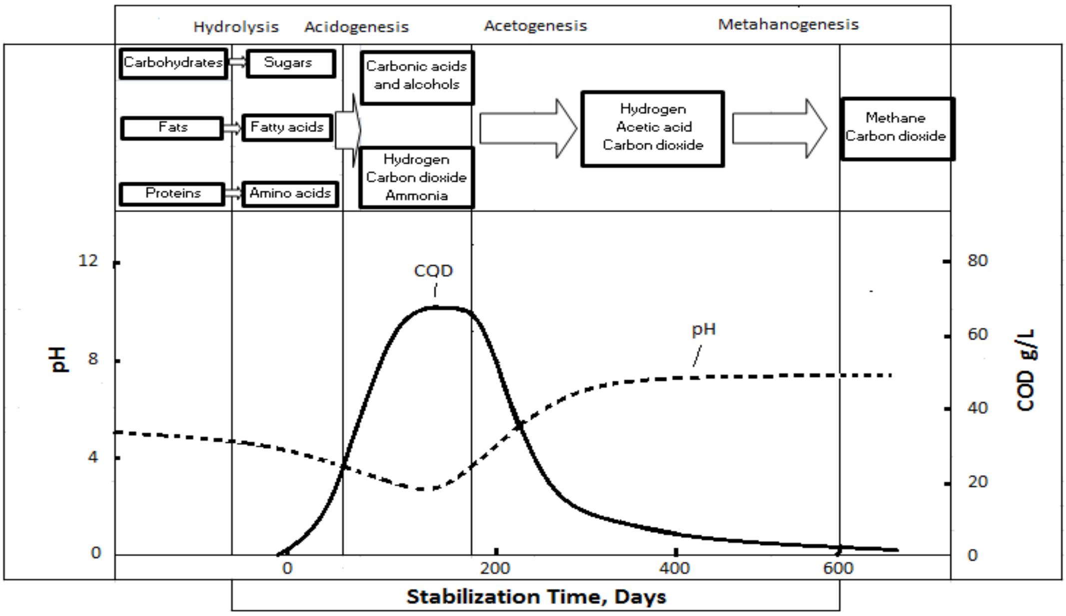

Figure 3: Illustration of COD and pH evolution in leachate in an landfill (redrawn from [19])

This difference in fresh waste leachate characteristics may be due to the variation in the conditions of biological activity. The content of ammonium (NH_4) (122 mg/L) and the acidity (pH = 4) of the leachate produced by household fresh waste may slow down certain phases of the biodegradation [3; 22]**.** Regarding total nitrogen values obtained in this study are in the range of a young leachate [30]**.**
The observed value of COD (54.31 g O_2/L) of the port's fresh waste leachate was quite high but not very different from that of the other waste. It is possible that the content in organic matter is responsible for these high values of COD [31; 32]**.**
The content in chlorides (3,721 mg/L) of the port's fresh waste leachate was well higher than in the other leachates and constituted the reason for the high electrical conductivity (Figures 5 and 6). As a matter of fact the waste of the port is essentially from fish industry that uses a lot of salt during the brining process. Moreover the readily biodegradable fish matter produces salts that dissolve in the leachate and increase the electrical conductivity and the concentration of chlorides**.** According to Berthe [33] and Robinson [34], the more the waste is pre-processed (ground) the more it is in a degraded state and hence the more organic matter rich leachate it generated. Sponza and Agdad [35] also confirmed that the grinding of waste has positive effects on the rate of their biological degradation. It can therefore be concluded that the waste form the port largely contributed to the high salinity reported in the leachate that percolated from the buried waste [5]**.**

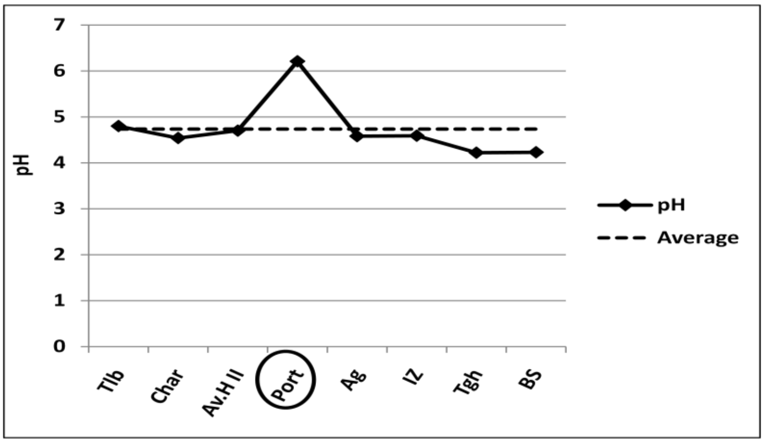

Figure 4: pH in the leachate of fresh waste from 8 neighbourhoods of Greater Agadir compared to the average value

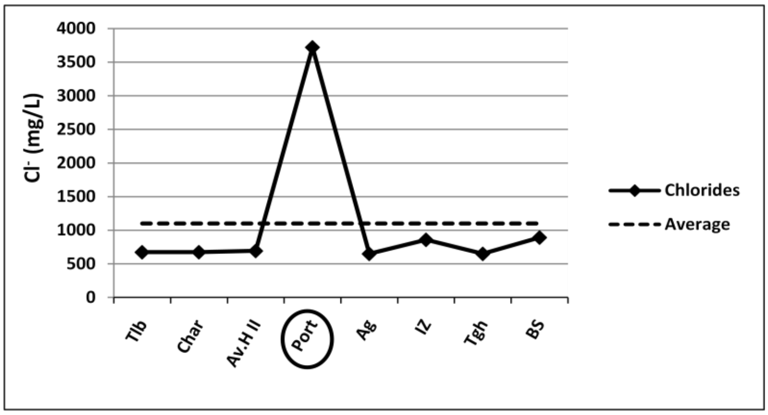

Figure 5: Chlorides in the fresh waste according to the 8 sectors sampled in Greater Agadir

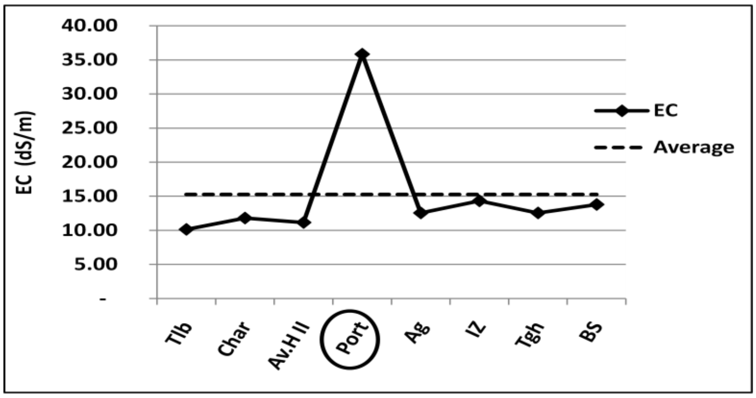

Figure 6: Electrical conductivity in the fresh waste according to the 8 sectors sampled in Greater Agadir

Table 11: Physicochemical composition of the leachate from the port's fresh waste, the other neighbourhoods and the upper limits for discharge

Parameters			Fresh household waste leachate (average)	Port fresh waste leachate	Limit values for direct discharge (in the environment)*	Limit values for indirect discharge (in the sewer)*
pH			4.52	6.21	6.5-8.5	6.5-8.5
BOD5		g/L	22.980	28.630	0.1	0.5
COD			44.770	54.310	0.5	1
Organic matter		mg/L	30.89	37.19	-	-
Total nitrogen			1780	1771	30	-
Ammonia			122	47	3	-
Electrical conductivity at 25 °C		dS/m	12.34	35.83	2.7	-
Chlorides		mg/L	868	3721	0.2	-
Nitrates			1.78	2.28	3	-
Nitrites			40	29.92	3	-
Phosphorus			94.52	75.55	10	10
Suspended matter		g/L	42.05	17.54	0.05	0.6
Major cations	Potassium	mg/L	21.29	15.76	3	-
	Sodium		13.87	18.28	3	-
	Calcium		356.61	567.3	3	-
	Magnesium		357.18	286.18	3	-
Metallic ions	Iron	mg/L	181.95	85.16	3	3
	Manganese		7.15	3.45	1	1
	Zinc (Zn)		14.22	5.35	5	5
	Copper (Cu)		0.23	0.11	0.5	1

* Values cited in [36]

Conclusion

This work represents a confirmation of the difficulty to characterize the leachate produced by urban waste because of the variability as indicated by the high values of standard deviations of the measurements (Tables 4 to 10). The results also show clearly that the waste originating from the port produces a leachate with distinct characteristics, especially having a high level of salinity. It can be inferred that the high salinity measured in the aged buried leachate produced by the landfill [5] is greatly contributed to by the waste coming from the fish industry of the port. Based on these results it is recommended that the waste from the port should be damped separately and treated according to its physicochemical characteristics. For this purpose a separate cell should be built for this particular waste with a pond for storage and treatment of the leachate welling out from it.

So far no leachate treatment system of the controlled landfill of Greater Agadir has been set yet. Nonetheless given the pollution load of the leachate whatever its origin (domestic or industrial), it cannot be discharged directly nor indirectly as its composition shows values that are higher than the upper limits for discharge (Table 11). It is therefore important to consider differential treatment processes depending on the type of waste and hence the leachate generated. It should be stressed that any treatment process should be adapted to the variability of the waste input and to the local conditions since in Agadir, the climate is warm even in winter and the rate of biomass degradation can be relatively high.

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