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Impact of Earthquake Demolition Debris on the Quality of Groundwater in Boumerdes, Algeria

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This study is a contribution to the assessment of actual impact on the quality of groundwater of buried demolition debris from the city of Boumerdes, in the North of Algeria 5 years after the May 21st 2003 earthquake hit the region. Leachate analysis indicated organic matter with relatively high COD (1136 mg/L O_2) and BOD_5 (200 mg/L O_2); whereas the pH yielded 7.65 thus indicating fermentation phase of the landfill. Heavy metal contents are beyond national standard limits except for Pb with 0.51 mg/L which is slightly higher than limit value of 0.5 mg/L. More than 5 years after the creation of this landfill and despite its predominant C and D nature, these results showed that it is following a typical urban wastes decomposition scheme. Same analysis carried on water samples drawn from the piezometers yielded following results: acidic pH (6.88), acceptable values of target heavy metals concentrations except for Zn with 0.779 mg/L. Additionally bacteriological cross analysis (membrane filter and multi-tube methods) showed groundwater contamination by total coliforms (1100/100 mL), fecal coliforms (11/100mL) and fecal *streptococci* (1100/100 mL).

Key Words: Demolition debris, Landfill, Leachate, Heavy metals, Groundwater, Infiltration.

INTRODUCTION

The solid waste management is governed by the standards of the user which must respect otherwise they expose themselves to pollution that may follows. For instance, it is common sense, that water pollution may be caused due to the industrial effluents such as exhaust fumes and gases liquid or solid wastes that strongly contribute to water quality impoverishment. Same applies for extensive agriculture which requires fertilizers that induce increasing water pollution risks. The pollution generated by solid waste from house demolition has long been underestimated as presenting no danger in the short term[1,2].

This study is a contribution for the assessment the impact on groundwater pollution by demolition debris generated by the may 21rd, 2003 earthquake of Boumerdes. To face the emergency and urgency, demolition debris were quickly buried in temporary sites (which still remain untreated) in places that poses no difficulty for approval (generally state owned agricultural lands) without any preliminary study of impact. Indeed, this disaster has caused severe damage to facilities that generated tens of millions of tons of debris and rubble. Thus, there are 22 landfills totalizing some 30 million cubic meters and occupying a total area of 100 ha.

Present study focuses on the landfill of the city of Boumerdes and surrounding communities (Boudouaou, Corso, Figuier and Tidjelabine), where debris of more than 2300 demolished homes have been stored.

This landfill is suspected to affect the quality of surface and underground as rainfalls generate leaching of stored debris which, in turn, generate lixiviates that infiltrate the soil and cause chemical pollution of water by the ETM. All of these inter-actions between the dump and the receiving environment exacerbate the risks of pollution. Present investigation concerns cross impact of possible pollution by the landfill on (i) Health and environment caused by unpleasant smoke and odor and toxic fume inhalation. (ii) Water and soil contamination caused by lixiviates.

Location of landfill: There are five landfills for Boumerdes and its communities, one in Tidjelabine, two in Figuer another one in Corso and the last one in Boudouaou.

All of these sites are in the form of low slope of about 5-10 % and covers an area of 10 ha, whereas their altitude varies between 850 and 900 m.

The slope promotes water runoff. Indeed, lixiviate or rainwater entering the waste is the source of runoff processes favouring pollution by infiltration through limy/sandy soil cracks. The selection of any current site for demolition debris land-filling obeyed only to criteria of accessibility and proximity.

Hydrological and geological context: The geological formations at the outcrop in the studied area consist of marls with intercalations of fissured limestone and alluvium, respectively, of Cretaceous age and Mio-Plio-Quaternary (Table-1).

TABLE-1
ESTIMATION OF MOST PREVALENT MATERIAL TYPES IN DISPOSED WASTES

Material type	Est. mass (tons)	(%)
Concrete (including iron framework)	399140	54.30
Bricks (clay)	6200	0.85
Gypsum	12680	1.75
Paints and wall coatings	2500	0.35
Lumber	3690	0.50
Plastics*	63616	8.65
Household waste**	212055	28.85
Miscellaneous***	35342	4.80

Tidjelabine landfill; *Mainly beverage containers, grocery and trash bags, films and durable items; **Includes food rests, stale fruits and vegetables leaves and grass, paper, textile, glass, plastic bags, domestic appliances and other small consumer electronics; ***Includes used vehicle parts, batteries, used oil, ash, electronics, tires, asphalt, industrial sludge, glass.

These formations give the sites a variable permeability in the horizontal and vertical directions. Indeed, frequent feature changes (transition from alluvial formation to cracked or compact limestone) are the reason for important variation in permeability. As a matter of fact, we switch from a permeability of about 10^{-2} m s^{-1} to nearly 10^{-6} m s^{-1}. Thus, the flow directions follow existing cracks.

However, the hydro-geological studies conducted in the area shows that there are two aquifer horizons. The first one has a relatively short depth (maximum 10 m), the alluvial Mio-Plio-Quaternary being its bottom seat and which may be polluted by inputs from the landfill. The second one is deeply located across the valangian-Albian sandstone.

Precipitations in the area average 410.5 mm $year^{-1}$ (2005/2006) and accentuate the movement of pollutants either through infiltration or by surface runoff.

Waste characterization: The town of Boumerdes covers an area of 1800 ha occupied by inhabitants (2005). The estimated masses (tons) of various types of debris[3] buried in the site is given in Table-2.

EXPERIMENTAL

In present study, a sampling campaign and analysis was performed on the leachate from the landfill and three control wells that serve as piezometers. The collection is made to the month of March 2007 and covered the major ions, heavy metals, nitrogen, chemical applications and biological oxygen demand (COD and BOD_5), organic matter and minerals and microbiological analysis of groundwater. Temperature, pH and conductivity were measured on site.

TABLE-2
LOCALIZATION AND USE OF THE SELECTED PIEZOMTERS CLOSE TO THE TIDJELABINE DISCHARGE

Desigantion of taking point	Situation *vis-a-vis* centre (O) of the landfill	Distance (m) from O
S1	East. Well of 2 m depth domestic use. piezometer	300
S2	North in residential. Well of 8 m depth domestic use	350
S3	South West in agricultural land. Well of 8 m depth irrigation use	420

The three wells designated S1, S2 and S3 were selected near the discharge. Table-2 gives information concerning the status of wells from the landfill. The proximity of the wells from the landfill centre is important because they are more liable and vulnerable to all forms of pollution.

Composition of leachate from a landfill: Landfill leachate is similar to complex industrial waste containing both contaminating substances: organic and inorganic. Often, the inorganic contaminants are very toxic. Thus, their composition varies depending on the nature of waste, age of discharge, the technical operating and climatic conditions[4]. Leachate may come from either waste water or rain weather and also from the water of the aquifer[5].

RESULTS AND DISCUSSION

The colour is the first indicator of pollution. The analyzed leachate taken downstream of the landfill has a brownish colour and a faecal smell, thus influencing the quality of groundwater. Results of leachate analysis are reported in Table-3. Heavy metals concentrations are compared with values of similar landfills in Table-4. Results of physical and chemical analysis of groundwater samples are given in Table-5, while their cross bacteriological states are given in Tables 6 and 7. Finally, Table-8 compares target heavy metals yields found in leachate with those in groundwater of the site.

It is noticed that the chemical oxygen demand (COD) in leachate exceed widely accepted standards. Indeed, it is above the average standard of Algeria which is about 120 mg L^{-1} and

TABLE-3
RESULTS OF LEACHATE SAMPLES ANALYSIS TIDJELABINE DISCHARGE

Concentrations	Sample 1	Sample 2	Sample 3	Sample 4	IANOR standard
pH	7.370	7.50	7.65	6.940	6.5-8.5
DCO (mg L^{-1})	36.400	1136.00	53.76	980.980	120.0
DBO_5 (mg L^{-1})	8.100	198.90	1.60	145.600	35.0
MES (mg L^{-1})	12.000	10.00	16.00	10.000	35.0
Nitrates (mg L^{-1})	0.300	0.10	0.30	0.200	50.0
Nitrites (mg L^{-1})	0.016	0.01	0.02	0.002	0.1
Chlorures (mg L^{-1})	62.400	60.98	31.19	25.520	500.0
Sulfates (mg L^{-1})	75.000	75.00	43.00	64.000	400.0
Phosphates (mg L^{-1})	13.000	8.00	0.39	0.740	10.0
Ammonical nitrogen (mg L^{-1})	0.010	0.02	0.01	0.040	30.0
Pb (mg L^{-1})	5.890	0.02	<0.01	0.510	0.5
Zn (mg L^{-1})	6.700	0.16	<0.01	0.470	3.0
Cd (mg L^{-1})	<0.010	<0.01	<0.01	2.780	0.2
Cu (mg L^{-1})	<0.010	<0.01	<0.01	<0.010	0.5

TABLE-4
COMPARISON OF THE LEVELS OF HEAVY METALS IN LANDFILL LEACHATE

Target metal (mg/L)	Tiaret	Eljedida	Wadi akrech	Eteffont	Tidjelabine
Zn	0.50	0.0474	0.700	0.740	6.700
Cu	–	0.1580	0.450	0.270	0.050
Ni	0.60	0.1330	0.250	0.210	6.700
Cr	0.30	0.1560	0.500	0.270	3.400

TABLE-5
RESULTS OF PHYSICAL-CHEMICAL ANALYSIS OF GROUNDWATER

Parameters	S1	S2	S3
pH	6.3700	6.5600	6.8500
HCO_3^- (g L^{-1})	40.5800	417.9700	88.0000
Ca^{2+} (mg L^{-1})	44.9200	116.7120	126.9730
Mg^{2+} (mg L^{-1})	13.4200	39.4950	0.0000
Cl^- (mg L^{-1})	09.1960	327.4800	98.8540
SO_4^{2-} (mg L^{-1})	38.6810	139.0870	399.1550
MES	0.3000×10^{-2}	1.7000×10^{-2}	0.7000×10^{-2}
DCO	74.00	32.00	82.00
BDO_5	30.00	20.00	40.00
NO_2^- (mg L^{-1})	0.0190	0.0100	0.0000
PO_4^{2-} (mg L^{-1})	0.0200	0.0400	0.1400
Cd (mg L^{-1})	0.0070	0.0078	0.0060
Cu (mg L^{-1})	0.0140	0.0047	0.0122
Pb (mg L^{-1})	0.0220	0.0000	0.0000
Zn (mg L^{-1})	0.0790	0.0124	0.7790

TABLE-6
BACTERIOLOGICAL COMPOSITION OF GROUNDWATER BY THE METHOD OF THE MEMBRANE FILTER

Germs	Well 1	Well 2	Well 3
Coliforms	> 300	> 300	> 300
Fecal Coliformes	Present	Present	Present
Fecal Streptococci	Present	Present	Present

TABLE-7
BACTERIOLOGICAL COMPOSITION OF GROUND WATER BY THE METHOD OF MULTIPLE TUBES

Germs	Well 1 (mL)	Well 2 (mL)	Well 3 (mL)
Total coliforms	11/100	28/100	1100/100
Fecal coliforms	11/100	3/100	7/100
Fecal streptococci	9/100	7/100	1100/100

TABLE-8
YIELDS OF HEAVY METALS IN LEACHATE *vs* GROUNDWATER

Heavy metal (mg/L)	Leachate	Groundwater
Cd	2.78	0.078
Cu	0.10	0.014
Pb	0.51	0.022
Zn	0.47	0.779

reached 1136 mg L^{-1}. As for BOD_5, it varies between 135 and 200 mg L^{-1} whereas the accepted standard is 40 mg L^{-1}, thus showing significant pollution. However, the actual concentration of BOD_5 is still higher than the values found because the medium is loaded with toxins.

The concentrations of heavy metals (cadmium, chromium, zinc and nickel) are beyond acceptable standards. The concentration of lead is at the limit of the standard. Heavy metals in leachate inhibit microbial growth.

The results of chemical characterization of raw leachate from Boumerdes landfill indicated a dual pollution:

(i) An organic pollution which results in a high load of COD in the leachate, in sample 2 for instance, the COD is about 1136 mg L^{-1} O_2 L^{-1} and BOD_5 is approximately 200 mg L^{-1} O_2 L^{-1}.

(ii) A mineral pollution that results in high concentrations of some additional heavy metals in leachate, such as in sample 1 for instance with values of 3.4 mg L^{-1} for Cr, 6.7 mg L^{-1} for Ni and 6.7 mg L^{-1} for Zn.

The metal composition of the leachate from the Boumerdes landfill seems to be typical of a landfill of household dominant character. Indeed, when comparing the concentrations of same metallic elements (Cu, Cr, Ni, Zn) to those of leachate generated by other garbage dumps in Tiaret (Algeria), Rabat (Marocco) or Eteffont (France), we find that the values are higher for the Tdjelabine landfill, except for Cu.

Therefore it becomes essential to recover and treat the juice from the landfill to avoid any risk of environmental contamination by infiltration of the leachate.

Applied to the analyzed leachate from the landfill, the ratio BOD_5/COD gives values ranging from 0.11-0.25, typical of an ancient but not yet stabilized landfill and corresponding to the acid phase of anaerobic degradation[6]. The ratio gives values ranging from 0.11-0.25, typical of an ancient but not yet stabilized landfill and corresponding to the acid phase of anaerobic degradation.

The results of analysis conducted on groundwater proved that the first aquifer (maximum 10 m depth) has already been contaminated by leachate effluents, thus confirming its state and condition of polluted non-potable water.

As a matter of fact, both piezometers S1 and S2 contain weak acid waters (pH of 6.37 and 6.56, respectively) indicating the influence of the discharge on groundwater. On the other hand, S3 has a higher pH of 6.85, but still under neutrality.

For the other parameters, mainly dissolved oxygen, (NO_3, COD, BOD_5), levels are found prove low organic matters content in groundwater, but still are higher than the accepted standards of potable water. Pick concentrations of target metals (0.078 for Cd, 0.014 for Cu, 0.022 for Pb and 0.779 for Zn) in groundwater are higher than acceptable limits.

Two methods have been used for the evaluation of bacteriological composition of groundwater in order to ensure more precise results. The membrane filter method confirmed the presence of target germs, the multi-tubes one quantified them. The results show that water wells contain important pathogens (Total Coliforms up to 1100, Fecal Coliforms up to 11 and Fecal streptococci up to 1100/100 mL) showing a significant bacteriological contamination of groundwater. Well 3 is the most polluted due to its location on the site. This latter is located downstream of the discharge and flows follow this direction. Furthermore, the permeability of cracks would promote the infiltration of leachate.

The temperature plays an important role in increasing bacterial activity and evaporation of water. Indeed, temperature is a key element in the enumeration of aquifer systems. It varies depending on seasonal ambient temperature, the geological nature of the soil and the depth of the aquifer level under soil surface[2]. In Tidjelabine case study temperature varies between

12 and 15 ºC, thus low enough to avoid micro-organisms proliferation in groundwater, so the important presence of coliforms and fecal streptococci can only be explained as the result of contamination by leachate infiltration.

Conclusion

This study concerned the impact of debris and rubble from the demolition of cities following an earthquake and which were considered safe and inert. In case of the Tidjelabine landfill, the results of the analysis conducted on leachate and water proved the severeness of this type of debris resulting in a real double impact on environment:

A direct impact on surface water as rainfalls are polluted by leachate runoff promoted by slope configuration of the site.

An indirect impact as groundwater is polluted by leachate infiltrations through cracks of porous soil.

The concentration of target heavy metals in leachate from the landfill is evolving towards a dominant municipal solid waste discharge, although it was, originally, a landfill for demolition and construction debris assumed to be inert[7]. A first explanation of this evolution may come from the presence of organic matters in the debris coming from demolished constructions by the earthquake at first hand and from household waste later as the status of this discharge remained open for sometime after the earthquake.

The presence of germs in the piezometers shows that water is no more potable in the vicinity of the landfill and users have been immediately informed about it. These results contribute to the enrichment of on the ground data concerning landfilled earthquake debris behaviour.

Because of higher risk of contamination of our limited water resources due to leach toxicity of the debris[8], we strongly recommend the Management of Boumerdes to quickly address the issue through the implementation of a two-phase program: reuse and recycling of the debris as a first priority, in order to eliminate the pollution source, followed by remediation of the site in the second place, using appropriate treatments for heavy metals polluted soil and groundwater.

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