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Seasonal changes in pollutant composition in leachates from a waste management landfill site: Magtaa Kheira case study

M. Almi[a,*], N. Sahraoui[a], D. Tassalit[b], B. Korichi[c], F. Khelifi[c], S. Ladjerem[c]

[a]*Laboratory of Matter's Valorization and Recycling of Materials for Sustainable Development (VRMDD), University of Sciences and Technology Houari Boumediene, El Alia BP32, 16111, Bab Ezzouar, Alger, Algeria, email: maralmi@usthb.dz (M. Almi)*
[b]*Solar Equipment Development Unit, UDES, Renewables Energy Development Center, Route National N11, BP 386, Bou-Ismail 42400, Tipaza, Algeria*
[c]*Laboratory of the Leachate Treatment Unit of the Magtaa Kheira Technical Landfill Center, Mehalma, Algeria*

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ABSTRACT

The aim of this study was to identify the composition of the leachate from a landfill center at a case study site in Magtaa Kheira city in Algeria and how it varied over seasons. The physico-chemical characterization of the Magtaa Kheira landfill leachate showed a high mineral and organic load. The organic contents were reflected by high values of chemical oxygen demand (14,094.85 mg·L^{-1}), biological oxygen demand (2,300 mg·L^{-1}). As for the mineral pollution, it was reflected by the high average electrical conductivity (26.13 mS·cm^{-1}). The results showed that the leachates of the Magtaa Kheira, were in an intermediate state between young and old leachates. The results of this spatio-temporal (i.e., space and time) study showed that the leachate contained high concentrations of organic and inorganic constituents beyond the permissible limits. All parameters such as electrical conductivity, biological oxygen demand, chemical oxygen demand, ammonium and orthophosphate correlated positively with temperature. This meant the warmer the season, the higher the contamination values. It was concluded that waste landfill age and seasonal temperature had a significant effect on leachate composition.

Keywords: Characterization; Landfill center; Leachate quality; Waste management; Seasonal variations

1. Introduction

The rational, safe, and sustainable management of waste is one of the major challenges facing humanity [1,2]. The production of waste is rapidly increasing in quantity, thus generating enormous public health and environmental risks. This situation is more worrying in poorer developing countries. Solid waste disposal methods include open dumps, sanitary landfills, incineration, composting, grinding and discharge to sewer, compaction, hog feeding, milling, dumping, reduction, and anaerobic digestion. Sanitary landfills are the most common techniques for waste management [1,2]. It represents an economical option because landfills offer the possibility of accumulating large amounts of solid waste with a very low cost as compared to other waste management methods [1]. However, this technique of waste disposal often produces large amounts of liquid leachate consisting mainly of contaminated wastewater with a high content of dissolved organic matter (DOM), which may seep out of the fill and into the surrounding water [3].

Leachates from municipal solid waste sites are generated as a mixture of rainwater percolation through the wastes, water contained in the wastes and those of its degradation

* Corresponding author.

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[4]. The physico-chemical quality of these effluents is very diverse and variable in time and space (i.e., spatio-temporal) [5]. As soon as waste is dumped, it begins to degrade through complex biological and physico-chemical processes. Leachate can contain organic matter (i.e., biodegradable, but also refractory to biodegradation) consisting mostly of humic substances [6], as well as ammoniacal nitrogen, heavy metals, organochlorines, and inorganic salts [7,8]. In the North African country of Algeria, for example, the situation is aggravated both by the population's concentration along the coastal area, where urban centers and industrial zones are situated, and by the deficiencies of the existing infrastructures, which are unable to deal more rationally with the waste problem.

The aim of this study was to identify the components of the leachate from a waste management landfill and how they varied. A case study site was chosen at Magtaa Kheira in Algeria over the seasons. The pollution potential was evaluated with respect to seasonal effect.

1.1. Case study area

Originally established by the former Ministry of Land Management and Environment (MATE), the present project was managed by EPIC-GECETAL, a public company that had been created in 2013 and was subordinate to the Wilaya of Algiers. Located in 4.7 km from the town of Mahelma in the West of the Capital, the technical landfill center of Magtaa Kheira was a class II center that covered an area of 90 ha (Figs. 1 and 2). It received household waste from 55 municipalities. This site was located at an altitude of more than ten meters above sea level. The climate of this site was

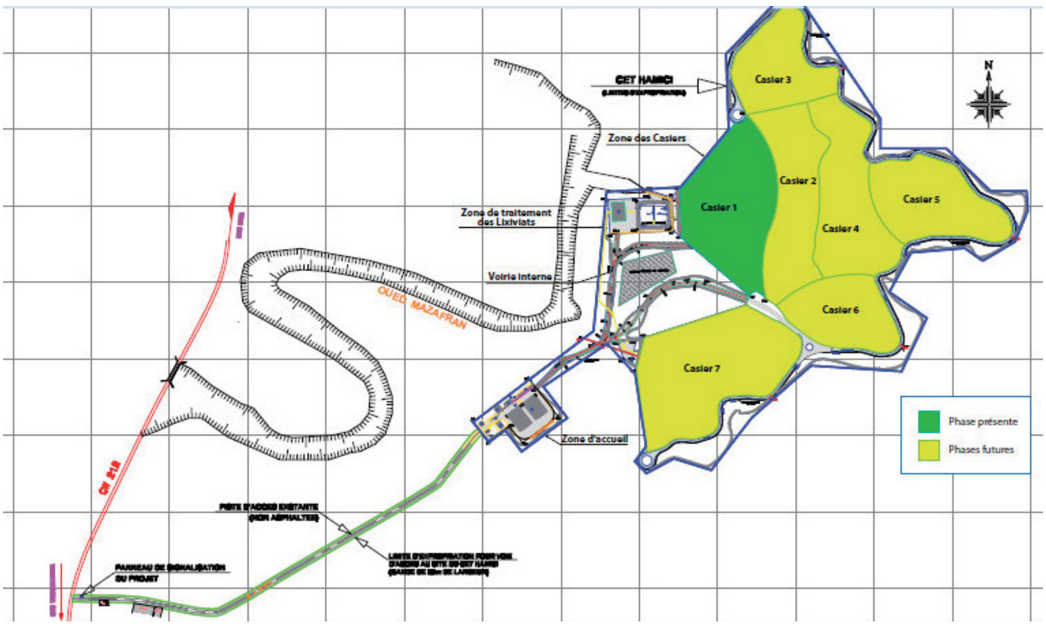

Fig. 1. Geographical location of the technical landfill center of Magtaa Kheira (Hamici).

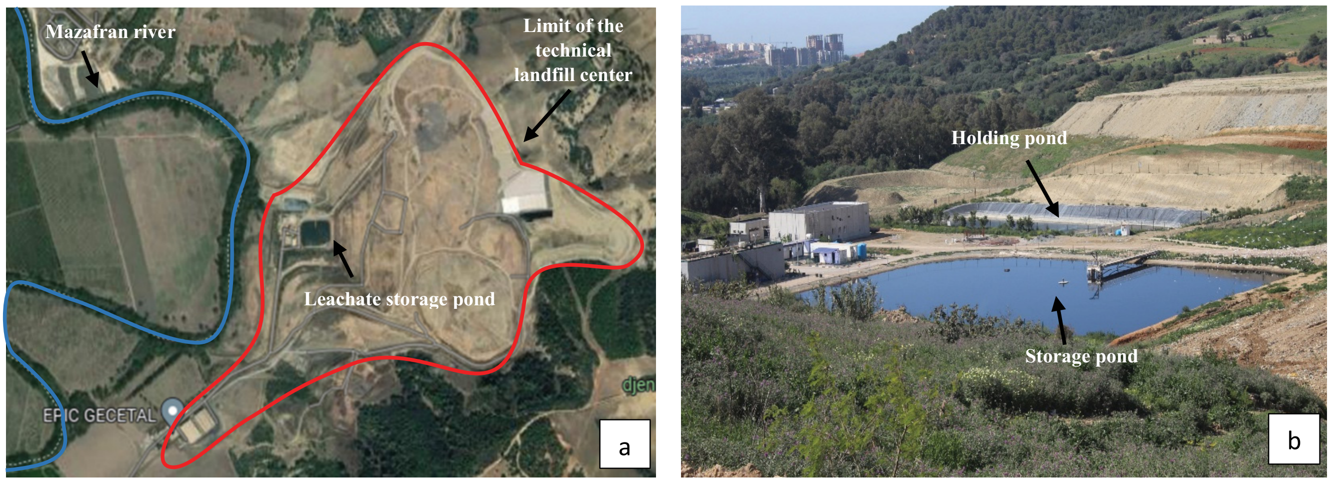

Fig. 2. (a) Limit of the Magtaa Kheira landfill site and (b) storage and retention pond for leachate from the landfill site.

characterized by a wet and cold winter and a warm and dry summer.

2. Materials and methods

2.1. Leachate sampling

The technical landfill center of Magtaa Kheira was equipped with a collection and drainage system of leachates which, after being accumulated at the bottom of the pits, were then drained to a storage pond of 30,000 m^3 capacity. Leachate samples were collected from the storage pond during the period of 2019, 2020, and 2021 at a rate of one c per month. The samples were immediately transported to the laboratory of the Magtaa Kheira station and were stored in a cold room at 4°C to minimize biological and chemical reactions.

2.2. Leachate characterization

The samples were characterized in terms of electrical conductivity (EC), biological oxygen demand (BOD_5), chemical oxygen demand (COD), ammonium (NH_4–N), and orthophosphates (PO4-P), which were measured in the laboratory of the Magtaa Kheira station according to Standard Protocols AFNOR and ISO. The pH and temperature were measured in situ at the time of sampling using a mobile multiparametric device. Nutrients were measured with reference to the

Table 1
References of analysis methods for the different pollution parameters

Parameters	Methods and equipment	References
Temperature and pH	pH meter Sensio (Hach)	NFT 90-008
Electrical conductivity (EC)	Conductivity meter (Mettler Toledo MC226)	NFT 90-031
BOD_5	Test BOD_5	ISO 5815
COD	Titrimetric method	ISO 6060
Ammonium	Spectrophotometer (Hach DR 2800-2400)	ISO 7150/1
Orthophosphates	Spectrophotometry	ISO 6878

Table 2
Physico-chemical properties of the leachates of Magtaa Kheira landfill as well as the Algerian regulatory limit for effluent discharge into the water environment

Characteristics	Leachate Magtaa Kheira	Regulatory discharge limits in the public hydraulic domain
Temperature, °C	22.47	30
pH	8.39	6.5–8.5
Electrical conductivity, mS·cm^{-1}	26.13	–
COD, mg·L^{-1}	14,094.85	120
BOD_5, mg·L^{-1}	2,300	35
NH_4–N, mg·L^{-1}	1,546.88	30
PO_4–N, mg·L^{-1}	19.95	10

Table 3
Physico-chemical characteristics of the leachates from the Magtaa Kheira landfill in comparison with literature studies

Characteristics	Magtaa Kheira	El Kerma (Algeria) [19]	Ouled Fayet et Biskra (Algeria) [20]		Akouedo (Cote d'ivoire) [18]	Fès (Morocco) [29]
			Ouled Fayet	Biskra		
Temperature	22.47	23.7	–	–	29.8	–
pH	8.39	8.19	7.9–8.1	6.8–8.2	7.68	7.66
Electrical conductivity, mS·cm^{-1}	26.13	120.3	–	–	7.80	24.6
COD, mg·L^{-1}	14,094.85	19,333	5,472	1,845.5	1,306.25	5,400
BOD_5, mg·L^{-1}	2,300	3,301	1,400	1,900	588.08	1,700
NH_4–N, mg·L^{-1}	1,546.88	2,726	–	–	388.4	–
PO_4–N, mg·L^{-1}	19.95	–	–	–	128.74	–

chemical analysis methods described by Gaïd [9]. The analysis of the organic matter focused on the parameters COD and BOD_5, that were measured according to the methods described by Rodier [10]. The references and standards relating to the analytical methods are presented in Table 1.

3. Results and discussion

The leachate from the Magtaa Kheira technical landfill center had a brownish color and a fecal smell. The examination of the average values of the physico-chemical parameters calculated during a period of three years covering 2019–2021 are summarized in Table 2. This indicated that the leachates presented a diversified and high polluting load in comparison with those mentioned in the literature which are assembled in Table 3. The chemical composition of leachate was specific to each landfill. It varied significantly with the nature and age of the landfill, the type of waste and its degree of decomposition, the method of landfilling, the nature of the landfill site and the climatic conditions [11–17].

3.1. Physical parameters: temperature, pH and electrical conductivity

The seasonal evolution of temperature revealed that the leachate from Magtaa Kheira had a temperature range of 16.77°C–26.26°C, with an average value of about 22.47°C. The maximum values were obtained during the summer season, in parallel with a low rainfall and a high atmospheric temperature (Fig. 3). These values would be favorable to the maintenance of colonies of "mesophilic" microorganisms that developed at a temperature between 20°C and 40°C [18]. A higher temperature was observed during the autumn season that could be explained by the increase in atmospheric temperature of the Mehalma region.

The monitoring of the pH parameter over the four seasons showed that the values oscillated between 7.5 and 9 with an average value of 8.05 (Fig. 4). This revealed that the hydrogen potential was slightly neutral to alkaline for the landfill of Magtaa Kheira. The results were similar to those obtained by others [18–21]. These values could be related to the low concentration of volatile organic compounds. During acid fermentation, the first phase of the anaerobic decomposition of waste, the young percolates were rich in volatile organic compounds. During this phase, the pH values recorded were generally lower than 4 [22]. As the landfill aged, the leachate becomes depleted in volatile organic compounds. This would then drive the pH up to 7 or higher [23].

Electrical conductivity reflected the amount of salinity and minerals in the leachate samples. It depends on the climatic conditions and the type of incoming waste. Bacteria present in municipal waste are responsible for oxidation, hydrolysis, and remineralization of organic matter, from which the leachate becomes rich in mineral elements [24]. The values of electrical conductivity recorded oscillate between 18, 61 mS·cm^{-1} and 29, 63 mS·cm^{-1}, the high values were observed in the dry season, due to the effect of temperature on the activity of bacteria and on the water fraction evaporation (Fig. 5). However, during the rainy season, the decrease of the conductivity could be explained by the dilution effect. Indeed, during the rainy season, the leachates receive a significant amount of water resulting in a considerable dilution of the chemical elements present [18].

The values of electrical conductivity measured for Magtaa Kheira leachate are similar to those found by Kehila et al. [20] for the Akouedo landfill (ABIDJAN-COTE

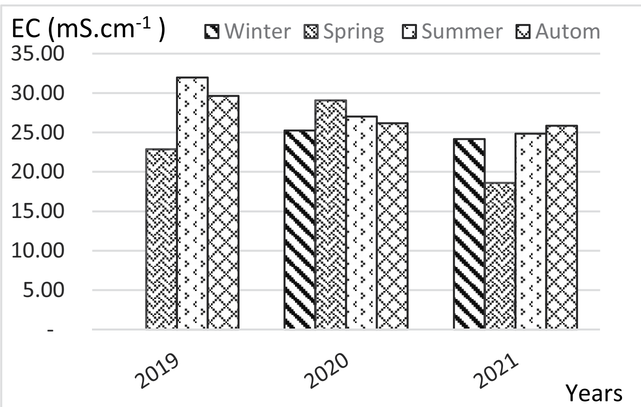

Fig. 3. Spatio-temporal evolution and temperature values of the Magtaa Kheira leachates.

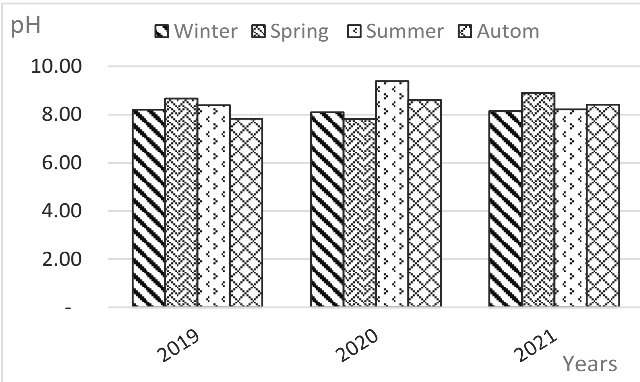

Fig. 4. Spatio-temporal evolution and pH values of Magtaa Kheira leachates.

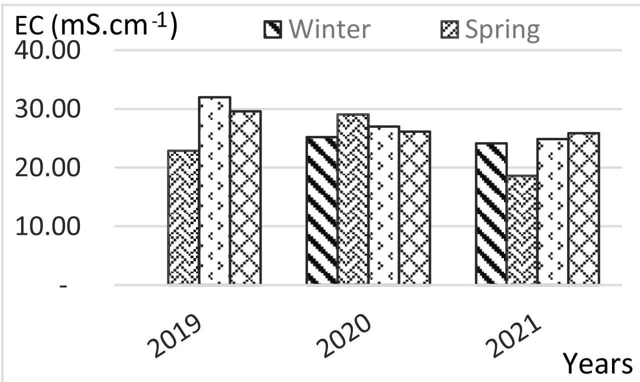

Fig. 5. Spatio-temporal evolution and EC values of Magtaa Kheira leachates.

D'IVOIRE), and largely lower than those observed by Bennama et al. [19] for the El Kerma landfill (ORAN).

3.2. Organic parameters: chemical and biological oxygen demand

Chemical oxygen demand (COD) represents the amount of oxygen consumed by chemical oxidizable materials contained in the water. It is representative of most organic compounds and mineral salts oxidizable [25]. The seasonal evolution of COD showed that high concentrations of COD were recorded during the summer season, these started to decrease with the arrival of winter while rains were high (Figs. 6 and 7). Several authors [26,27] have shown that when the temperature of the leachate was higher, the increase in organic load was associated with the maximum development of bacterial abundance and a decrease in oxygen concentrations due to its consumption by decomposers. The COD values obtained were like those published by Bennama et al. [19] for El Kerma landfill (Oran) and those obtained by Saadi et al. [28] on Oujda landfill (Morocco). However, they were much higher than those recorded in Fes (Morocco) by Khalil et al. [29] and those contributed by Mokhtaria et al. [30] on the Tiaret landfill in Algeria. This difference in COD values may have been related to the design of the landfill, the

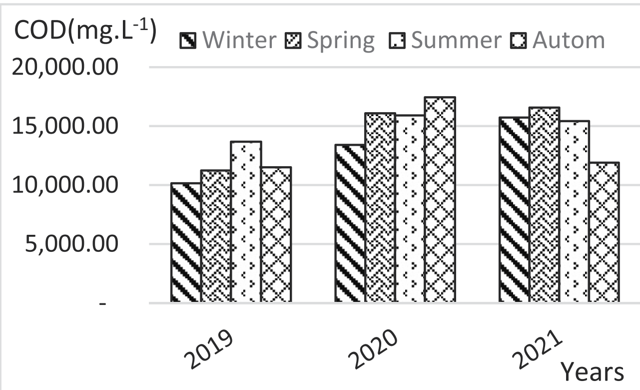

Fig. 6. Spatio-temporal evolution and COD values of Magtaa Kheira leachates.

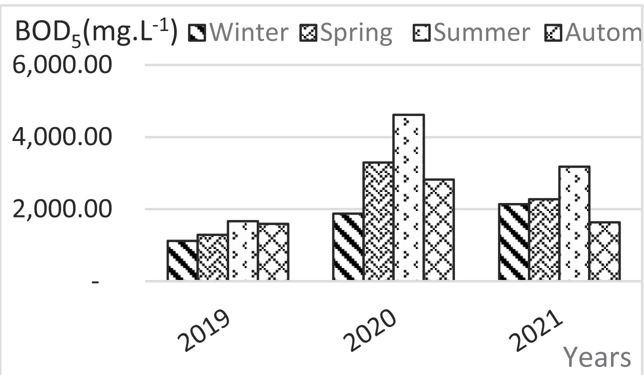

Fig. 7. Spatio-temporal evolution and BOD_5 values of Magtaa Kheira leachates.

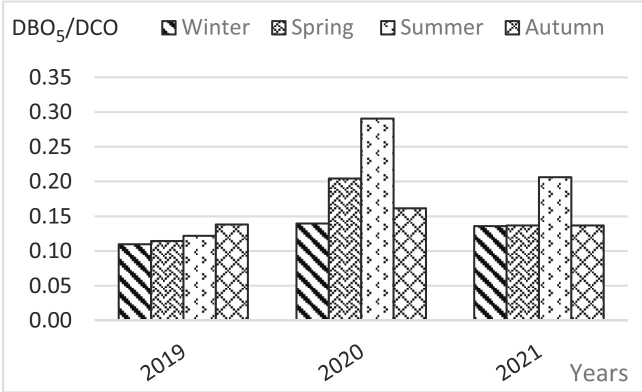

Fig. 8. Spatio-temporal evolution and BOD_5/COD ratio values of Magtaa Kheira leachates.

nature and quantity of the waste, and different climatic factors such as rainfall, air humidity and temperature. According to other studies [31], these different factors are the basis for the variability of the pollutant loads.

Biological oxygen demand (BOD) is the amount of oxygen required to oxidize (biodegradable) organic matter in 5 d by biological process (oxidation of biodegradable organic matter by bacteria), this parameter indicates the maturity of the landfill which generally decreases with time [32]. For new landfills, BOD values are between 2,000 and 30,000 mg·L^{-1}; but for mature landfills, the BOD value varies from 100 to 200 mg·L^{-1} [22]. In the current study the seasonal evolution of this parameter seemed to be like that of COD, in fact the highest BOD contents were recorded during the summer season (Fig. 7). This began to decrease with the arrival of winter. This may have been due to the fact that in winter season, the combined effect of increased precipitation and lower temperature inhibited the development of decomposers. The measured values of BOD were very close to those observed in the landfill of Fes [33] in 2015, and largely higher than those found by Bennama et al. [19] for the landfill of El Karma (Oran).

The BOD_5/COD ratio, which provides information on the landfill fermentation stage, varied between 0.11 and 0.29 (Fig. 8). According to Kouadioet al. [21] this ratio was greater than 0.5 for young leachate, less than 0.1 for stabilized leachate and between 0.1 and 0.5 for intermediate leachate. This explained that intermediate leachates were present in which the organic matter had not reached the final stage of degradation and that at this stage the landfill was going through an unstable phase of methane fermentation [4]. In summer, BOD_5/COD ratio values are higher than those recorded in winter in relation to the summer increase of the BOD.

3.3. Nutritious salts

Ammonium NH_4–N is a water soluble gas. The result represents a high level of ammonium in the leachates of Magtaa Kheira (Fig. 9). The ammonium values registered varied between 1,798.42 and 2,111.15 mg·L^{-1} in the dry season, and from 1,399.99 to 1,694.33 mg·L^{-1}

during the wet season. These values were comparable to those found by Rhouat et al. [34] for the Meknes landfill (Morocco), and those contributed by Naveen et al. [35] for the Mavallipura landfill. The high ammonium concentrations recorded during the warm season were explained by the fact that the activity of nitrifying bacteria is optimal only within a specific temperature interval, outside of this interval the nitrification process is inhibited. In addition, the pH also affected the ammonium concentration. According to Morrill and Dawson [36], at legal pH values, nitrification processes decelerated due to the suppression of the nitrifying population.

The results showed that the concentration of orthophosphate PO_4 fluctuated between 15.87 and 32.08 mg·L^{-1}. These values were higher than those found by Bennama et al. [19] where they reported that the leachates of the landfill of El Kerma (Oran) had an average value of 2.11 mg·L^{-1}. However, Merzouki et al. [37] found in the leachates of the landfill of Fkih Ben Salah in Morocco an average value of 100.95 mg·L^{-1}, which was largely higher than that found in this study. These high levels could be attributed to the waste organic fraction which contained phosphorus (mainly phospholipids and phosphoproteins). During biodegradation there was a release of phosphorus and therefore an increase in phosphate concentration [38,39].

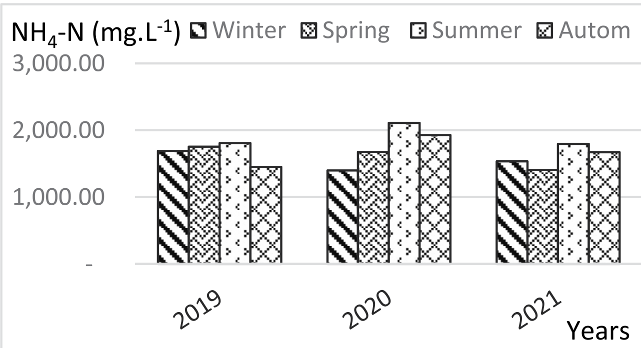

Fig. 9. Spatio-temporal evolution and NH_4–N values of Magtaa Kheira leachates.

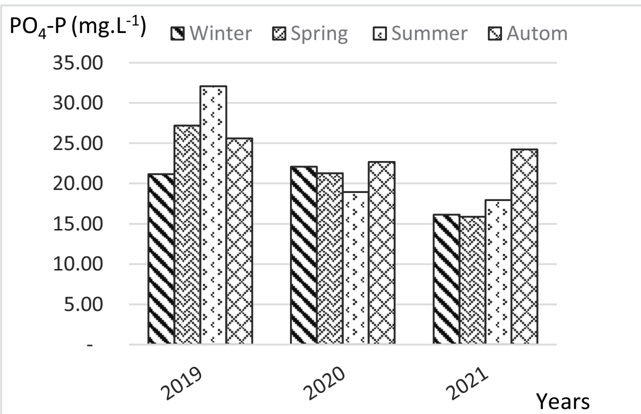

Fig. 10. Lack of the figure which represents the spatial-temporal evolution and the values of PO_4–P.

4. Conclusions

The physico-chemical characterization of the Magtaa Kheira landfill leachate showed a high mineral and organic load. The organic contents were reflected by high values of COD (14,094.85 mg·L^{-1}), BOD_5 (2,300 mg·L^{-1}). As for the mineral pollution, it was reflected by the high average electrical conductivity (26.13 mS·cm^{-1}). The results showed that the leachates of the Magtaa Kheira, were in an intermediate state between young and old leachates. The measured leachate samples would necessitate an adequate treatment approach to reduce the contaminants to a satisfactory level before discharge to the receiving system. A variety of factors influence landfill leachate composition. The rate of precipitation and evaporation determines the volume of leachate production from a landfill. Therefore, climate and seasonal weather variations have a substantial impact on leachate production and composition.

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References

[1] M.T. Sohail, Y. Mahfooz, S. Hussain, M.B. Khan, N. Ul Hadi, Impacts of landfill sites on groundwater quality in Lahore, Pakistan, Abasyn J. Soc. Sci., 10 (2017) 199–210.
[2] M.D. Vaverková, D. Adamcová, Case study of landfill reclamation at Czech landfill site, Environ. Eng. Manage. J., 17 (2018) 641–648.
[3] N. Calace, A. Liberatori, B.M. Petronio, M. Pietroletti, Characteristics of different molecular weight fractions of organic matter in landfill leachate and their role in soil sorption of heavy metals, Environ. Pollut., 113 (2001) 331–339.
[4] R. Hakkou, M. Wahbi, A. Bachnou, K. Elamari, L. Hanich, M. Hibti, Impact de la décharge publique de Marrakech (Maroc) sur les ressources en eau, Bull. Eng. Geol. Environ., 60 (2001) 325–336.
[5] A. Baun, S.D. Jensen, L. Bjeg, T.H. Christensen, N. Nyholm, Environ. Technol., 34 (2000) 647–652.
[6] K.-H. Kang, H.S. Shin, H. Park, Characterization of humic substances present in landfill leachates with different landfill ages and its implications, Water Res., 36 (2002) 4023–4032.
[7] Z.-p. Wang, Z. Zhang, Y.-j. Lin, N.-s. Deng, T. Tao, K. Zhuo, Landfill leachate treatment by a coagulation-photooxidation process, J. Hazard. Mater., 95 (2002) 153–159.
[8] R. Chemlal, L. Azzouz, R. Kernani, N. Abdi, H. Lounici, H. Grib, N. Mameri, N. Drouiche, Combination of advanced oxidation and biological processes for the landfill leachate treatment, Ecol. Eng., 73 (2014) 281–289.
[9] A. Gaïd, Epuration biologique des eaux usées urbains, Tome I. édition OPU, Alger 1984.
[10] J. Rodier, Degrément L'analyse de l'eau, 9ème Edition, Dunod, 2009.
[11] A. Navarro, D. Bernard, N. Millot, Les problèmes de pollution par les lixiviats de décharge, T.S.M.-L'eau, 11 (1988) 541–546.
[12] G. Matejka, M. Rinke, R. Mejbri, H. Bril, Pollution engendrée par un lixiviat de décharge d'ordures ménagères: bilan hydrique et caractérisation, Environ. Technol., 15 (1994) 313–322.
[13] H. Khattabi, Intérêts de 1'étude des paramètres hydrogéologiques et hydrobiologiques pour la compréhension du fonctionnement de la station de traitement des lixiviats de la décharge d'ordures ménagères d'Etueffont (Belfort, France), Thèse de doctorat 3ème cycle, Université Franche Comté, France, 2002, 171 pages.
[14] O.O. Aluko, M.K.C. Sridhar, P.A. Oluwande, Characterization of leachates from a municipal solid waste landfill site in Ibadan, Nigeria, J. Environ. Health Res., 2 (2003) 32–37.

[15] A. Chofqi, A. Younsi, E. Kbir Lhadi, J. Mania, J. Mudry, A. Veron, Environmental impact of an urban landfill on a coastal aquifer (El Jadida, Morocco), J. Afr. Earth Sci., 39 (2004) 509−516.
[16] T.A. Kurniawan, W.-h. Lo, G.Y.S. Chan, Physico-chemical treatments for removal of recalcitrant contaminants from landfill leachate, J. Hazard. Mater., 129 (2006) 80−100.
[17] S. Renou, S. Poulain, J. Gagnaire, D. Cadarache, B. Marrot, P. Moulin, Lixiviat de centre de stockage: déchetgénéré par des déchets, L'eau, l'industrie, les nuisances, 310 (2008) 37−43.
[18] K.I. Kouame, Pollution physico-chimique des eaux dans la zone de la décharge d'Akouedo et analyse du risque de contamination de la nappe d'Abidjan par un modèle de simulation des écoulements et du transport des pollutants, Thèse de Doctorat, Université d'Abobo Adjamé, Côte d'Ivoire, 2007, 212 p.
[19] T. Bennama, A. Younsi, D. Zoubir, A. Debab, Caractérisation et traitement physico-chimique des lixiviats de la décharge publique d'El-Kerma (Algérie) par adsorption en discontinu sur de la sciure de bois naturelle et activée chimiquement, Water Qual. Res. J., 45 (2010) 81–90.
[20] Y. Kehila, F. Mezouari, G. Matejka, Impact de l'enfouissement des déchets solides urbains en Algérie: expertise de deux centres d'enfouissement technique (CET) à Alger et Biskra, déchets - revue francophone d'écologie industrielle, 56 (2009)-4e trimester.
[21] G. Kouadio, B. Dongui, A. Trokourey, Détermination de la pollution chimique des eaux de la zone de la décharge d'Akouédo-Abidjan, (Côte d'Ivoire), Revue des Sciences et Techniques, 1 (2000) 33–41.
[22] G. Tchobanoglous, H. Theisen, S. Vigil, Integrated Solid Waste Management, McGraw-Hill International Edition, New York, 1993, 978 p.
[23] P. Kjeldsen, M.A. Barlaz, A.P. Rooker, A. Baun, A. Ledin, T.A. Christensen, Present and long-term composition of MSW landfill leachate: a review, Crit. Rev. Env. Sci. Technol., 32 (2002) 297–336.
[24] N.M. Driskill, Characterization and Treatment of Organic Matter, UV Quenching Substances, and Organic Nitrogen in Landfill Leachates, Master Thesis, The Faculty of the Virginia-Polytechnic Institute, Virginia, USA, 2013.
[25] M. Makhoukh, M. Sbaa, A. Berrahou, M. Van Clooster, Contribution to the physico-chemical study of the surface waters of Moulouya River (Eastern Morocco), Larhyiss J., 9 (2011) 149–169 (in French).
[26] E.S.K. Chian, F.B. Dewalle, Sanitary landfill leachates and their treatment, J. Environ. Eng. Div. ASCE, 102 (1976) 411, doi: 10.1061/JEEGAV.0000476.
[27] J. Harmsen, Identification of organic compounds in leachate from a waste tip, Water Res., 17 (1983) 699–705.
[28] S. Saadi, M. Sbaa, M. ELkharmouz, Caractérisation physicochimique de lixiviats du centre d'enfouissement technique de la ville d'Oujda (Maroc oriental), Science Lib., Editions Mersenne, 5 (2013) 1–12.
[29] F. Khalil, O. Bouaouine, H. Chtioui, S. Souabi, M.A. Aboulhassan, A. Ouammou, Traitement des lixiviats de décharge par coagulation-floculation (Treatment of landfill leachate by coagulation-flocculation), J. Mater. Environ. Sci., 6 (2015) 1337–1342.
[30] M.M. Mokhtaria, B.B. Eddine, D. Larbi, H. Azzedine, L. Rabah, Cractéristiques de la décharge publique de la ville de Tiaret et son impact sur la qualité des eaux souterraines, Courrier du savoir, 93–99 (2007) 112 p.
[31] T.H. Christensen, P. Kjeldsen, P.L. Bjerg, D.L. Jensen, J.B. Christensen, A. Baum, H.J. Albrechtsen, G. Heron, Biogeochemistry of landfill leachate plumes, Appl. Geochem., 16 (2001) 659–718.
[32] B. Barjinder, M.S. Saini, M.K. Jha, Effect of age and seasonal variations on leachate characteristics of municipal solid waste landfill, Int. J. Res. Eng. Technol., 2 (2013) 223–232.
[33] O. Bouaouin, F. Khalil, H. Chtioui, H. Zaitan, A. Harrach, Traitement par électrocoagulation des lixiviats de la décharge publique contrôlée de la ville de Fès, Larhyss J., ISSN1112-3680 (2015) 53–67.
[34] S. Rhouat, M.S. Elyoubi, F. Dimane, Physico-chemical characterization of Meknes municipal landfill leachate and assessment of the seasonal effects using PCA, Environ. Eng. Manage. J. (EEMJ), 18 (2019) 2405–2415.
[35] B.P. Naveen, M.M. Durga, T.G. Sitharam, P.V. Sivapullaiah, T.V. Ramachandra, Physico-chemical and biological characterization of urban municipal landfill leachate, Environ. Pollut., 220 (2017) 1–12, doi: 10.1016/j.envpol.2016.09.002.
[36] L.G. Morrill, J.E. Dawson, Patterns observed for the oxidation of ammonium to nitrate by soil organisms, Soil Sci. Soc. Am., 31 (1967) 757–760.
[37] H. Merzouki, H. Hanine, B. Lekhlif, Physico-chemical characterization of leachate discharge Fkih Ben Salah from Morocco, J. Mater. Environ. Sci., 6 (2015) 1354–1363.
[38] G.S. Toor, S. Hunger, J. Derek Peak, J.T. Sims, D.L. Sparks, Advances in the characterization of phosphorus in organic wastes: environmental and agronomic applications, Adv. Agron., 89 (2006) 1–72.
[39] D. Fatta, A. Papadopoulos, M. Loizidou, A study on the landfill leachate and its impact on the groundwater quality of the greater area, Environ. Geochem. Health., 21 (1999) 175–190.