VOL. 19, NO. 22, NOVEMBER 2024 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

# STATISTICAL COMPARISON OF EFFLUENTS FROM THREE OLIVE OIL EXTRACTION SYSTEMS AND THEIR ADVERSE EFFECTS ON THE ECOSYSTEM

Omar Elrhaouat[1,2], Abdelmajid Chafik[1], Sakina Belhamidi[3] and Mohammed Ouhssine[2]
[1]Superior School of Education and Training, Ibn Tofail University, Kenitra, Morocco
[2]Laboratory of Natural Resources and Sustainable Development, Faculty of Sciences, Ibn Tofail University, Kenitra, Morocco
[3]Superior School of Technology, Ibn Tofail University, Kenitra, Morocco
E-Mail: omar.elrhaouat@uit.ac.ma

**ABSTRACT**

Wastewater from olive oil mills pollutes the ecosystem and poses potential risks to soil and human health in terms of heavy metals. These effluents are discharged to the ecosystem by three types of olive oil extraction systems (modern continuous centrifugation system, modern discontinuous system, and traditional pressure system), which are compared with each other to explore which is more toxic. To do this, a factorial analysis including Principal Component Analysis (PCA) was applied with sampling adequacy validating the results by the Kaiser-Mayer-Olkin test (0.78) and Bartlett's significant test. The analysis revealed that the traditional discontinuous system is the more toxic of the two modern systems. As in the case of Zinc and Iron, they present average concentrations of 185.75±47.61 and 51.75±11.16 mg/L respectively, exceeding the required standards. These metal pollutants effectively degrade the ecosystem and pose problems in agriculture through bioaccumulation and inhibition of plant germination, with of course high acidity and high salinity factors inhibiting root growth and pre-existing vegetation.

**Keywords:** heavy metals, olive mills of wastewater (OMW), PCA.

Manuscript Received 20 July 2024; Revised 30 November 2024; Published 31 December 2024

## 1. INTRODUCTION

Among the Mediterranean countries that produce olive oil on an international scale, Morocco has become one of the leading countries in the production of this precious foodstuff at the national level and has therefore adopted the strategy of exporting this product and becoming one of the strongest competitors. However, this production is also accompanied by environmental risks due to the generation of wastewater from oil mills and industrial plants. These effluents contain high concentrations of metallic elements, which pose a major threat to soil and water bodies, as they exceed national and international discharge standards. The Mediterranean region is characterized by an almost worldwide majority of olive oil production, around 98%, during the olive harvest period (October to February) [1]. Moreover, these industrial effluents are difficult to biodegrade due to the presence of phytotoxic and antimicrobial compounds such as lipids (fatty acids), polyphenols, and agricultural insecticides [2]. The wastewater generated by these plants is discharged directly into the ecosystem without being treated conventionally, thereby considerably degrading the quality of soil, surface water, and groundwater. Due to the high organic matter content, self-purification of the water becomes difficult, which can lead to pollution spreading over long distances [3], particularly in the case of excess heavy metals. Consequently, these heavy metals pose an environmental problem due to human activities, producing wastes and by-products that can affect soil quality and preservation [4, 5, and 6]. It is logical to assume that the consumption of various vegetables loaded with heavy metals may present a potential health risk [7], as is the case for cereals containing harmful heavy metals [8]. The olive oil extraction systems studied in this work are: the modern continuous centrifugation system (MCS), the modern discontinuous system (MDS), and the traditional pressure system (TDS). Faced with this situation, these effluents need to be treated to avoid any pollution of the environment, in particular to preserve the health of the population.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

In this study, the wastewater from oil mills is discharged directly into the environment, including the soil, the sewage system, and the Rdom River, which flows through a large part of the province of Sidi Kacem, the capital in 1981 [9], belonging to the Rabat-Salé-Kénitra region. "The Gharb plain, covering an area of 4,000 km2, contains a major aquifer complex made up of two aquifer units: a shallow free aquifer and a deep semi-confined aquifer. The aquifer is fed by rainfall infiltration on the outcrops, by the convergence of deep flows from the Maâmora aquifer, by percolation through the beds of the Ouergha and Sebou rivers to the east of the plain, and by the restitution of irrigation water. Flows are made up of flows to the ocean, as well as withdrawals for drinking water and agriculture" [10]. The study area has a moderate, semi-arid Mediterranean climate, with annual precipitation reaching 445 mm. It is relatively well known for a long dry period (May-September) with moderate temperatures (December: 11°C and August: 39°C) [9].

### 2.2 Experimental

Sampling was carried out periodically over 5 months (October, November, December, January and February). Four samples were taken for each month. The 12 study sites are divided into three categories according to the type of olive oil extraction system, namely the modern continuous centrifugal system (continuous phase system) and the modern and traditional pressurized batch systems. The bottles used were sterile, with a volume of one liter, and rinsed with these effluents before being hermetically sealed. Samples were stored at 4°C and transported directly to the laboratories for specific analyses, using the sample storage and handling guide [11].

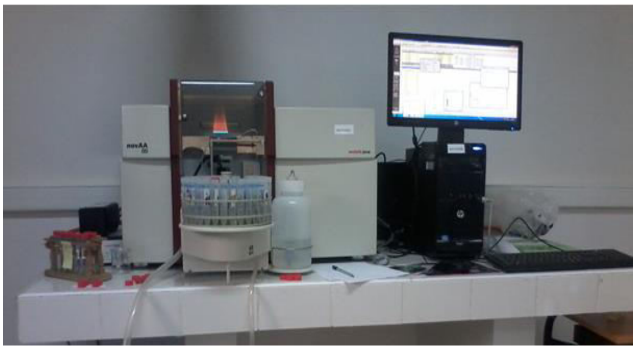

**Figure-1.** Flame atomic absorption spectroscopy (University Center for Analysis, Technology Transfer and Incubator Expertise, Faculty of Sciences-Kenitra).

In this work, flame atomic absorption spectroscopy equipment is used specifically to measure the heavy metals present in these effluents, via the NOVAA 350 instrument from Analytik Jena AG. The flame used is of the acetylene/air type (50 mm slit burner, coded as standard) and a 0.7 annular slit pneumatic nebulizer (platinum/rhodium, graphite nozzle) with a flow rate of 4-6 ml/min. To this end, the NOVAA 350 complies with the requirements of DIN-EN 61326 and is environmentally compatible with the requirements of DIN ISO 9022-3: 9022-32-03-0 and 9022-2: 2003/01. It also meets the requirements of EC directives 2006/95/EC and 2004/108/EC (manufacturing and testing). Before analyzing each element, the sample must be diluted to decreasing concentrations with standards for each metal to be analyzed (as standards: standards are available at 1000 ppm in 120 and 500 mL vials for flame analysis). A series of six solutions containing 0.1 to 0.6 ppm of the element to be analyzed was prepared, with an ultrapure solution checked as a blank to establish a calibration curve A = f([metal]) under the software to obtain the required concentration. The statistical study was processed using Xlstat V.14 and JMP V.17 software, with principal component analysis and correlation coefficients between the various heavy metals.

## 3. RESULTS AND DISCUSSIONS

Heavy metals are a major concern for the environment and human health and are present in nature, liquid and solid waste. Table 2 shows descriptive statistics for heavy metals, with concentrations ranging from minimum to maximum, as well as their standard deviations. The 12 oïl mill wastewater treatment units were grouped into three categories of systems with a specific pollution gradient, namely the modern continuous system, modern batch systems, and the traditional system. In general, the three types of oil mill wastewater systems have average values for the following heavy metals: Ni, Cr, Cd, Fe, and Zn, approximately 0.16±0.10, 0.30±0.11, 0.24±0.07, 51.75±11.16 and 185.75±47.61mg/L, respectively. The effluents from these industrial plants are characterized by a more acidic pH of 4.89±0.47 and a higher salinity of 12.25±4.15 (Table-1); this poses negative effects such as soil clogging and inhibition of seed germination of different plant species as well as reduced root growth.

**Table-1.** OMW descriptive statistics.

| **Statistics** | **pH** | **Salinity** (mg/L) |
|---|---|---|
| Minimum | 4,020 | 3,950 |
| Maximum | 7,070 | 23,900 |
| Median | 4,905 | 11,515 |
| Mean | 4,898 | 12,248 |
| Standard deviation (n) | 0,473 | 4,154 |
| Coefficient of variation (n) | 0,097 | 0,339 |

VOL. 19, NO. 22, NOVEMBER 2024 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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**Table-2.** Descriptive statistics of the heavy metals (mg/L).

| Variable | Observations | Minimum | Maximum | Mean | Rejection standards |
|---|---|---|---|---|---|
| As | 12 | 0.15 | 0.91 | 0.38±0.22 | 0.22 |
| Cd | 12 | 0.13 | 0.34 | 0.23±0.7 | 0.07 |
| Cr | 12 | 0.07 | 0.41 | 0.29±0.11 | 0.11 |
| Hg | 12 | 0.31 | 1.63 | 1.20±0.33 | 0.33 |
| Ni | 12 | 0.08 | 0.40 | 0.16±0.10 | 0.10 |
| Se | 12 | 0.07 | 0.93 | 0.41±0.27 | 0.25 |
| Pb | 12 | 1.17 | 2.73 | 1.93±0.51 | 0.51 |
| Zn | 12 | 132.00 | 259.00 | 185.75±47.61 | 45.44 |
| Cu | 12 | 3.04 | 4.11 | 3.63±0.39 | 0.38 |
| Fe | 12 | 35.62 | 64.67 | 51.75±11.16 | 11.06 |

Figure-2 shows the correlation matrix for the various metal elements, with the highest correlation coefficients being As-Cd (0.98), Se-Zn (0.96), Cr-Pb (0.94), As-Pb (0.85), As-Cr (0.82), Cd-Cr (0.80), and Cd-Pb (0.82). The results obtained reveal that the mean values of the metal elements Cd, Cr, Fe and Ni appear to be lower than the concentrations recorded by Salvemini (1985) (Cr = 0.66, Ni = 3.36, Cd = 0.84, Zn = 10, Fe = 103.4 mg/L), as well as Cu = 0.009 mg/L (discontinuous system) and 0.01 mg/L (continuous system) [12], in contrast to the concentration of Zn, which is higher than that recorded by [13]. The average values of the metallic elements Cd, Zn, Cu, Fe, As, Hg, and Pb exceed the standards; on the other hand, the concentration of Cr remains within the standards [14]. These correlations represent existing interactions between these elements, affecting the metabolism of microorganisms and the limitation of carbon and phosphorus; this is the case for Zn with Cd, Cr, Pb, and as, which are 0.86, 0.93, 0.97, and 0.90 respectively, and for Cr with Se, Pb and 0. 92 and 0.94 respectively. This correlation reflects the synergistic effect of these heavy metals on soil health, as well as on plants and humans in terms of bioaccumulation, biomagnification, and bioconcentration, which cause homeostasis disturbances.

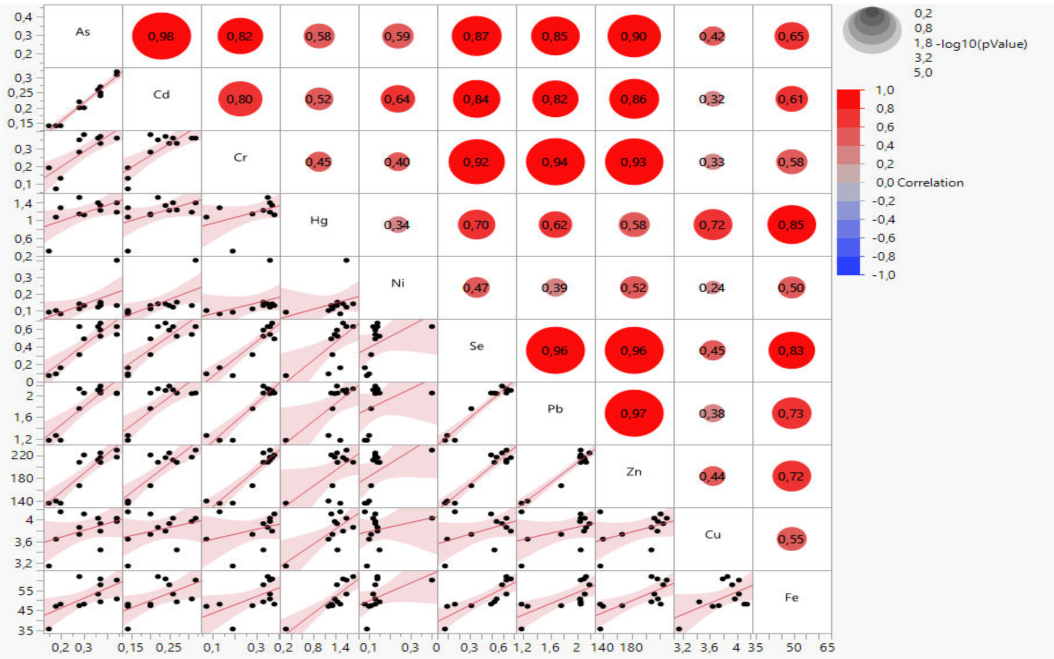


**Figure-2.** Matrix of scatter plots.

In Table-3, the sphericity test (Bartlett's test) is characterized by a highly significant probability (p-value = 0.0001) and below the significance level α = 0.05, making it possible to reject the null hypothesis (H0) and accept the alternative hypothesis (Ha). Bartlett's sphericity test shows that the correlation matrix no longer corresponds to the identity matrix, rejecting the null hypothesis and suggesting that the variables are correlated and ideal. The Kaiser test (KMO) is used to measure the consistency of the principal component analysis (PCA), which must be between 0.5 and 1. In this case, the KMO value is 0.783, indicating good sample adequacy.

**Table-3.** Test of sphericity of Bartlett.

| Sphericity of Bartlett | |
|---|---|
| Khi² (Actual value) | 129.520 |
| Khi² (Breaking value) | 61.656 |
| DDL | 45 |
| Probability (p-value) | 0.0001 |
| Significance threshold (α) | 0.05 |

Table-4 shows the total inertia of a maximum dispersion of the projected scatterplot, which is 85.86% in order to lose as little information as possible; it is also considered as a set of variances. With a low information loss of 14.14%.

**Table-4.** Presentation of total inertia.

| | F1 | F2 |
|---|---|---|
| Eigenvalue | 8.027 | 0.559 |
| Variability (%) | 80.270 | 5.594 |
| Cumulative % | 80.270 | 85.864 |

**Table-5.** Correlations the variables with the factors.

| Heavy metals | F1 | F2 |
|---|---|---|
| As | 0.867 | -0.323 |
| Cd | 0.941 | -0.241 |
| Cr | 0.885 | -0.161 |
| Hg | 0.770 | 0.536 |
| Ni | 0.815 | 0.047 |
| Se | 0.923 | 0.209 |
| Pb | 0.965 | -0.074 |
| Zn | 0.912 | -0.109 |
| Cu | 0.930 | 0.062 |
| Fe | 0.933 | 0.127 |

In terms of the correlation circle, the various variables (heavy metals) show strong correlations with the main component F1 rather than F2 (Table-5), which explains their high concentration in the traditional discontinuous system compared with the systems (Figure-6). In terms of the correlation circle, all heavy metals are positively correlated on the F1 axis, with a variability of 80.27% (Figure-3). The categorical variables are distributed from left to right on the F1 axis along a gradient of increasing pollution of these metals according to the farming systems used for olive oil extraction (SCM, SDM, and SDT). The total inertia of the variables represents a significant variability of 85.86% in the F1 x F2 factorial plane (Table-4).

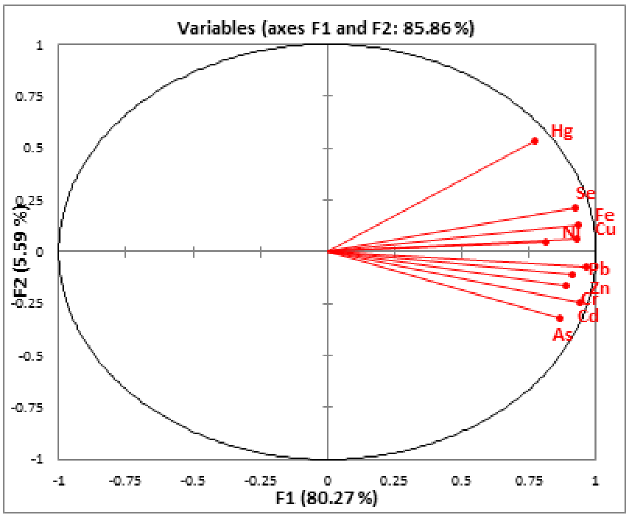


**Figure-3.** Projection of the variables on the factorial plan F1xF2 (85.86%).

**Table-6.** Squared cosines of the variables.

| | F1 | F2 |
|---|---|---|
| As | 0.751 | 0.104 |
| Cd | 0.886 | 0.058 |
| Cr | 0.783 | 0.026 |
| Hg | 0.593 | 0.288 |
| Ni | 0.664 | 0.002 |
| Se | 0.852 | 0.044 |
| Pb | 0.931 | 0.005 |
| Zn | 0.832 | 0.012 |
| Cu | 0.866 | 0.004 |
| Fe | 0.870 | 0.016 |

The three categories of oil mill wastewater treatment systems are considered additional qualitative variables in the principal components analysis. The qualitative variable is a categorical variable of oil mill wastewater type, presented as SCM, SDM, and SDT (Figure-4). This will give us levels in terms of oil mill wastewater pollution on the F1 factorial plane, presenting an increasing gradient of pollution from left to right on the F1 axis, starting with the modern continuous system (sites: Fham2, Ait Lahssen and Ara IN2), passing through the modern discontinuous system (sites: Jerar, Rmail, Hamou, Dour43, Area IN1 and Road Tg), and arriving at the

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences



traditional discontinuous system (sites: Fhama1, Grinate H and Chlihate) presented in Figure-4.

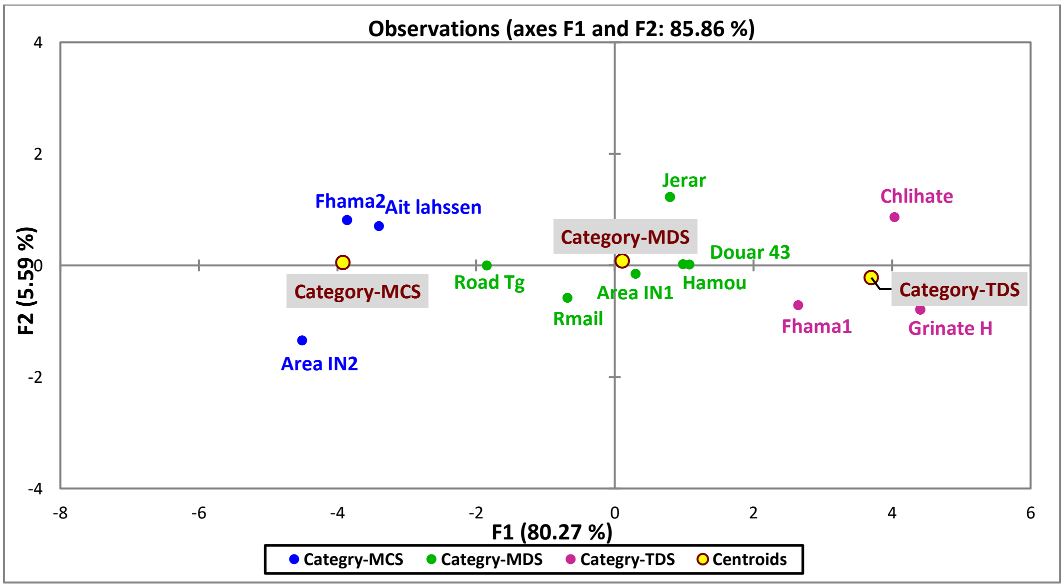


**Figure-4.** Projection of the individuals on the factorial plan F1xF2 (85.86%).

Figure-5 shows the variables and individuals projected onto the factorial plane (F1 x F2) with inertia of 85.86%, indicating that the traditional oil mill wastewater treatment system (study sites Fhama &, Grinate H and Chlihate) generates significant concentrations of these different heavy metals compared to modern continuous and discontinuous systems. According to previous research, heavy metal contamination leads to a significant drop in soil fertility [18], producing toxicities and damage to soil micro-organisms, particularly Hg, Cr, Zn, Cd, As, Ni, Cu, and Pb [19]. This contamination also leads to changes in microbial diversity and structure [20]. As a result, trace metals in soil accumulate in plant and animal food chains, causing ecosystem and public health problems [21].

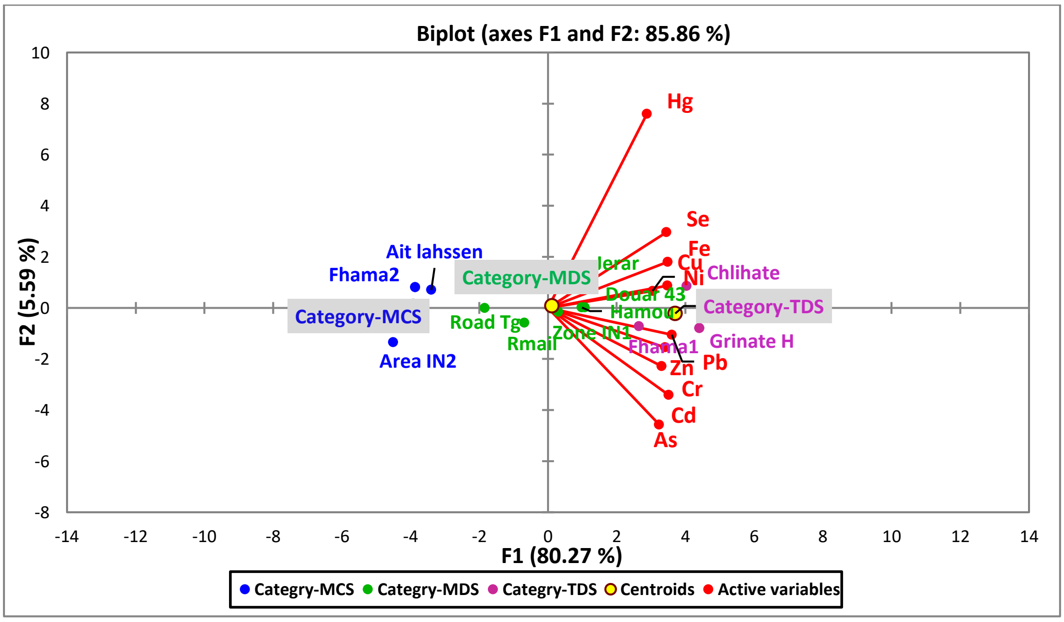


**Figure-5.** Variables and individuals projected on the factorial plane F1xF2 (85.86%).

For example, if there is an excess of Ni in the soil, it becomes toxic and can decrease the root growth of plants, leading to leaf chlorosis [22, 23]. Similarly, excess as can cause vegetation death [24]. These are serious consequences that affect the ecosystem functioning of the soil, produced by the presence of heavy metals that inhibit bacterial activity and growth [25], making the soil infertile and blocking the germination of vegetation in combination with other factors such as pH acidity, salinity, lipids, and polyphenols. Furthermore, these elements As, Cr, Pb, Ni, and Cu have negative effects on biological life directly or indirectly at the aquatic level [26]. Previous studies have shown that increased Cu concentrations inhibit the activity of certain seed germination enzymes, thereby modifying seed structure [27, 28]. Furthermore, bioaccumulation of traces such as Pb and Cd can occur in various plant crops [29, 30], after which their successive exposure has negative effects on human health, in terms of cancer and impacts on the nervous system [31, 32]. In addition, excess heavy metals such as Cd can cause kidney stones in humans, while Pb specifically affects the nervous system in children [33].

## 4. CONCLUSION

According to this study, the traditional discontinuous pressure system is the most polluting and toxic of all modern systems and is characterized by increased concentrations of heavy metals, representing a contamination risk for the environment and public health. Indeed, soil quality is threatened by the harmful effects of heavy metals on vegetation, in particular, the reduction or even inhibition of the germination of various seeds by spreading on soil and direct discharge into surface waters, leading to the asphyxiation of living organisms; these effluents are rich in salinity, which is a factor that disrupts cell permeability, as well as acid pH, which has a negative influence on plant species that are not tolerant of acidity. Indeed, heavy metals pose a real environmental and health problem in terms of the high concentrations that exceed the required standards.

## REFERENCES

[1] Doula M. K., Moreno-Ortego J. L., Tinivella F., Inglezakis V. J., Sarris A., Komnitsas K. 2017. Chapter 2 - Olive mill waste: recent advances for the sustainable development of the olive oil industry. J. Oliv. Mill. Wast. 29-56. https://doi.org/10.1016/B978-0-12-805314-0.00002-9.

[2] Dagga F. 2015. ABU and Böhmer B. Hazardous olive-mill wastewater problem and solution, site Internet: http://www.euro-arab.com/studies/english/water/html.

[3] Mebirouk M. 2002. Rejections of the oil mills, development of a process integrated for the biological breakdown of polyphenols in the margin, CMPP, News. (11).

[4] El Khalil H., Schwartz C., Elhamiani Kubiniok J., Morel J. L., Boularbah A. 2008. Contribution of technic materials to the mobile fraction of metals in urban soils in Marrakech (Morocco). J. Soil. Sedi. 17-22. https://doi.org/10.1065/jss2008.01.269.

[5] El Khalil H., Schwartz C., Elhamiani O., Kubiniok J., Morel J. L and Boularbah A. 2013. Distribution of major elements and trace metals as indicators of technosolisation of urban and suburban soils. J. Soil. Sedi. 13, 519-530. https://doi.org/10.1007/s11368-012-0594-x.

[6] Nehls T., Rokia S., Mekiffer B, Schwartz C. and Wessolek G. 2013. Contribution of bricks to urban soil properties. J. Soil. Sedi. 13(3): 575-584. https://doi.org/10.1007/s11368-012-0559-0.

[7] Huang Z., Pan X. D., Wu, P. G., Han J. L. and Qing-Chen. Q. 2014. Heavy metals in vegetables and health risk to population in Zhejiang, China. J. Food. Control. 36(1): 248-252, http://dx.doi.org/10.1016/j.foodcont.2013.08.036.

[8] Hermandez-Martinez R. and Navaro-Blasco I. 2013. Survey of total mercury and arsenic content in infant cereals marketed in Spain and estimated dietary intake. J. Food. Control. 30(2): 423-432. https://doi.org/10.1016/j.foodcont.2012.08.016.

[9] 2006. National Office of Drinking Water (NODW). Report: Study of cleansing of the town of Sidi Kacem. p. 101.

[10] 2016. Gharb Aquifer System. Sebou Hydraulic Basin Agency (ABHS). https://www.abhsebou.ma/presentation-of-the-basin/groundwater/gharb-aquifer-system/(accessed on 09/01/2023).

[11] 2019. International Organization for Standardization (ISO). 5667-3, 2019. Water Quality-Sampling, Part 3: Preservation and handling of water samples (ISO 5667-3:2018). p. 61.

[12] Arienzo M. and Capasso R. 2000. Analysis of metal cations and inorganic anions in olive oil mill wastewaters by atomic absorption spectroscopy and ion chromatography. Detection of metals bound mainly to the organic polymeric fraction. J. Agri. Food. Chem. 48(4): 1405-1410. https://doi.org/10.1021/jf990588x.

[13] Salvemini F. 1985. Chemical composition and biological evaluation of a feed obtained by drying the

vegetation waters of olives. Journal of Fatty Substances. 112, 559-564.

[14] 1994. Committee Standards and Standards (CNS). Department of the Environment of Morocco, Rabat.

[15] Krzanowski W. J. 1992. Review of A User's Guide to Principal Components, by J. E. Jackson. J. Royal. Statis. Soci. Series A (Statistics in Society). 155(1): 173-174, https://doi.org/10.2307/2982678.

[16] Beatriz H., Rafael P., Marisol V., Enrique B., Fernandez J. M. and Louis F. 2000. Temporal evolution of groundwater composition in an alluvial aquifer (Pisuerga River, Spain) by principal component analysis. J. Wat. Res. 34(3): 807-816. https://doi.org/10.1016/S0043-1354(99)00225-0.

[17] Stetzenbach K. J., Hodge V. F., Guo C., Farnham I. M., Johannesson K. H. 2001. Geochemical and statistical evidence of deep carbonate groundwater within overlying volcanic rock aquifers/aquitards of southern Nevada, USA, J. Hydrol. 243, 3-4, 2001, 254-271, ISSN 0022-1694, https://doi.org/10.1016/S0022-1694(00)00418-2.

[18] El-Naggar A., Lee S. S., Rinklebe J., Farooq M., Song H., Sarmah A. K., Zimmerman A. R., Ahmad M., Shaheen S. M. and Ok Y. S. 2019. Biochar application to low fertility soils: A review of current status, and prospects, Geoderma. 337, 2019, 536-554, ISSN 0016-7061, https://doi.org/10.1016/j.geoderma.2018.09.034.

[19] Mierzwa-Hersztek M., Gondek K., Klimkowicz P. A., Baran A., Bajda T. 2018. Sewage sludge biochars management ecotoxicity, mobility of heavy metals and soil microbial biomass. Envir. Toxic. Chem. 37, 1197-1207. https://doi.org/10.1002/etc.4045.

[20] Oliveira A. and Pampulha M. E. 2006. Effects of long-term heavy metal contamination on soil microbial characteristics, J. Biosc. Bioeng. 102(3): 157-161, ISSN 1389-1723, https://doi.org/10.1263/jbb.102.157.

[21] Nabulo G., Young S. D., Black C. R. 2010. Assessing risk to human health from tropical leafy vegetables grown on contaminated urban soils. Sci. Tot. Envir. 15, 408(22): 5338-51. https://doi.org/10.1016/j.scitotenv.2010.06.034.

[22] Molas J. and Baran S. 2004. Relationship between the chemical forms of nickel applied to the soil and its uptake and toxicity to barley plants (Hordeum vulgare L.). J. Geoderma. 122, 247-255. https://doi.org/10.1016/j.geoderma.2004.01.011.

[23] Himmelbauer M. L., Puschenreiter M., Schnepf A., Loiskandl W., Wenzel W. W. 2005. Root morphology of Thlaspi goesingense hálácsy grown on serpentine soil. J. Plan. Nutri. Soil. Sci. 168, 138-144, https://doi.org/10.1002/jpln.200420434.

[24] Tripathi R. D., Srivastava S., Mishra S., Singh N., Tuli R., Gupta D. K. and Maathuis F. J. M. 2007. Arsenic hazards, strategies for tolerance and remediation by plant. Trends. Biotech. 25(4): 158-165. https://doi.org/10.1016/j.tibtech.2007.02.003.

[25] Gong S., Wang H., Lou F., Qin R. and Fu T. 2022. Calcareous materials effectively reduce the accumulation of Cd in potatoes in acidic cadmium-contaminated farmland soils in mining areas. Inter. J. Envir. Resea. Pub. Heal. 19(18): 11736. https://doi.org/10.3390/ijerph191811736.

[26] Jinqing L., Ping Y., Bin C., Fei G., Hongying S. and Meina L. 2016. Distribution and contamination assessment of heavy metals in surface sediments of the Luanhe River estuary, northwest of the Bohaie Sea. J. Mar. Pollu. Bull. 109(1): 633-639, https://doi.org/10.1016/j.marpolbul.2016.05.020.

[27] Chatterjee J. et Chatterjee C. 2000. Phytotoxicity of cobalt, chromium, and copper in cauliflower. Environmental Pollution. 109: 69-74.

[28] Hall J. L. 2002. Cellular mechanisms for heavy metal detoxification and tolerance. J Exp Bot. 53: 1-11.

[29] Hao X. Z., Zhou D. M., Huang D. Q., Cang L., Zhang H. L. and Wang H. 2009. Heavy Metal Transfer from Soil to Vegetable in Southern Jiangsu Province, China. J. Pédosph. 19(3): 305-311. https://doi.org/10.1016/S1002-0160(09)60121-1.

[30] Hernández M. R. and Navarro-Blasco I. 2012. Estimation of dietary intake and content of lead and cadmium in infant cereals marketed in Spain. J. Food. Control. 26(1): 6-14, https://doi.org/10.1016/j.foodcont.2011.12.024.

[31] Karalliedde L. and Brooke N. 2012. Toxicity of heavy metals and trace elements, Essentials of toxicology for

health protection: A manual for the professional field, Oxf. Med., 2 Ed. p. 352. Chapter 14, https://doi: 10.1093/med/9780199652549.003.0104.

[32] Pan X. D., Tang J., Chen Q. W. P. G. and Han J. L. 2013. Evaluation of direct sampling method for trace elements analysis in Chinese rice wine by ICP-OES. Europ. Food. Rese. Tech. 236(3): 531-535. https://doi.org/10.1007/s00217-012-1888-3.

[33] Toplan S., Ozcelik D., Gulyasar T. and Akyocu M. C. Changes in hemorheological parameters due to lead exposure in female rats. J. Tra. Ele. Medi. Biol. 2004; 18(2): 179-182. https://doi.org/10.1016/j.jtemb.2004.02.006.

[34] Ahmad P., Sarwat M., Bhat N. A., Wani M. R., Kazi A. G. & Tran L.-S. P. 2015. Alleviation of Cadmium Toxicity in Brassica juncea L. (Czern. & Coss.) by Calcium Application Involves Various Physiological and Biochemical Strategies. PLOS ONE, 10(1): e0114571. https://doi.org/10.1371/journal.pone.0114571

[35] Mondal N. K., Das C. & Roy S. 2013. Effect of Varying Cadmium Stress on Chickpea (Cicer arietinum L) Seedlings: An Ultrastructural Study. 7.

[36] Shanti S. Sharma, Vijay Kumar, Responses of wild type and abscisic acid mutants of arabidopsis thaliana to cadmium, Journal of Plant Physiology, Volume 159, Issue 12, 2002, Pages 1323-1327, ISSN 0176-1617, https://doi.org/10.1078/0176-1617-00601.