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Pollution estimation from olive mills wastewater in Jordan

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ABSTRACT

Olive mill wastewaters (OMWWs) are a significant source of environmental pollution, especially in important olive oil producing countries such as Spain, Greece, Syria, Jordan and other countries in the Mediterranean. Due to cost issue no treatments plants are currently available at the mills; therefore, OMWW is normally discharged into the environment causing serious environmental problems such as: coloring and pollution of surface and ground waters, soil surface, and foul odors problems. Approximately 209,000 tons of olives have been processed in Jordan in 2017, which generated 175,000 m^3 of OMWWs. They generated rougly 3,069 tons of BOD_5, 7,956 tons of COD, 149 tons of residual olive oil, 2.07 tons of phenols, 3,753 ton total suspended solids and 4.2 ton of phosphorous. The OMWW is rich in organic matter expressed as BOD_5 and COD with COD/BOD_5 of 2.6 indicated that OMWWs is not suitable for biological treatment and therefore must be treated before discharge to the environment or sewer system. Cleaner production options and proper environmental waste management systems at the mills are needed to reduce their environmental impact. This may include the adoption of the two-phase mills to reduce water use to less than half the quantities used in traditional and three phases mills.

1. Introduction

Olive mill wastewater (OMWW) is the liquid by-product generated during olive oil production process [1]. More than 800 million olive trees grown worldwide and the Mediterranean accounts for 97% of the global olive tree farming [2, 3]. The annual production of table olives and olive oil reaches up to 10 and 2,000 million tones, respectively. The olive mill wastewaters (OMWWs) generation reached 30 million tons annually in Mediterranean basin [4, 5].

The disposal and treatment of this liquid waste is the main problems of the olive oil industry because of its high organic load [6] and content of phytotoxic and antibacterial phenolic substances, which resist biological degradation [7, 8, 9, 10]. Due to these characteristics, the disposal of OMWWs in urban sewage treatment plants is not viable. Recycling of OMWWs as soil amendment in agriculture land, either in fresh untreated form or after further treatments, to recover some organic materials to be used in the field or industry are the main used methods for their management [11, 12, 13, 14]. Other waste streams generated from mill operations include pomace (olive cake), earthy waste, odor and noise.

Olive mill wastewater (OMWWs) chemical composition is highly variable both qualitatively and quantitatively [15]. It depends on many factors such as: climatic conditions, cultivar type, fruit maturity [16, 17], and olive oil extraction method [18].

Jordan has 25 million olive trees, which produce approximately 220,000 tons of olive annually, 35,000 tons of oil, 60,000 tons of olive pomace and around 200,000 m^3 of olive mills wastewaters (OMWWs) [19, 20]. The objective of this research was to quantitatively estimate the national pollution loads from the olive mills industry in the country and possible waste management and treatment options.

2. Materials and methods

The study was started by conducting a field survey on all olive oil mills in Jordan in 2017. The objectives of the survey were to establish an industrial data base related to the olive oil production sector and its complimentary industries in the country. The data base helped in achieving the following: 1) Identify, locate and collect data on olive oil mills in the country, 2) construct a relevant database, and map the identified olive oil mills on a GIS database system, 3) assess actual management practices used in olive oil production and assess relevant expertise, 4) determine the existence of in-line/complimentary industries and related practices.

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The study also assessed the olive mills owners' willingness to participate in proposed solutions for treatments options and managements of the waste. The mills owners' questionnaire covered technical aspects of the milling processes in terms of production methods and level of automation. It also covered information related to capital investment, operation and maintenance costs. The questionnaire was also designed to obtain feedback from the mills owners regarding their readiness to contribute financially in treating the wastewater resulting from milling activities.

2.1. Environmental audits for selected olive mills using different extraction techniques

The study was initiated with the selection of fifteen olive mills in the northern of Jordan (Irbid and Ajloun governorates) using different oil extraction techniques (traditional, two phase and three phase continuous techniques) for environmental auditing and analyzing their waste chemical characteristics. The field audits covered two traditional mills out of (8) mills, five two phases out of (25) mills and eight three phases mills out of (79) mills, which can be considered as a representable sample of different extraction techniques in the country. The audit includes measurement of water used in processing of one ton of olives and the quantity of OMWWs generated in each extraction processes. Clean water was used in washing of olives and in oil separations. OMWWs generated consisted of water consumed in the production processes in addition to vegetables water from the olive's fruits.

Samples of OMWWs were obtained in triplicates from the selected mills for chemical characteristics analysis according to the specific extraction techniques (i.e. traditional or continuous processes). The laboratory analyses of effluents samples were carried out to identify selected pollutant parameters levels, which include phosphorus, oil and grease (residual olive oil) following the methodology presented by APHA [21]. Other parameters which include BOD_5, COD, TSS, phenols, were taken from previous studied conducted in 2015 [18]. The pollution loads per ton of olives processed in relation to extraction processes were estimated based on chemical characteristics of the waste's samples. The outcomes of the environmental audits conducted in November 2017 which includes water consumption in oil extraction and OMWWs generation from each extraction process and the laboratory analyses of effluents samples were used to calculate the emission factors per pollutant type selected in each oil extraction methods. The pollutants load from each extraction techniques were calculated by multiplying the field measurements of flows in each mill (l/ton) by the average chemical characteristics analyses results of effluents samples (g/l). Multiplying the pollution loads (g/ton) by total activity rate (production volume in ton) in each mill, the national pollution loads in relation to oil extraction techniques were estimated. The associated environmental impacts of the parameters studied were assessed based on the pollutants generated, their quantity and characteristics in relation to extraction methods.

3. Results and discussion

3.1. Current disposal methods of olive mills wastewater

The survey showed that there are 112 working mills in Jordan, of which 93% are automatic generating around 200,000 m^3 of wastewater during the milling season (3 months per year). The survey identified different methods applied by olive mills owners to dispose of olive mills wastewater. It showed that 80% of mills owners dispose OMWWs in cesspools, 15% in drying beds and around 5% used other methods. It was noticed that none of the mills were connected to the sewage system because the wastewater characteristics were not in compliance with the corresponding local specifications.

3.2. Olive mills owners' contribution for building central treatment plants

Only 21% of the mill's owners were willing to bear the cost of hauling the OMWWs to the nearest central treatment plant, about 17% showed willingness to bear part of the expenses, while about 52% were not willing to bear any expenses. The fine for spills by oil mills reach 1000 $, for major spills which causes serious soil and water pollution, the mill will be closed for the next season.

3.3. Water consumption results

The first process in olive oil productions started with olives washing by water, to reduce soil contamination, which can create a flavor defect called "soil taste". The water use in the mills depends on the olive pressing methods and the working environments. The water consumption and olive mill wastewaters (OMWWs) generation rates based on the field measurement results are presented below. These results will be used as the basis in the calculations of the national pollution load. Table 1 present's actual water consumptions ranges in mills and the corresponding water consumption cited in literature.

Water consumption by traditional and two-phase mills go a long with what cited by literature 300–500 L of water per ton of olives processed [3], the three phase mills consumed double the amount of water used by traditional and two-phase mills as a result of process requirements. This will reduce the various components concentration already exist in the olive vegetation water (water in the olive fruit). However, this dilution factor results in increases in the quantities of generated wastewaters.

Fig. 1 presents the national distribution of water consumption by olive mill sector across the different governorates in the country. The total water consumption by olive mill sector for 2017 season was estimated to be approximately 138,450 m^3 as declared by mill owners.

3.4. OMWWs audit results

Table 2 presents the measured OMWWs discharged rates generated by mills and the corresponding discharge rates cited in literature.

The two-phase system is by far the lowest water consumption and wastewater generation in olive oil production. Field measurements confirmed that the two-phase mills water consumption rate is less than 400 l/ton. Water was consumed mainly in the olive washing and malaxing operation. The three phase mills produced the highest OMWWs rates with an average of 1000 l/ton which is in line with what sited in literature.

Fig. 1 also presents the national distribution of OMWWs generated from the olive mill sector across the different governorates in the country. The estimated total generated OMWWs for the 2017 season was approximately 175,000 m^3. As expected, northern Jordan were most of the rain fed trees grow accounts for the highest OMWWs generated on the national level (66.3 % of the total OMWWs), followed by middle of the country (26.3%), and the rest (7.4%) is in south of the country.

3.5. Quantity of olive processed

Table 3 presents olives quantities processed in 2017 per governorate by each extraction techniques. Three phases mills processed 135,000 tons of olives which was account for 65% of the total olives processed in the country.

Table 1
Water consumptions rates at mills.

Mill Type	Water consumption rates (l/ton of processed olive)	
	Measurement Results (range)	Theoretical (RAC/CP) [25]
Traditional	(320–400) l/ton	(400–600) l/ton
Two Phase	(250–350) l/ton	(120) l/ton
Three Phase	(750–980) l/ton	(700–1000) l/ton

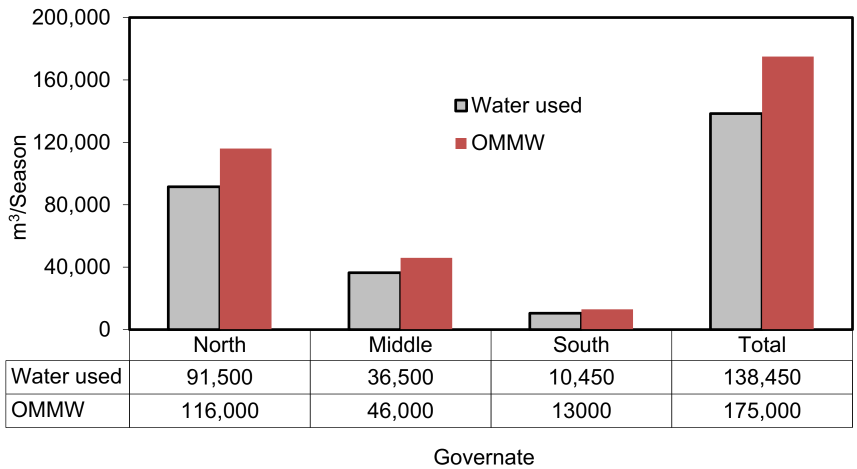

Fig. 1. National distribution of water consumption and OMWWs generated per region.

Table 2
Generated Olive Mill Wastewaters (OMWWs) quantities.

Mill Type	Water Generation Rates (l/ton of processed olive)	
	Audit Measurement Results	Theoretical (RAC/CP) [25]
Traditional	(450–600)	(400–600)
Two Phase	(330–400)	(300)
Three Phase	(965–1190)	(1000–1200)

Table 3
Mills distribution per extraction methods, governorate and amount of processed olives in ton during 2017 season.

	Oil Extraction Techniques			
	Three Phases	Two Phases	Traditional	Total
Number of mills	79	25	8	112
%	70.54	22.32	7.14	100
Ton of olives	135,000	59,000	15,000	209,000
%	64.60	28.23	7.17	100

Table 3 shows that the majority of the Jordanian olive mills are three-phase (70.54 %), followed by two-phase (22.32 %) and traditional mills (7.14 %). In total, Jordan processed some 209,000 tons of olives in 2017, which is a good harvest season, out of which 15,000 tons processed in traditional mills, 59,000 tons in two-phase mills, and 135,000 tons of olives in three-phase mills.

3.6. Wastes generation rates

Table 4 presents the amount of wastewater generated per ton of processed olives by each extraction methods. The last column in the table shows the total OMWWs produced (l/season) by each extraction methods. The three phase mills produced 143,775 m^3/season, while the two phases mills produced 22,892 m^3/season and the traditional mills produced 8,025 m^3/season.

Table 4
Amount of wastewater generated per ton of processed olives per mill type.

Mill Type	Olive processed (ton/season) (A)	Wastewater produced per ton of olives (l/ton) (B)	Wastewater produced (l/season) (C = A x B)
Traditional	(range: 480–634) 15,000[a]	(450–600) 535[b]	8,025,000
2 - Phases	(range: 1,300–2,250) 59,000[a]	(330–400) 388[b]	22,892,000
3 - Phases	(range: 1,750–2,900) 135,000[a]	(965–1190) 1065[b]	143,775,000

[a] represents total olive processed ton per season for each extraction method.
[b] represents averages of wastewater produced per ton of olive processed.

The average volume of wastewater per ton of processed olives is estimated based on the averages for each technology in column three of Table 4 i.e. 535 l/t of olives for traditional mills, 388 l/t for 2-phase, and 1,065 l/t for 3-phase mills. The quantities of wastewater generated per ton of olive processed in traditional and two phases mills were much lower than those generated in three phase mill which is in line with literature. The three phase mills produced 1065 l/ton of olive processed, which is 2.5 times the amount of water produced in the two-phase mills.

Table 5 presents the OMWWs chemical analysis results for the audited olive mills as presented by [18]. Their study showed that all parameters tested were higher in traditional mills and the lowest in the two-phase mills as shown in Table 5. For example, the residual olive oil in wastewater from traditional mills was 13.13 g/l, while for the two and three phases mills were 0.02 g/l and 0.30 g/l, respectively. The high concentration of polyphenols (40 mg/l) and residual olive oil in OMWWS from traditional mills may be as a result of low oil extraction efficiency and excessive water consumption in oil separation in the traditional mills. Polyphenols are more soluble in water than in fats, as a result, the more time the water is in contact with the olive oil, the more polyphenols being absorbed in the water, eventually being discharged with the OMWWs generated. In addition, the low production process efficiency in traditional mills resulted in higher concentration of TSS discharged (52 g/l) compared to two phase mills (0.18 g/l) and 23 g/l in three phase mills.

As shown in Table 5 the BOD_5 averages were 41, 0.06 and 19.5 g/l for traditional, two and three phases, respectively. The highest COD of 105 g/l also found in the traditional mills, while the lowest COD of 0.37 g/l was obtained from the two phases mills. The COD/BOD ratios were 2.56, 6.06 and 2.53 for the traditional, two and three phases, respectively. This high ratio indicates that this kind of vegetable water is not suitable for

Table 5
OMWW chemical characteristics (g/l) results for the audited olive mills[c].

Mill Type	BOD_5	COD	Residual olive oil	Phenols	TSS	Phosphorus
Traditional	41	105	13.13	0.038	51.59	0.25
Two Phase[d]	0.06	0.37	0.015	7.80e-4	0.18	1.98e-3
Three Phase	19.5	50	0.30	0.012	23	0.14

[c] represent average values of all samples taken in triplicates [18].
[d] The sample was collected from the washing tank which explains the low pollution load.

biological treatment [22]. Similar ratios of (2.1–2.4) were reported by [23] for traditional and three phases mills, respectively. The highest TSS of 51.59 g/l was found from the traditional mills which might be as a result of low production efficiency [3]. Effluents from traditional mills generated the highest pollution load, while the two-phase mills produced the lowest pollution in agreement to what reported by [24].

Table 6 presents the total pollution loads calculated based on audited mills' effluent quantities and pollution parameters characteristics. They were calculated by multiplying the obtained laboratory results given in Table 5 and the total amount of vegetable water generated per season in the last column of Table 4 (column (C)). The pollution generated by the three phase's mills constituted large portion of the waste generated due to their large numbers and large capacity compared to other techniques. They produced 2,739 tons of BOD_5, 7, 106 tons of COD, 43 tons of residual olive oil, 1,747 tons of phenols, 3,332 tons of TSS and 21 tons of phosphorus.

Table 7 presents the pollution loads per one ton of processed olives as a function of extraction techniques. They were obtained by dividing the values presented in Table 6 (kg/season) by the total olives processed per season (ton/season) column (A) in Table 4.

The traditional mills produce the highest pollution load per ton of olive processed. They produced 21.94 kg/t of BOD_5, 56.18 kg/t of COD, 7.02 kg/t residual olive oil, 20.33 g/t phenol and 27.79 kg/t total suspended solid (TSS) as shown in Table 7. The three-phase mill produce the second highest pollution load with values 20.29 kg/t of BOD_5, 52.63 kg/t of COD, 0.32 g/t residual olive oil, 12.94 g/t phenol and 24.68 kg/t total suspended solid (TSS). On the contrary, the two-phase mills produced the minimum pollution load per ton of olive processed. They produced 23.5 g/t of BOD5, 142.2 g/t of COD, 5.7 g/t residual olive oil, 0.31 g/t phenol and 68.1 g/t total suspended solid (TSS), which can be considered as environmentally friendly machine in terms of generated wastewater quantities and quality. The average values of pollutions produced per ton of olive processed by each technology as shown in Table 7 are used as the emission factors per ton of olive processed to calculate the national pollution loads generated by the olive mills industries in Jordan.

3.7. National pollution loads

Several parameters in the OMWWs chemical characteristics are directly influenced by the oil extraction system including residual oil, phenols, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD). OMWWs contains high concentration of total suspended solids (TSS), phenols and other organic matter as shown in this study. The organic load is characterized by high levels of BOD (20–22 kg/ton) and COD (52–56 kg/ton), in addition to having a very high concentration of residual olive oil of 7 kg/ton from traditional mills. Table 8 shows national pollution loads based on mill types. It is calculated by multiplying the amount of total olives processed (ton/season) in each extraction techniques by the pollution parameters (kg/ton) obtained in Table 7 (the averages values for traditional, 3-phases as well as the 2- phase's mills).

Traditional mills produced 14 % of all phenol discharges in Jordan even they constitute 7.14% of total mills. Utilization of oil/water separators at the mills to recover residual olive oil from OMWWs, this will reduce the pollution loads influx to the surrounding environment which will recover 149 tons of residual olive oil that might be used completely in soap industries. The mills produced large amount of pollutant each year to the neighboring area which accumulated over time. These pollutants include 3,069-ton BOD5, 7,957 ton of COD, 3,753 ton of TSS and 4.2 ton of prosperous.

3.8. Environmental impact of olive oil mill's wastes

Water quantities used in the mills depends on labor practices and pressing techniques (three phases mills required large amounts of water). The uncontrolled disposal of untreated Olive Mill Wastewaters (OMWWs) on the soil and water has the disadvantage of spreading materials that are foul smelling and probably pathogenic in the environment. OMWWs (locally known as "Zibar") is made up of the vegetation waters of the olive, frequently mixed with water added in the process. They present a high, polluting power with toxic effect. In fact, OMWWs is among the "strongest" industrial effluents with COD up to 220 g/l [25].

Technical and economical solutions are not yet been available to treat OMMWs [26]. As a result, some olive mills release their wastewater to the environment illegally. Therefore, there is a need for plans to handle the wastes efficiently to reduce their environmental impact and leads to a sustainable use of resources. One alternative and economical solution is introducing the cleaner production options to reduce the waste production from washing and mixing.

Significant odor complaints can be detected around the mills as a result of gas emissions from fermentation process which take place when the OMWWs is discharged into the land or water body and/or stored in open ponds. Several volatile organic acids and other low-boiling organic matters produce bad odors that can be smelled in the air. Also, as a result of evaporation from the ponds, methane and other pungent gases (like hydrogen sulfide) released which pollute air, water streams and soil. OMWWs has high organic content and many complex organic materials which resist natural biodegradation therefore has negative environmental effects such as odors, discoloring of natural waters and toxicity,

Table 6
Pollution loads (ton per season) based on extraction methods.

Type of Mill	BOD_5	COD	Residual olive oil	Phenols	TSS	Phosphorus
Traditional	329	842	105	0.31	417	1.99
2-Phase	1.39	8.39	0.34	0.017	4.02	0.045
3-Phase	2,738	7,106	43	1,747	3,332	20.60

Table 7
Pollution loads per ton of processed olives by each extraction methods.

Type of Mill	BOD 5 (kg/t)	COD (kg/t)	Residual olive oil (kg/t)	Phenols (g/t)	TSS (kg/t)	Phosphorus (g/t)
Traditional	21.94	56.18	7.02	20.33	27.79	0.13
2-Phase[e]	0.0235	0.1422	0.0057	0.3007	0.0681	0.0008
3-Phase	20.29	52.63	0.32	12.94	24.68	0.15

[e] The values could be used as representative results to determine the pollution loads expected from olive washing wastewater generated at any mill type.

Table 8
National pollution generation (ton/season).

	Mills	Olives ton	BOD_5	COD	Residual olive oil	Phenols	TSS	P
3- Phase	79	135,000	2,739	7,105.60	42.94	1.75	3,332	2.10
2- Phase	25	59,000	1.39	8.39	0.338	0.018	4.02	0.045
Traditional	8	15,000	329	842.63	105.33	0.31	417	1.99
Total	112	209,000	3,069	7,956.62	148.62	2.07	3,753	4.135

threat to marine life by building impenetrable film on the surface causing oxygen transfer problem.

Odor generation was felt around mills which are mainly influenced by lack of good housekeeping, lack of good hygienic conditions, improper waste storage areas, and long storage period of pomace or OMWWs and weather conditions. The field audits revealed that most of the modern mills (two and three phase technology mills) are cleaner, with better hygienic conditions and better good housekeeping measures resulting in lower odor emissions. However, this fact could be offset by improper storage or long-term onsite storage of generated pomace (olive cake) or OMWWs.

As for traditional mills, the lack of proper hygienic conditions or good housekeeping is due to the fact that most of its machinery and production process is exposed to air (open) and its operation is characterized by higher spills and leakages than modern mills due to high reliance on manual operation. Again, improper and long-term storage has additional direct influence on overall odor emissions. Traditional mills generate the lowest quantity of pomace compared to other technologies (38%–50%) with the lowest moisture content (25%–31%). However, due to low efficiency, the pomace contains the highest residual oil content (6%).

The olive oil industries in Jordan do nothing in terms of waste management, so introducing cleaner production options, prevention, control and treatment measures in olive oil industries should be implemented. Proper environmental waste management's system in the mills, training of operators and technical assistance for stakeholders to encourage them to maintain principles of green processing of olive oil is essential. Minimization of water consumption in production by using ecological decanters (2-phase mills), utilization of oil/water separators at the mills to recover residual olive oil and reduce pollution loads to the surrounding environment should be encouraged, this will recover 150 ton of olive oil annually. The government should set regulations and standards for the olive oil effluents and enforce these regulations by adequate monitoring strategy. The study also concluded that there is an urgent need to set an emergency plan to handle the olive mills wastewater and avoid its discharge to the environment. The idea of establishing more than one central pretreatment plant would be a viable and a feasible option for the treatment of olive mills wastewater in Jordan.

The increased acidity and the reductive potential of the OMWWs makes them extremely corrosive for any sewage pipeline system, while their composition and their extremely high organic load strictly prohibits even the thought of disposing them into any municipal wastewater treatment unit.

The disposal of OMWWs in the soil, which has been proposed as a temporary solution to the problem, has similar negative consequences. Apart from the intensive malodor and the requirements of large areas, liquid wastes bring about a dramatic change in the composition of the soil's microbial community by inducing the growth of specific groups of microorganisms, changing the air-water balance of soil and probably reducing soil fertility. The concentration of organic load in the solid waste (olive cake) from the three-phase olive mills reaches 94% of the dry weight, a fact that is considered beneficial for the cultivations. Their oil content though, may reduce infiltration rate and water retention and increase soil hydrophobicity [27]. Despite this fact, disposal of solid olive mill waste (pomace) results in increase in saturation hydraulic conductivity, water retention and capillary elevation [28].

Large scale technical solutions for OMWWs treatment are not yet been commercially available [26]. Some measures can be taken to reduce the waste production from washing and mixing, thus reducing their environmental impact. The following suggestions can help in reducing waste volume and better waste management.

- The use of clean technologies such as ecological decanters should be encouraged and introduced in olive milling industries. This will minimize water consumption in oil separation and hence the generated wastewater,
- Active participation of olive mills owner association should be sought when considering environmental solutions for the olive mills wastewater problem,
- Economic incentive must be introduced to encourage olive mills owners to install cleaner production units. Such incentives include the provision of tax exemptions and soft loans for acquiring clean productions units and equipment.
- There is a need to widen the environmental awareness campaign about the environmental impacts of olive mills wastewater to foster the compliance and commitment for handling the wastewater in an environmentally safe and sound manner,
- Central treatment plants should be considered as a viable option for olive mills wastewater treatment in Jordan. Two plants should be constructed one at Al-Ekaider land fill in the north of the country where 100,000 m^3 sealed pond was constructed mainly for OMWW disposal in 2008. The second treatment plant can be built at Al-Humra land fill in Balqa province where 10,000 m^3 sealed evaporation pond was also constructed in 2008 for the disposal of olive mills wastewater. Both sites are closed to major olive mills in the country. The transportation cost to these dumpsites from neighboring mills is around 100 $ for 20 m^3 septic tank.

4. Conclusion

The majority of the Jordanian olive mills are three-phase mill (70.54 %), followed by two-phase (22.32 %) and traditional mills (7.14 %). In total, Jordan processed some 209,000 tons of olives in 2017, which is a good harvest season, out of which 15,000 tons in traditional mills, 59,000 tons in two-phase mills, and 135,000 tons of olives in three-phase mills. The results showed that OMWWs contains high levels of organic matter in addition to phenols and therefore must be treated before discharge to the environment or sewer system. The OMWWs generated in traditional mills contains higher organic content and phenols more than two and three phase mills. The organic load is characterized by high levels of BOD and COD with a BOD/COD ratio of more than 2.6 indicating its resistance to biological degradation. OMWWs also, contain high concentration of total suspended solids (TSS), phenols in addition to having a very high concentration of residual olive oil. Approximately 175,000 m^3 of OMWWs was generated in 2017 which generate roughly:

- 3,068 tons of BOD_5,
- 7,957 tons of COD,
- 149 tons of residual olive oil,
- 2.1 tons of phenols,
- 3,753 ton total suspended solids (TSS) and
- 4.2 ton of Phosphorous.

Declarations

Author contribution statement

Adnan I. Khdair, Ghaida Abu-Rumman, Sawsan I. Khdair: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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