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Improvement of the sustainable olive mill wastewater (OMWW) management in the region of Sousse (Tunisia) via ArcGIS Software

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Abstract

In Tunisia, the evacuation of olive mill wastewater (OMWW) in storage tanks remains the most common way to manage this toxic effluent. Several environmental damages are registered due to the inappropriate locations of this OMWW tanks. Indeed, the storage tanks locations must be carefully selected where hydrogeological, environmental as well as socioeconomic criteria must be simultaneously considered. For this purpose, an integrated approach based on Geographic Information System (GIS), Global Positioning System (GPS) and multicriteria method (Analytic Hierarchy Process AHP) were developed to asses OMWW tanks sustainable management in Sousse region (Tunisia). The present paper consists to evaluate the current management of OMWW tanks in comparison with the existing standards. The results showed that most of the sites were not in the appropriate zone and did not meet the necessary standards and the minimum requirement to put in a storage tank, as expressed by the exclusion criteria. This strongly emphasizes the seriousness of the deteriorated environmental situation in the region. An awareness of these dangers that threaten public health and have some other associated risks is important. Hard work to resolve this situation is urgently required.

1. INTRODUCTION

Tunisia is one of the most important olive growing countries in the Mediterranean. It represents a major world power in the olive oil sector. Olive oil is a typical product in the Mediterranean region. Thus, Tunisia is classified the fourth biggest olive oil producer (6% of the world production) after Spain (45%), Italy (10%) and Greece (9%) (IOC, 2021).

However, the olive industry generates olive oil as its main product, but it has the disadvantage of generating large quantities of waste product defined as olive mill wastewater (OMWW) which can lead to significant environmental pollution due to their high phytotoxicity. Which is characterized by a low pH (3.5–5.5), a high content of organic matter (COD of 45–220 g O_2/l) and phenolic compounds (0.5–24 g/l) (Paraskeva and Diamadopoulos, 2006; Khdair et al., 2019).

Therefore, several methods have been used to treat, reduce, and disperse large amounts of OMWW such as coagulation-flocculation; infiltration-percolation, adsorption, constructed wetlands and distillation have been investigated individually or in combination in order to reduce pollutants content (Elayadi et al., 2019; De Almeida et al., 2018; Papaoikonomou et al., 2021; Achak et al., 2019). However, these methods present several limitations such as generation of large amount of sludge, irreversible, high cost and incomplete elimination of pollutants (Elayadi et al., 2021).

In Tunisia, to get rid of this harmful product and despite the multitude of modes of recovery and treatment two alternatives are practically presented: i) their evacuation in storage tanks which is the most alternative used in Tunisia. ii) their spreading on agricultural grounds which was allowed from 2013 by the promulgation of

Decree No. 2013-1308 of February 26, 2013, setting the conditions and terms of management of OMWW from oil mills for their use in agriculture (Abichou, 2011; Mekki et al., 2013; Dakhli and Lamouri, 2013).

Nevertheless, the bad geographical distribution of the storage tanks (the most used method); as well as the non-conformity of many of them with the norms; further complicates the environmental situation by anarchic discharges in nature which can cause problems of contamination of the ground water and soils (Shabou et al., 2009; Aydi et al., 2016; Issaoui et al., 2021; Elkadri et al., 2022). In this framework, Siting decisions are governed by pre-existing land-use dynamics, as well as the nature of potential interactions of the disposal site with the pre-existing environmental, hydrogeological, and socio-economic parameters of the area (Sumathi et al., 2008). The selected location must comply with national regulations and at the same time must minimize economic, environmental, health and social costs (Shabou et al., 2009).

The region of Sousse is characterized by a bad geographical distribution of the OMWW storage tanks located in urban areas and are permeable. these conditions increasing the probability of contamination of soil and groundwater (Shabou et al., 2009). Such situations can be avoided by a good selection of the appropriate locations to put in an OMWW storage tank (Elkadri et al., 2019; 2022). Obviously, to put-in a storage tank, a set of standards and restrictions must be considered (TMESD, 2010). Furthermore, the sustainable management of OMWW was studied by some authors (Shabou et al., 2009; Gorsevski and Jankowski, 2010; Moeinaddini et al., 2010; Khamehchiyan et al., 2011; Eskandari et al., 2012; Gorsevski et al., 2012; Komnitsas and Zaharaki, 2012; Nazari et al., 2012; Sahnoun et al., 2012; Aydi et al., 2016; Issaoui et al., 2021; Elkadri et al., 2022). These studies have implemented a Geographic Information System (GIS) technique, recognized as relevant in these research topics making possible the management of large volumes of spatial data (Kontos et al., 2003). The combination of GIS and multicriteria analysis finds the most flexible solution which facilitates and simplifies the analysis, (Issaoui et al., 2021).

The present study was realized in the coastal region (Sousse) in Tunisia which is characterized by a high olive oil yield that generates large quantities of OMWW; which actually represents an environmental problem (Elkadri et al., 2022). So, this study can only be achieved through an advanced study based on multi-criteria approach and a complicated spatial data set by applying a methodological approach integrating the Geographical Information System (GIS) tools and multi-criteria analysis.

The main aim of this study was the evaluation of the current situation of the evacuation of olive mill wastewater (OMWW) in the coastal region (Sousse) in Tunisia.

2. MATERIAL AND METHODS

2. 1. Case study

The study area corresponds to a coastal zone (Sousse) located in the central east of Tunisia (Fig. 1). This region is known for its olive trees vocation. Thus, the olive occupies 87 000 ha (5 million trees). The annual mean production is 76 000 T of olive which correspond to18 000 T of oil (CRDA Sousse, 2021).

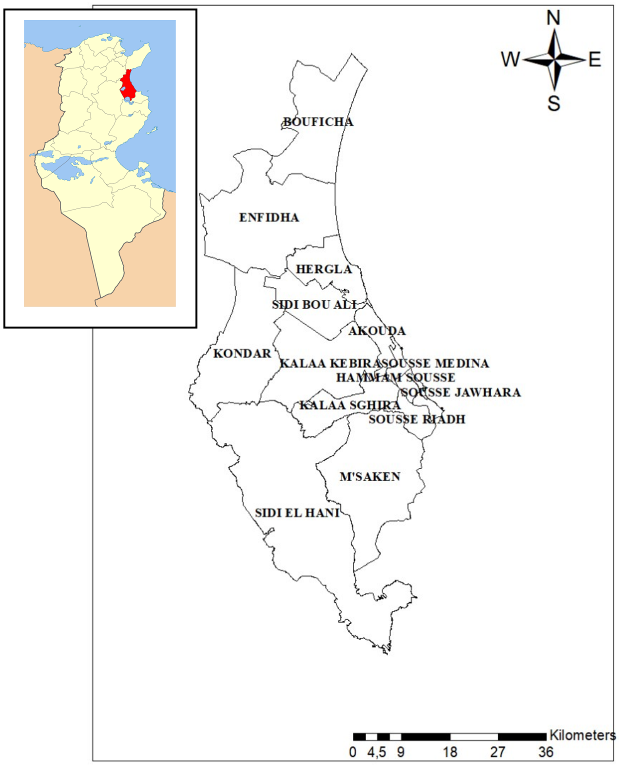

Fig. 1. Study area location map (Sousse in Tunisia).

2. 2. Methodological framework and data analysis procedures

Choice of adequate areas to the installation of storage tanks should be kept away from fragile and permeable grounds, watercourses, and urban centers (Elkadri et al., 2022). The OMWW storage tank projects require a previous impact study where a set of criteria such as: hydrogeological, environmental and socio-economic. Curiously, they were also classified in two categories: exclusion criteria (constraints) and appreciation criteria (Eastman, 2001). The appreciation criteria have the effect of reinforcing or reducing the relevance of selected locations obtained by exclusion criteria (Eastman, 1993). In our case, we will only apply the exclusion criteria to put on an OMWW tank and to evaluate the location of existing sites.

This spatial multicriteria analysis is undertaken within the integration of spatial geographic and mapping tools mainly GIS and GPS and multi-criteria analysis based on the AHP method in the selection of the criteria in a hierarchical way. Thus, the present study uses the GIS technique to make possible the analysis of the multiple spatial data and provide a visual representation of suitable areas. The GPS permits to situate the existing OMWW storage tanks in the obtained exclusion map to check whether these sites are in the adequate area or not. Therefore, multicriteria decision analysis is a structured approach to analyze problems with multiple criteria and alternatives (Mustajoki and Hamalainem, 2007). Furthermore, GIS has the ability to generate the hydro- geological, the environmental and the socio-economic data and integrating the existing diverse datasets sharing a compatible spatial referencing system (Malczewski, 2006; Sener et al., 2006; Gemitzi et al., 2007; Giordano and Riedel., 2008; Al-Adamat et al., 2010; Sauri-Riancho et al., 2011).

2. 2. 1. GIS Technical Implementation

The present study uses the GIS technique to make possible the analysis of the multiple spatial data and provide a visual representation of suggested alternatives. Thematic maps were digitalized using the ArcGIS software. All the thematic maps were transformed on a raster grid subsequently used by Idrisi Selva software. A raster grid cell of 100×100 m^2 was generated. Exclusion criteria were combined using the Boolean approach (Sahnoun et al., 2012; Elkadri et al., 2022).

2. 2 .2. Decision criteria formulation

exclusion criteria are hard criteria or criteria of elimination and the appreciation criteria have the effect of reinforcing or reducing the relevance of selected locations obtained by the exclusion criteria (Eastman, 1993). These criteria will be considered simultaneously leading to a multicriteria problem. According to Vincke (1992), the most challenging part of the multicriteria analysis is the formulation of the decision problem. In this study, the decision criteria problem is built in a hierarchical way structured on several levels as suggested by the AHP (Analytic Hierarchy Process) method. The first level represents the goal of the decisional problem, the second levels that follow describe the sub-criteria in more details (Martel, 1999). The hierarchical structure of proposed criteria is summarized in Table 1.

2. 2. 3. Exclusion criteria (constraints) characterization

The exclusion criteria or constraints are the limiting sub-criteria required to determine suitable OMWW storage tanks areas. The

Table 1. Hierarchical structure for the exclusion and appreciation criteria within AHP method.

Level 1 **Goals**	**Level 2** **Criteria**	**Level 3** **Sub-criteria**
Suitable location to OMWW storage tanks	Hydro-geology	Permeability
		Altitude, slope
		Water supply wells
		Hydrographic network (rivers, streams...)
		Wetlands
	Environment	Protected zones and touristic areas
		Olfactory impact
	Socio economic	Urbanization areas proximity
		Road network proximity

interposition at the same time of the different constraints through a Boolean approach delineates the geographically suitable area for storage tanks installation. The study area was categorized into two classes: 1 was allocated to zones verifying the condition and 0 was allocated to the other zones. The resulting image is called a Boolean image. The exclusion criteria were submitted to a distance evaluation: proximity or remoteness and a creation of buffer zone around spatial objects (roads, residential areas, slope, permeability, hydrographic network, protected zones and touristic areas, olfactory impact, water supply wells, wetlands). Every assessment of distance gives an image representing the adequacy of the sites to the criteria after reclassification. The last step consisted on combining, by superposition, the information contained in Boolean layers relative to the exclusion criteria mentioned above. The logical operator ''AND'' was used in this part; it translates the intersection between conditions that must be absolutely satisfied.

3. RESULTS

To diagnose the current situation of the existing OMWW storage tanks and the adequacy of their location in the Sousse region, an overlay map of existing tanks with standards has been obtained (Fig. 2). In fact, to get the map of exclusion criteria, the Boolean method has been implemented for constraints. It means the classification of the studied area into two classes: unsuitable (0) and suitable (1). To obtain this map, a set of exclusion criteria for each level: hydrogeological, environmental and socioeconomic (as previously mentioned), must be strictly taken into account for many justified reasons as follows:

3. 1. Characteristics of the hydrogeological criteria

** Soil permeability*

Depending on the characteristics of geological texture in the study region, this criterion is classified into two categories. High and medium permeability soils are considered unsuitable for OMWW disposal, while soils with low and very low permeability are considered fairly suitable and optimal to install an OMWW storage tank. The permeability of the underlying soil has a significant impact on the number of pollutants escaping from OMWW landfills. It influences the quantity of pollutants leaching from an OMWW disposal site to the ground (Aydi et al., 2016).

** Land slope*

The slope related to the degree of soil improvement is one of the main factors of

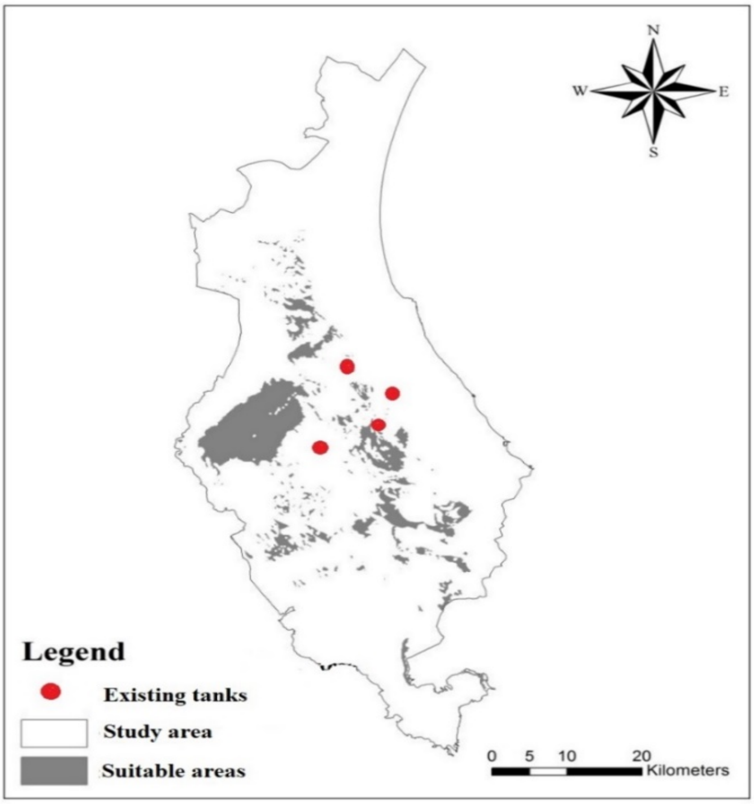

Fig. 2. Contrasting map between existing sites and exclusion criteria in Sousse region (Tunisia).

OMWW tank aptitude analysis. Moreover, Sharp slopes increase wastewater runoff, and thereby increase the possibility of environmental contamination (Aydi et al., 2016). Hence, the slope value of land surface less than 3% was considered suitable (Shabou et al., 2009; Sahnoun et al., 2012; Elkadri et al., 2022).

** Distance from wetlands*

The OMWW tank must be far from areas such as the coast, lakes, and sebkhas. A 2000 m buffer zone of protected area around these features is needed (Abessi and Saeedi, 2010; Elkadri et al., 2022).

** The distance from water supply wells*

This criterion is crucial to identify the suitable placement of OMWW tanks. Indeed, storage tanks create harmful odors with irretrievable human and environmental effects which make them unsuitable for nearby water wells (Aydi et al., 2016). Thus, a 200 m buffer was placed around each well (Shabou et al., 2009; Elkadri et al., 2022).

** Hydrographic network (Streams, rivers, etc.)*

Storage tanks should not be close to the sea, streams, lakes, and rivers. Accordingly, in this study, a buffer distance of 200 m for streams, permanent, and temporary rivers was considered sufficient to put in an OMWW storage tank (Shabou et al., 2009; Sahnoun et al., 2012).

3. 2. Characteristics of the environmental criteria

** The distance from protected areas and tourist zones*

A storage tank should not be placed near any protected areas such as coastal area with an important tourist character. For this reason, a buffer zone of 10 000 m from those areas was considered (Elkadri et al., 2022).

3. 3. Characteristics of Socio-economic criteria

** Distance from roads*

The transportation costs and esthetical considerations would be of good practice for good planning (Aydi et al., 2016), and according to this basis, landfills should not be placed longerinside300 m of any main high ways and city roads (Elkadri et al., 2022).

** Distance from Residential areas*

OMWW storage tanks are undesirable due to their negative impact mainly mosquitoes and bad smells. For this reason, a buffer area of 1500 m has been preconized (Abessi and Saeedi, 2010; Sahnoun et al., 2012; Elkadri et al., 2022).

3. 4. Boolean resultant via ArcGIS software (Hydrogeological, environmental and socioeconomic criteria's)

Results of the superposition of all mentioned exclusion criteria maps for the environmental, hydrogeological and socioeconomic levels results in a global exclusion map, the so-called Boolean resultant which shows the suitable areas for the discharge of OMWW in Sousse region. Then, by moving on the field, we acquired the GPS coordinates (X and Y) of each one of the existing storage tanks in the study area and projected them onto the same map (Boolean resultant) via ArcGIS software (Fig. 2).

The aggregated map (Fig. 2) shows suitable areas (grey color) for OMWW discharge that are limited in space and that correspond to a cloud that extends from the delegation of El Nfidha to the delegation of Sidi El Heni through the delegations of Kalaa Kebira, Kalaa Saghira, Kondar, Hergla, Sidi Bouali, and Msaken.

Indeed, by comparing the actual positions of OMWW storage tanks in Sousse region with the exclusion map, we observe that the majority of the existing tanks are not in the appropriate areas (3 tanks) and just one tank is in suitable area of the Kalaa Kébira. We also notice that there are only four existing storage tanks in the total region where three of them concentrated in Kalaa Kebira and one located in Sidi Bouali. On the other hand, there are no OMWW tanks in the other productive areas (delegations) despite the signifcant generated amounts of OMWW mainly in the delegations of Mseken, Bouficha and Enfidha. This was at the root of many problems, mainly the uncontrolled discharge of OMWW in the nature, and the OMWW important transport costs paid by producers from these uncovered zones. So, this bad geographic distribution of storage tanks between the production areas further complicates the environmental situation through uncontrolled discharge.

In fact, the majority of the existent sites are not suitable as OMWW storage tanks and this is mainly due to the intersection of the set of exclusion criteria (distance from roads, residential areas, slope, permeability, hydrographic network, protected zones and touristic areas, olfactory impact, water supply wells and wetlands) that represent the minimum requirements to which the locations of the sites must comply. These sites can represent serious environmental problems that can lead to irreversible environmental damage mainly affecting groundwater resources and soil quality. The population distribution, public safety, population lifestyle, region planning, sensitive areas and road safety are examples of non-measurable costs that affect the overall social costs of an OMWW disposal site (Issaoui et al., 2021). For this reason, the current problem must be solved as soon as possible to avoid damages that can affect the environment. Certainly, the risk involved the bad localization of the OMWW storage tanks is very high, but the resolution of this kind of problem seems very difficult given the social problems that can burst, particularly conflicts with the owners of these sites located outside the appropriate area (Shabou et al., 2009; Aydi et al., 2016; Issaoui et al., 2021; Elkadri et al., 2022).

Hence, the management of OMWW storage tank projects remains a matter of territorial planning, where the essential elements of sustainable development (health, wealth, sociability, beauty) must be considered (Naranjo Gómez et al., 2020). In this way, OMWW storage tank management is a central concern of territorial planning strategies, where institutions assign rules and standards to preserve the environment and to maintain the social welfare of local populations (Codosero Rodas et al., 2020). It is important to assume that this spatial concept involves multiple criteria due to the need to use the land responsibly and preserve harmony with nature (Codosero Rodas et al., 2020). Then, policymakers and the main actors involved in the encouragement of sustainable development play a crucial role in recognizing the economic, environmental, and social consequences (Coccia, 2017; Rodríguez-Serrano et al., 2017). Such planning tools promote future prosperity for those living in the territory, fostering the rights of local populations in the preserved environment and eroding social unbalances and spatial disparities (Codosero Rodas et al., 2020). In this light, it is important to assess OMWW storage tank locations in a spatial and a multicriteria context in order to achieve sustainable regional development. Thus, the selection of suitable areas in which to install OMWW storage tanks is a very complex spatial and territorial problem which prioritizes the link between the multicriteria process and geographic territorial management.

Finally, the establishment of controlled and well-designed OMWW tanks becomes a difficult and, in some situations, politically and socially unacceptable task. Consequently, social, economic and environmental costs are indirectly increased as a result of the site selection process. In this context, the proposal of an operational plan or a limitation of suitable areas for the installation of new sites can be a good alternative to mitigate some conflicts, reorganize poorly located sites and anticipate possible problems related to future projects.

4. CONCLUSION

The olive oil processing industry requires large quantities of water and generates huge quantities of toxic olive mill waste water (OMWW). In Tunisia, these effluents are often stored in storage tanks. In some cases, notably the region of Sousse, the distribution of these tanks hinders the discharge operation. Indeed, the region of Sousse is characterized by a bad geographical distribution of the OMWW storage tanks between the production areas.

For this reason, the evaluation of the locations of these tanks with respect to exclusion criteria; established by the Ministry of Environment; is a very important step in revealing the real environmental and social situation for OMWW storage tank localization. These criteria are environmental, hydrogeological, and socio-economic in character and the evaluation was undertaken using a multicriteria and GIS methodology that compared the existing locations (established by GPS on a map) with the standards set by the authorities (exclusion criteria). The results showed that most of the sites were not in the appropriate zone and did not meet the standards. These results reveal the deteriorated environmental and social situation in Sousse region. Many infractions were registered affecting both the physical environment and the human being. In fact, some storage tanks are located on vulnerable areas where soils are of medium and high permeability, of high slope, or near of hydrographic network. Some other tanks are near agglomeration of population and roads. In all these cases, the localization of the most OMWW storage tanks in Sousse region does not meet the standards and the minimum criteria to be considered to put in a storage tank, which are the exclusion criteria.

This emphasizes deeply the seriousness of the environmental situation in the region of Sousse, which awareness of these dangers that threaten environment and public health are urgent.

In conclusion, this study opens up many possibilities for further research. Indeed, the proposed model can be generalized to evaluate the national OMWW storage tank management policy. It is also possible to adapt the implemented methodology to other fields to address other aspects of sustainable territorial management.

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