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Olive Mill Waste Water Risk Assessment Based on GIS Techniques in Crete, Greece

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Abstract

Water resources are subjected to different pollution sources. Point source water pollution of surface water is an important issue when considering the limited surface water availability as well as the potential knock-on effects of this pollution on human health as well as habitat and land degradation. One of the main point sources of water pollution is Olive Mill Waste Water (OMWW). OMWW is the liquid by-product generated during olive oil production. However, there is no standardized method to assess the risk of water pollution by OMWW for any given river basin. This research addressed the above issue by designing a detailed quantitative risk assessment methodology, which utilizes Geographic Information System (GIS) modeling to classify within a watershed individual sub-catchment risk of water pollution occurring from olive mill waste discharges. The research presents the proposed criteria and calculations required to estimate sub-catchment risk significance and comments on the potential of the method for wider application. This research combines elements from risk assessment frameworks, Multi-Criteria Analysis (MCA), and GIS. MCA helped in aggregating different aspects and elements associated with this environmental problem, while GIS modeling tools helped in obtaining many criterion values and providing insight into how different objects interact in nature and how these interactions influence risk at the watershed level. The proposed method was tested in the Keritis watershed in Crete, Greece, where OMWW is one of the main stressors influencing water quality, and the results indicated that this method has the potential to be a useful guide to prioritize risk management actions and mitigation measures to be incorporated in River Basin Management Plans.

Keywords: GIS, Multi-Criteria Analysis, Olive Mill Waste Water, Point Source, Risk Assessment, Water Pollution.

1. Introduction

The largest volumes of freshwater are stored underground as groundwater, accounting for about 0.6 percent of the total (Woodford, 2006). Only a miniature fraction (0.01 percent) is present as fresh surface water in lakes, streams, and rivers. However, this proportion is very important for many of the terrestrial ecosystems, including humans. The quality of this fresh water is vitally important due to its diverse uses including drinking, generating energy, growing crops, harvesting fish, running machinery and carrying waste. Water is also vital as a habitat for both freshwater and marine plants and animals (Barbera *et al.*, 2013; Goula and Adamopoulos, 2013).

A major environmental issue in Mediterranean region is the pollution of aquatic ecosystems through the discharge of industrial and domestic effluents in water bodies (Kalogerakis *et al.*, 2013). One of the main polluting activities in Mediterranean region is the olive mills agricultural industries. The Mediterranean region accounts for 95% of the global olive oil production while about 10% of the total EU olive oil is produced in Greece (Niaounakis and Halvadakis, 2006). Olive Mill Waste Water (OMWW) is the liquid by-product generated during olive oil production. It contains pollutants and hazardous materials in different concentrations which may cause negative impacts on humans and environmental degradation. Hence, sustainable management approaches at the watershed level are needed, taking in consideration different aspects of this pressure that affect the quality and sustainability of water resources (Billington, 2005).

It should be noted that one ton of processed olives produced a polluting load equivalent to that of 50-100 inhabitants or the pollution due to 1 m^3 OMWW corresponds to 100-200 m^3 of domestic sewage (Niaounakis and Halvadakis, 2006). According to Paliatziki (2006), 50 m^3 of olive oil mill wastewater are equivalent to the waste produced by 30000 citizens. The microbial content of OMWW is variable and contains a high number of bacteria and fungi. Among the bacterial strains identified are several species of *Acinetobacter*, *Pseudomonas,* and *Enterobacter*. The pathogenic *Klebsiella pneumoniae* ss *pneumonia*e has also been isolated from untreated and treated OMWW (Skerratt and Ammar, 1999).

The Water Framework Directive (WFD, 2000/60/EC) is a framework for a European environmental legislation which aims to harmonize existing European water policies and to improve water quality in all aquatic environments within the community area. It emphasizes the need of new integrated approach resulting in the protection and improvement of the sustainable use of all waters (Rekolainen *et al.*, 2003).

Integrated River Basin Management Plans (RBMP) is required by the Directive at national and regional/local scale. The main objectives of the RBMP include the prevention of further deterioration of water resources and the promotion of sustainable water use that ensures the progressive reduction of pollution (Bodini *et al.*, 2011). An integrated catchment management approach underpins a risk-based land management framework to all activities within a spatial land-use planning framework (Fiorentino *et al.*, 2003). However, there is no standardized method to assess the risk of water pollution from OMWW for any given river basin. To this end, a risk assessment methodology is required for point source water pollution in order to achieve effective and sustainable management of water resources. Risk assessment and management is a useful tool that supports informed, consistent and defensible decision making (Billington, 2005).

Risk assessment process needs to proceed from well-developed frameworks to address different aspects of environmental problems and elements and to recognize the linkages between them. However, the analysis of these linkages requires the development of modeling systems (Malczewski, 2004). In this context, researchers and policy makers rely increasingly on the use of computer models to understand and cope with such problems (Dietz, 2000). These models play a large role in managing and making decisions about water resources. They provide insight into how different objects interact in nature and how these interactions influence water resources in a watershed (Carver, 1991). Being a beneficial decision support tool, risk assessment requires different kinds of tools, such as risk quantification algorithms, spatial representations, and dynamic simulation models which characterize the method provided in this research.

The aim of this research is to establish a decision support framework for a point source water pollution risk assessment and management and more specifically to develop a quantitative risk assessment method for Olive Mill Waste water pollution.

2. Materials and Methods

2.1. Study area

The hydrological basin of Keritis is in the north part of Chania Prefecture, on the island of Crete, Greece (Figure 1). It covers a total area of 16,036 ha and consists of about 10 villages. The area has a sub-humid Mediterranean climate with an annual average temperature of 19.96 °C (Soupios *et al.*, 2007; Elhag and Bahrawi, 2016a). It is characterized by a humid and relatively cold winter and a dry and warm summer. The weather during the winter, which starts in November, is unstable because of the frequent changes from low to high pressures (Soupios *et al.,* 2007). The annual rainfall for the study area has been estimated to be 824 mm (Papafilippaki *et al.*, 2007). According to Soupios *et al.* (2007), about 65% of the annual precipitation is lost to evapotranspiration, 21% as runoff to sea and only 14% recharges the groundwater. The rainfall is mainly concentrated in the winter months while the drought period extends to more than 6 months, from May until October (Soupios *et al*., 2007). The monthly evaporation ranges from 140 mm to more than 310 mm in the peak month which results in a limited availability of the water resources. The growing water demands make the water resources management extremely important for sustainable development in this region (Zagklis *et al.*, 2013; Kapellakis *et al.*, 2015). Thus, ensuring that available surface water is not contaminated is a priority and required by the WFD for integrated River Basin Management Plans (RBMP). The watershed of Keritis is mainly an agricultural area where the most common cultivations are olive trees, citrus trees, vineyards, and vegetables. The area has also light industrial activities such as olive mills, wineries, and other agricultural factories. In the coastal zone of Keritis watershed, there are many touristic units (Papafilippaki *et al.*, 2007). Six olive mills are operating in the area. These mills gather their produced wastewater in five lagoons. All the lagoons are very close to the stream network of the basin. Fortunately, it has been found that none of the mills has a possible flow path to Agia Lake. However, the possible flow paths were all directed to Keritis Stream, which is, therefore, the surface water body considered by the analysis below. Figure 1, overleaf shows the location of the olive mills and lagoons in relation to the water bodies in Keritis watershed.

2.2. Soil Sampling

Data from the field is necessary to determine some criterion values. These criteria include the water quality parameter. Samples from surface water bodies in the target watershed were collected within a pre-planned sampling strategy and analyzed for the chemicals and parameters associated with polluting source namely OMWW (Elhag and Bahrawi, 2015).

2.3. Multi-Criteria Analysis (MCA)

Several criteria have been developed and evaluated using Multi-Criteria Analysis to quantify the risk of the pollution caused by OMWW and transmitted to humans and NATURA 2000 sites via surface water bodies. This analysis has the following steps of Mendoza *et al.,* (2002).

2.3.1. Development of risk evaluation criteria;

Evaluation of the risk can be achieved by breaking it down into its primary components. These components are related to the magnitude and probability and estimated by criteria. A criterion can be defined as a basis for a decision that can be measured and evaluated (Eastman, 2003). In this context, the developed criteria are related to the following components:

1. Components of magnitude:

- 1st magnitude component: spatial scale;
- 2nd magnitude component: temporal scale

2. Components of probability:

- 1st probability component: probability of hazard occurring;
- 2nd probability component: probability of receptor being exposed to hazard;
- 3rd probability component: probability of harm resulting from exposure;

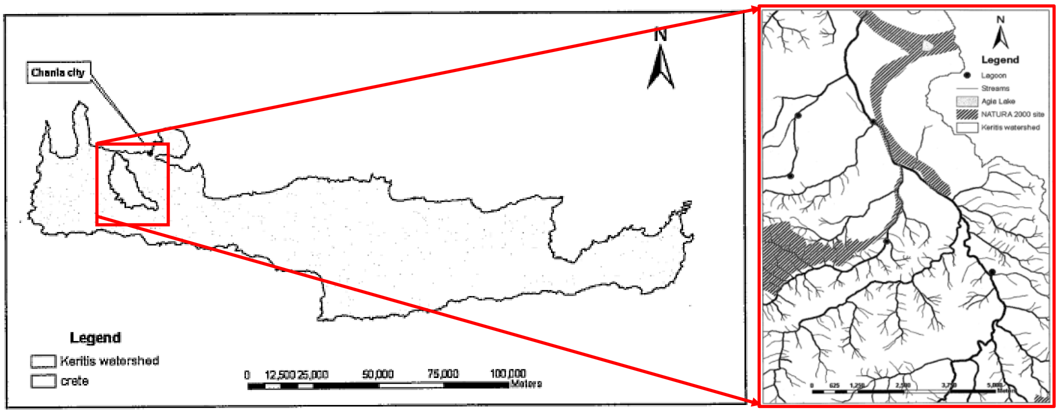

Figure 1. Location of Keritis watershed in Crete Island, Greece.

Having fully understood the risk generating process and the controlling factors as well as the characteristics of OMWW, eleven criteria have been developed in the frame of each component abovementioned. It is important here to state the addressed risk which is the risk of OMWW on human health and ecological values which may be carried by the surface water bodies. Since two groups of receptors were considered (Humans and NATURA sites), the assessment has been pursued in two directions. This means that every direction has its own criteria which might be interconnected with other direction. Below is a description of the rational way by which the criteria have been developed for both receptor groups (Figure 2).

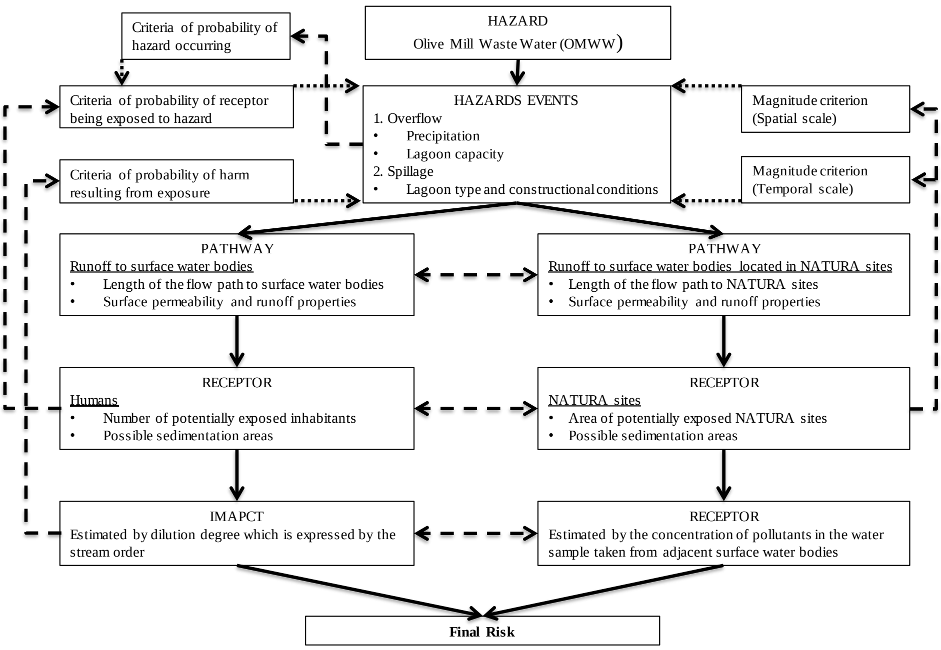

Figure 2. Illustration of the factors considered in criterion development

2.3.2. Standardization of criterion values;

Because of the different scales upon which criteria are measured, it is necessary to standardize them before being combined. There are varieties of standardization procedures, typically using the minimum and maximum values as scaling points (Eastman, 2003). These functions transform the values to dimensionless values between 0 and 1, which makes the criteria of different dimensions comparable (Mendoza and Macoun, 1999). The functions are implemented either as a benefit (the higher the criterion score, the higher the likelihood or magnitude of risk) or as a cost (the lower the criterion score the higher the likelihood or magnitude of risk). The linear scaling functions are:

a- for benefit criteria

$$C_i = \frac{R - R_{min}}{R_{max} - R_{min}} \quad (1)$$

b- for cost criteria

$$C_i = \frac{R_{max} - R}{R_{max} - R_{min}} \quad (2)$$

Where:

C_i: the standardized criterion value;

R: the origin criterion value;

R_{min}: the minimum value of all units (lagoons or sub-catchments); and

R_{max}: the maximum value of all units (lagoons or sub-catchments).

2.3.3. Assignment of criterion weights:

Individual factors are weighted to reflect their relative importance with respect to the risk. Hence, factors that are deemed more significant indicators of risk for a given sub-catchment can be assigned higher weights thereby giving them greater importance in the estimation of the risk of point-source water pollution (Mendoza *et al.*, 2002). These weights are assigned within every group of criteria to show the importance of every criterion in relation to that component. To calculate the weights of multiple criteria, the Analytic Hierarchy Process (AHP) was used. AHP is a multi-criteria decision support method developed by Saaty (1980), which uses paired comparisons in order to calculate the weights of multiple criteria. To calculate the consistency ratio (CR), which is a numerical index that detects inconsistencies that may arise due to human error; it is recommended to revise the preference matrix if the consistency ratio exceeds 0.1. This ratio is calculated using the following formulas:

$$CR = \frac{CI}{RI} \quad (3)$$

and

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (4)$$

Where:

CR: consistency ratio;

CI: consistency index;

RI: average consistency index;

λ_{max}: greatest eigenvalue of the preference matrix; and

n: order of matrix.

2.3.4. Applying an aggregation rule.

In this step, standardized criterion scores are combined using an aggregation rule. Aggregation rule is the procedure by which criteria are selected and combined to arrive at a particular evaluation of the risk. Multi-Criteria Evaluation (MCE) can be achieved by weighted linear combination (WLC) procedure wherein standardized criteria are combined by mean of a weighted average (Eastman, 2003). Thus the equation by which the criteria are combined is:

$$R = \sum w_j c_i \quad (5)$$

Where:

R: the risk value of specific sub-catchment;

W_j: the weight of criterion j and

C_i: the score of criterion i

3. Results and Discussion

3.1. Soil chemical analysis

Sampling strategy consists of collecting samples from the points where the possible flow paths from lagoons join the receiving streams (Table 1). Five different sample locations in total are shown in Figure 3. However, there were some cases where the samples were collected from locations further along of these joining points due to difficulties in the accessibility to these points. This sampling strategy was designed in order the chemical tests to show the worst case where the pollutants are in the highest possible concentrations and not affected by the dilution process. It should be noted that the dilution of the pollutants is taken into consideration in another criterion. Such an approach restricts biased sampling and minimizes the bias of one criterion's effect to the other.

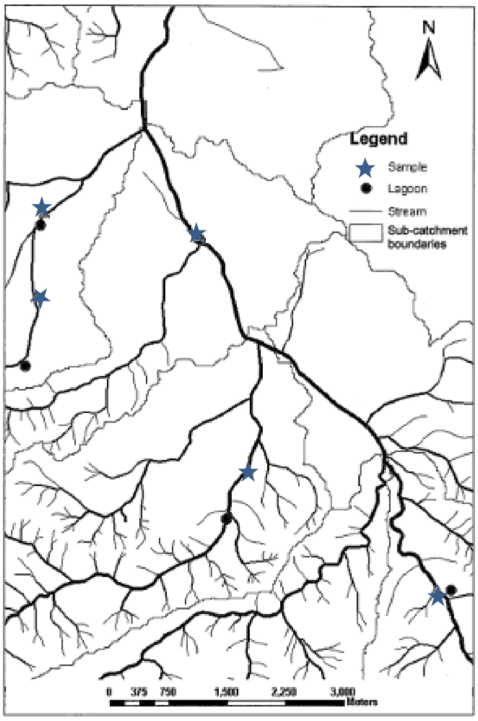

Figure 3. Location of sampling sites and Keritis lagoon

3.2. Development of risk evaluation criteria

To be able to quantify criteria and assign their values, the watershed under investigation should be divided into sub-catchments depending on its hydrological model. This should be kept in mind for the clear understanding of different analytical steps of the designated watershed. Table 2 below lists the developed criteria used to feed the Multi-Criteria Analysis (Justino *et al.*, 2005).

3.3. Standardization of criterion values

An essential step due to the differences in the criterion units, standardization of the criterion values was performed by applying the standardization functions (Malczewski, 2006). Table 3, presents the standardized criterion values of all risk components at the lagoon and sub-catchment level. However, sub-catchment one, two, and eight were excluded since there were no possible connecting pathways between them and any lagoon, and therefore, they classified as no risk areas.

Table 1. Results of chemical analyses of Ketrits soils

Elements	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
pH	8.34	8.51	8.35	8.23	8.15
Magnesium	7.94	9.95	6.38	6.13	5.97
Potassium	0.44	1.03	1.15	2.6	1.05
Sodium	6.3	10.4	14.4	16.4	15.5
Sulphates	50	60	50	60	60
HCO_3	170.8	219.6	85.4	73.2	109.8
Nitrates	0	2.02	0	0.384	0.4
Copper	0	0.001	0.006	0.001	0.002
Iron	0.025	0.005	0.102	0.531	0.528
Zinc	0	0	0	0	0
Manganese	0.002	0	0.017	0.207	0.239
Phosphorus	0.088	0.071	0.722	0.049	0.05
Phenols (phenol index)	0.164	0.176	0.964	0.232	0.225

Table 2. List of developed criteria classified according to their components

No.	Criterion	Component
1	Number of potentially exposed inhabitants	1st magnitude component
2	Area of potentially exposed NATURA sites	
3	Possible sedimentation areas	2nd magnitude component
4	Precipitation	1st magnitude component
5	Waste volume to lagoon capacity ratio	
6	Lagoon conditions	
7	Length of the flow path to surface water bodies	2nd magnitude component
8	Length of the flow path to NATURA sites	
9	Surface permeability and runoff properties	
10	Water quality parameters	3rd magnitude component
11	Dilution degree expressed by the stream order	

3.4. Assignment of criterion weights

Thereafter, the analysis was separated into two directions according to the addressed receptors. The first direction addressed the hazard of OMWW transported by surface water bodies to the humans while the second direction addresses the hazard of OMWW transported by surface water bodies to NATURA sites. This means that two risk maps (for humans and NATURA sites) were produced as a result of this analysis. This separation is due to the slight differences in the criteria used for each receptor. Table 4 illustrates these differences.

The starting point of assigning weights to the used criteria is to develop the comparison matrix. Three comparison matrices were developed for the three components of the risk probability criteria for analysis direction 1 and another three for direction 2. It should be noted here that while the matrices of the 1st and 2nd probability components are valid for both directions, the matrix of the 3rd component is limited for the 1st direction since the other direction has one criterion regarding this component. Also, no comparison matrix was developed for the spatial component of the magnitude for both directions since there was only one criterion to estimate that component, which is the case where the pair-wise comparison is not applicable.

The relative importance of the criteria used for the third group (the probability of harm resulting) is given according to the degree of harm resulting from each element or compound which can be found in the literature. Unlike the previous matrices, this is not applied for the second calculation direction which has a single criterion in this component since there is no specific threshold for chemicals in relation to different habitat types.

Table 3. Standardized criterion values

		(A)*	(B)*	(C)*			(D)*												
		Pollution	**NATURA sites**	**Prec.**	**Ratio**	**Cond**	**pH**	**Mg**	**K**	**Na**	**SO_4**	**HCO_3**	**NO_3**	**Cu**	**Fe**	**Zn**	**Mn**	**P**	**Phenols**
Criterion																			
Sub-Catch. 3	Lagoon 1			1.00	0.55	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Lagoon 2			0.62	0.57	0.00	0.10	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Lagoon 3	0.43	0.00	0.79	0.96	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.35	0.00	0.00	0.07	1.00
	Lagoon 4			0.66	0.89	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
	Lagoon 5			0.91	0.44	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
Sub-Catch. 4	Lagoon 1			1.00	0.55	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Lagoon 2			0.62	0.57	0.00	0.10	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Lagoon 3	0.70	0.12	0.79	0.96	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.35	0.00	0.00	0.07	1.00
	Lagoon 4			0.66	0.89	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
	Lagoon 5			0.91	0.44	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
Sub-Catch. 5	Lagoon 1			1.00	0.55	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Lagoon 2			0.62	0.57	0.00	0.10	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Lagoon 3	0.85	0.19	0.79	0.96	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.35	0.00	0.00	0.07	1.00
	Lagoon 4			0.66	0.89	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
	Lagoon 5			0.91	0.44	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
Sub-Catch. 6	Lagoon 1			1.00	0.55	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Lagoon 2			0.62	0.57	0.00	0.10	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Lagoon 3	0.82	1.00	0.79	0.96	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.35	0.00	0.00	0.07	1.00
	Lagoon 4			0.66	0.89	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
	Lagoon 5			0.91	0.44	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
Sub-Catch. 7	Lagoon 1			1.00	0.55	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Lagoon 2			0.62	0.57	0.00	0.10	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Lagoon 3	0.73	0.14	0.79	0.96	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.35	0.00	0.00	0.07	1.00
	Lagoon 4			0.66	0.89	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
	Lagoon 5			0.91	0.44	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
Sub-Catch. 9	Lagoon 1			1.00	0.55	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Lagoon 2			0.62	0.57	0.00	0.10	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Lagoon 3	1.00	0.00	0.79	0.96	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.35	0.00	0.00	0.07	1.00
	Lagoon 4			0.66	0.89	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
	Lagoon 5			0.91	0.44	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00

(A): Criterion of the magnitude component (for human receptor group)
(B): Criterion of the magnitude component (for NATURA sites receptor group)
(C): Criterion of the 1st probability component (for both receptor groups)
(D): Criterion of the 3rd probability component (for human receptor group)

Table 4. List of criteria for both receptor groups

No.	Criterion			Receptor group
1	Number of potentially exposed inhabitants			Humans
2	Possible sedimentation areas			
3	Precipitation			
4	Waste volume to lagoon capacity ratio			
5	Lagoon conditions			
6	Length of the flow path to surface water bodies			
7	Surface permeability and runoff properties			
8	Water quality parameters	8.1	Magnesium (Mg)	
		8.2	Potassium (K)	
		8.3	Sodium (Na)	
		8.4	Sulfates ($S0_4$)	
		8.5	Bicarbonate	
		8.6	Nitrate ($N0_3$)	
		8.7	Copper (Cu)	
		8.8	Iron (Fe)	
		8.9	Zinc (Zn)	
		8.10	Manganese (Mn)	
		8.11	Phosphorus (P)	
		8.12	Phenols	
		8.13	pH	
1	Area of potentially exposed NATURA sites			NATURA sites
2	Possible sedimentation areas			
3	Precipitation			
4	Waste volume to lagoon capacity ratio			
5	Lagoon conditions			
6	Length of the flow path to NATURA sites			
7	Surface permeability and runoff properties			
8	Dilution degree expressed by the stream order			

The relative importance of the compared criteria was taken into consideration while filling the comparison matrices. This relative importance is controlled by several factors which vary according to the nature of the problem and the group of criteria. Site specifications control the assignment of relative importance. Therefore, a site visit was conducted to achieve a more accurate estimation of every criterion weight.

In the first group (the criteria which estimated the probability of a hazard occurring) the importance was given for the precipitation criterion since it is the main reason causing the overflow and, therefore, releasing the hazard being a frequent event. For the second group (the criteria which estimate the probability of hazard and receptor co-occurrence), which the flow generated from lagoons to be washed away by the receiving stream and transported to the watershed outlet, this can be concluded when trying to simulate the hazard generating process (Elhag and Bahrawi, 2016b).

For the third ground and during the heavy storms, the smallest streams will be flowing as well as the pathways connecting lagoons with streams, thus, the probability of pollutants to be routed within the streams is higher than to be infiltrated through surface layers into the groundwater. In other words, the length of the pathway of a possible flow is affecting this component more than the surface permeability and runoff properties. The obtained weights for criteria regarding humans and NATURA sites are listed in Table 5 and 6 humans and NATURA sites, respectively. The consistency ratios of the three matrices were 0, 0, and 0.0005, respectively. According to Saaty (1979), these values are acceptable since they are less than 0.1.

3.5. Applying an aggregation rule

At this point, every criterion had its standardized values referred either to a lagoon or a sub-catchment as well as it relative weight. When aggregating these criteria, every sub-catchment will have one value of the magnitude component. Likewise, every lagoon will have one value of the first and the third probability component. From the other hand, every lagoon will have values of the second probability component are as many as the possibly receiving sub-catchments. These values are obtained using the formulas 1-5 which are basically substitutions of the formula of Weighted Linear Combination (WLC). The next step for both directions is to combine the three components of the probability. Applying this formula resulted in a value (score) of the probability of a specific lagoon to contribute the risk in a specific sub-catchment. This was applied on the 1st and 2nd directions and the results are shown in Table 5 and 6, respectively.

Regarding the risk on human health in sub-catchments one, two, and eight, calculations returned a risk value of zero for each of these sub-catchments. Since the risk is the product (multiplication) of its magnitude and probability and their primary components, the value of zero can be obtained if one, or more, of these primary components, has a value of zero (Figure 4). Hence, although the magnitude of consequences in these sub-catchments is significant, the probability of these consequences is zero. More specifically, the probability of receptor being exposed to the hazard in these sub-catchments is zero, meaning that there is no connecting pathway between the sources of hazard and the receptors. According to DEFRA (2002) and EPA (1997) guidelines, if it can be shown that no actual or potential connection exists, then the risk requires no further attention.

Since the aim of this analysis was to find the risk value in each sub-catchment regarding humans and NATURA sites, one probability value is needed for every sub-catchment. The product of the probability of all lagoons to contribute the risk in a sub-catchment was calculated and normalized by dividing by the highest product in each direction of the analysis as shown in Table 5 and 6. The last step was the multiplication of the magnitude, calculated by the standardized product, which represents the probability. The calculated values are shown in Table 7.

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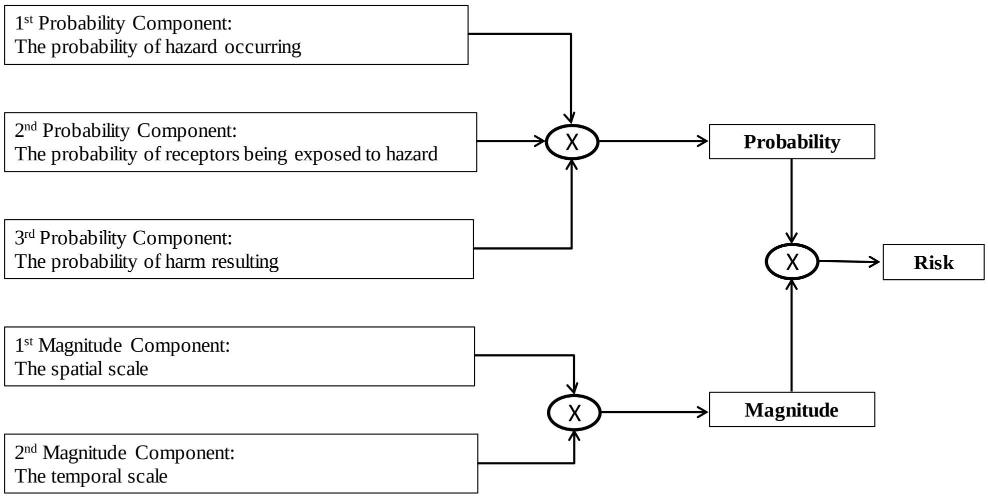

Figure 4. The mathematical relationship between risk components; it can be shown that a risk with a value of zero can result if one, or more, of these components, has a value of zero due to the multiplication between them

Table 5. Lagoons' contribution scores to risk in different sub-catchments (receptor group: Humans)

	Lagoon 1	Lagoon 2	Lagoon 3	Lagoon 4	Lagoon 5	Lagoon 6	Lagoon 7
Sub-Catch. 1	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable
Sub-Catch. 2	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable
Sub-Catch. 3	0.001980	inapplicable	inapplicable	inapplicable	inapplicable	0.001980	0.013558
Sub-Catch. 4	inapplicable	inapplicable	0.052529	inapplicable	inapplicable	0.052529	0.359689
Sub-Catch. 5	0.000876	0.003280	0.027026	inapplicable	inapplicable	0.031182	0.213517
Sub-Catch. 6	0.000912	inapplicable	inapplicable	inapplicable	inapplicable	0.000912	0.006245
Sub-Catch. 7	0.000912	inapplicable	inapplicable	inapplicable	inapplicable	0.000912	0.006245
Sub-Catch. 8	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable
Sub-Catch. 9	inapplicable	inapplicable	inapplicable	0.075817	0.070223	0.146040	1.00000

Table 6. Lagoons' contribution scores to risk in different sub-catchments (receptor group: NATURA sites)

	Lagoon 1	Lagoon 2	Lagoon 3	Lagoon 4	Lagoon 5	Lagoon 6	Lagoon 7
Sub-Catch. 1	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable
Sub-Catch. 2	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable
Sub-Catch. 3	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable
Sub-Catch. 4	inapplicable	inapplicable	0.454477	inapplicable	inapplicable	0.454477	1.000000
Sub-Catch. 5	0.212143	inapplicable	0.134057	inapplicable	inapplicable	0.346200	0.761755
Sub-Catch. 6	0.231964	inapplicable	inapplicable	inapplicable	inapplicable	0.231964	0.510398
Sub-Catch. 7	0.231964	inapplicable	inapplicable	inapplicable	inapplicable	0.231964	0.510398
Sub-Catch. 8	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable
Sub-Catch. 9	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable	inapplicable

Table 7 lists the risk value broken into its magnitude and probability components and classified into five classes based on the Natural Brakes listed in Table 8, for risk on human health and NATURA sites. These results are represented in Figure 5 shows the risk of OMWW on human health, while Figure 6 shows the risk of OMWW on NATURA sites.

Moving to sub-catchment three, the obtained risk value was very low, about 0.0058, the 3rd probability component has mainly influenced this result. Given that lagoon 1 is the only source contributing to the risk in this sub-catchment, the chemical tests under this lagoon indicated the high quality of stream water. This can be observed in the field since the possible connecting pathway is a 5th order stream where chemicals can be rapidly diluted once entering the stream. This means that the probability of harm resulting from the hazard and, therefore, the overall risk value is very low.

The obtained risk values in sub-catchment four and five were 0.25 and 0.18, respectively. This indicates based on the Natural Breaks classification, a relatively moderate risk (Jenks, 1967). These two sub-catchments have a similar condition. While the magnitude and the 1st and the 2nd probability components have significantly high values, the 3rd probability component decreases the final risk values of these sub-catchments. It can be forecasted that hazardous chemicals may be transported in sub-catchments four and five through streams of 4th and 5th order, respectively. This results in a quick dilution process of the chemicals possibly entering those streams which are reflected in the calculation model by the results of chemical tests.

Table 7. Obtained risk value for each sub-catchment in Keritis watershed

Sub-catchment	Magnitude	Probability	Risk	Classification
			Humans	
Sub-Catch. 1	0.000000	0.432000	0.000000	No Risk
Sub-Catch. 2	0.000000	0.379000	0.000000	No Risk
Sub-Catch. 3	0.013558	0.430000	0.005830	Low Risk
Sub-Catch. 4	0.359689	0.702000	0.252502	Moderate Risk
Sub-Catch. 5	0.213517	0.851000	0.181703	Moderate Risk
Sub-Catch. 6	0.006245	0.820000	0.005121	Very Low Risk
Sub-Catch. 7	0.006245	0.726000	0.004534	Very Low Risk
Sub-Catch. 8	0.000000	0.262000	0.000000	No Risk
Sub-Catch. 9	1.000000	1.000000	1.000000	High Risk
			NATURA sites	
Sub-Catch. 1	0.000000	0.000000	0.000000	No Risk
Sub-Catch. 2	0.000000	0.000000	0.000000	No Risk
Sub-Catch. 3	0.000000	0.000000	0.000000	No Risk
Sub-Catch. 4	1.000000	0.124000	0.124000	Low Risk
Sub-Catch. 5	0.761755	0.190000	0.144733	Moderate Risk
Sub-Catch. 6	0.510398	0.990000	0.509888	High Risk
Sub-Catch. 7	0.510398	0.140000	0.071456	Very Low Risk
Sub-Catch. 8	0.000000	0.000000	0.000000	No Risk
Sub-Catch. 9	0.000000	0.000000	0.000000	No Risk

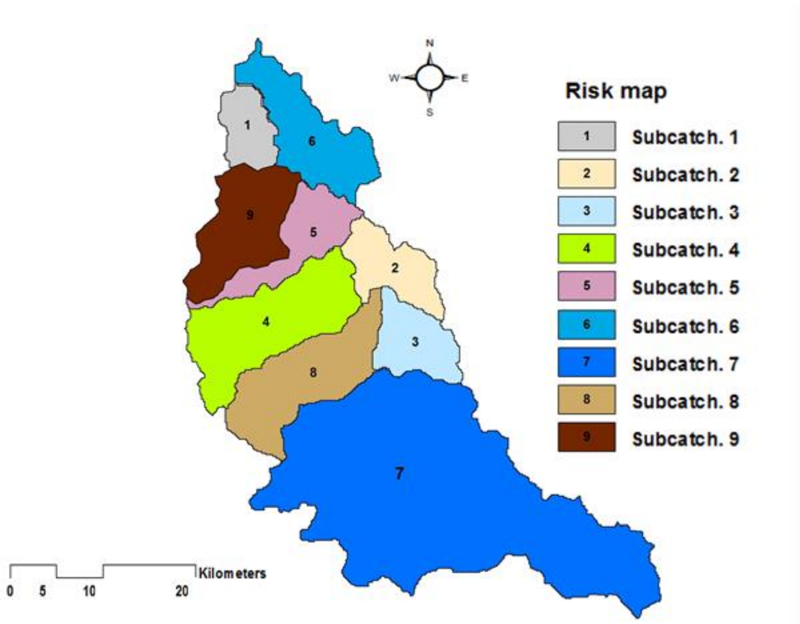

Figure 5. Risk map on human health in Keritis watershed caused by OMWW

Table 8. Natural breaks classification of obtained risk values

Class	Receptor: Humans		Receptor: NATURA sites		Description
	From	To	From	To	
1	0.000000	0.000000	0.000000	0.000000	**No risk**
2	0.000001	0.005121	0.000001	0.071456	**Very low risk**
3	0.005122	0.005830	0.071457	0.124000	**Low risk**
4	0.005831	0.252502	0.124001	0.144733	**Moderate risk**
5	0.252503	1.000000	0.144734	0.509888	**High risk**

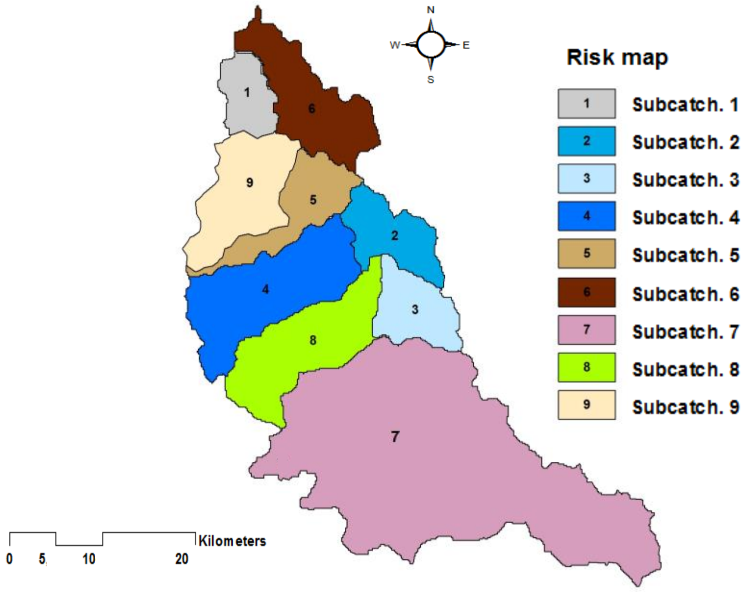

Figure 6. Risk map on NATURA sites in Keritis watershed caused by OMWW

Although there are no lagoons located in sub-catchments six and seven, the calculations indicate very low values of risk. These risk values resulted from the contribution of lagoons located in the other sub-catchment. However, these risk values were very low mainly because of the long pathways through which hazardous substances may be transported. These long pathways are subjected to a high dilution degree which highly mitigates the pollution and decreases the pollutant concentrations.

The highest value of risk was assigned to sub-catchment nine. In fact, many factors have influenced the calculations resulting in such a value. First of all, this sub-catchment contains two lagoons which can release a potential hazard. These two lagoons are located near to streams with a low order of 3. From another point of view, the probability hazard occurring was relatively high due to the high precipitation over the lagoons located in this sub-catchment. Moreover, the results of chemical tests stated a high probability of harm resulting specifically from the high phenol concentrations. Beside all the factors, the magnitude component of risk in this sub-catchment was the highest of all resulting in a high-risk value assigned to this sub-catchment (Pierantozzi *et al.*, 2012).

Regarding the results of the risk on NATURA sites, calculations resulted in various risk values which have been classified into five classes as shown in Table 8. For sub-catchments one, two, three, eight, and nine, the obtained risk values were all zeros; this is due to the fact that there are no NATURA sites located in these sub-catchments, which is why the magnitude of consequences was assigned a value of zero. Since the magnitude component of risk is zero, the risk value is also zero, given that the risk is the multiplication of its magnitude and probability components (Tsiknia *et al.*, 2014). Moving to sub-catchment seven, the assigned value indicates very low risk. This is due to the long connecting pathway between the sources of hazard and NATURA areas in this sub-catchment. This influences the 2nd and 3rd probability components, meaning that this pathway is insignificant and may lead to negligible impacts since the pollutants are more likely to be diluted once reaching the site (Zalidis *et al.*, 2004).

The highest probability of consequences was in sub-catchment four. This value is due to the short distance between the source of hazard and NATURA areas. Also, the high probability of hazard occurrence, especially the high precipitation, has contributed to this high probability. However, the overall risk value was relatively low because of the low value of magnitude component represented in a small affected area of NATURA sites in this sub-catchment. Likewise, the probability of consequences in sub-catchment five is considered to be high, while the magnitude was low. Accordingly, a moderate risk value was assigned to this sub-catchment. Finally, calculations indicate that the risk of OMWW on NATURA sites is the highest of all. This high-risk value is a result from the relatively high probability of consequences to which large NATURA areas are exposed.

From the above discussion, it can be concluded that receptors (inhabitants and sensitive habitats) within Keritis watershed faces the risk of OMWW pollution. However, different sub-catchments are subjected to this risk to different degrees. This differentiation resulted from risk assessment process that took into account several criteria controlling the risk. In this analysis, a significant risk value is defined as the value lays in the last two classes based on the Natural Breaks classification. Therefore, regarding the risk on human health, the assessment showed that inhabitants within sub-catchment four and nine are exposed to a significant risk of water pollution by OMWW. From another point of view, the assessment showed a high risk to which NATURA areas is sub-catchments five and six are subjected.

Nassar *et al.*, (2014) urgently stressed the need for an environmentally safe and cost-effective solution to Olive Mill Waste Water treatment. One of the management measures that may be applied is to stop the permissions for olive mills in the identified high-risk areas. However, though it reduces water pollution in the study area at a minimum cost, it is expected not to be socially acceptable since a large part of the local economy is based on olive oil production. A possible appropriate management action could be the Inorganic flocculation. This method has, according to Kapellakis *et al.*, (2015) many advantages; it can be easily implemented, it mitigate surface water pollution instantly, it is an environmentally friendly technology, it has been applied in other cases, and its cost is not prohibited for olive oil mill owners. However, risk management is not within the scope of research, and it has been recommended as a further research in Keritis watershed.

4. Conclusions

Research objectives aimed at development of a detailed quantitative methodology to assess the risk on Olive Mill Waste Water. In order to do so, it has been required to investigate in depth the environmental problem of Olive Mill Waste Water. Being an environmental problem, water pollution by Olive Mill Waste Water was studied in terms of the controlling factors associated with it in a spatial and temporal scale. These controlling factors are essential for modeling and simulating the risk generating process. Moreover, a full picture of the potential sources of pollution and the expected receptors, as well as the connecting pathways, was drawn, resulting in a conceptual model of this environmental problem. Having defined the risk generating process and the generic conceptual model, the quantitative approach of risk assessment was built. Within this quantitative approach, several criteria were developed. These criteria are, simply, the controlling factors defined in the risk generating process and the conceptual model. Consequently, these criteria must be quantified and standardized to be compatible with the developed calculation model. The calculation model has been established to quantitatively assess the risk in every sub-catchment within the studied watershed. It has been designed in a way to calculate an overall potential risk a sub-catchment may face as a result of the contribution of all point-sources of pollution within the watershed. This is one of the main strengths of this method as it can provide an output for a calculation unit (a sub-catchment) by considering and analyzing inputs from all sources of pollution (lagoons) in the main watershed (all the other sub-catchments). The implemented methodology has shown the applicability of this methodology and its potential as a decision supporting tool. Applying this methodology, the risk map of Olive Mill Waste Water in every sub-catchment within Keritis watershed could be assessed quantitatively. This can be counted as strength, being a replicable methodology for many cases. Another strength point of this methodology is its flexibility to add or remove criteria as well as changing their weights based on the specific needs of different case studies without affecting the calculation model. This is a very important issue since the controlling factors of environmental problems are more likely to change spatially and temporally. It can be effectively refined to address other point-sources of water pollution. In this case, the calculation model may need some modification in light of the new problem formulation. However, the generic frame of this methodology, consisting of the main steps, is still valid.

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