STREAM NETWORK POLLUTION BY OLIVE OIL WASTE WATER RISK ASSESSMENT IN CRETE, GREECE

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ABSTRACT

One of the major spinoff of olive oil production is what so called Olive Mill Waste Water (OMWW). Discharge of OMWW into rivers system in Crete had led to heavy organic pollution and several drastic environmental impacts especially the diminishing of rivers biodiversity. The current research study aims to map and evaluate the environmental hazards initiated by olive mill waste water pollution discharged into surface stream network of Kolymvari agricultural area located in western Crete, Greece. Implemented methodology is based on collecting of volumetric pollutant samples, locating source points of pollution and determining pollutant surface flow paths under GIS environment. The help of Multi Criteria Analysis was to evaluate the risk of each source point of pollution. Potential pollutants sinks of OMWW in rivers stream network were located and mapped with aid of relevant GIS tools. Different watersheds and its accumulative pollution risk in respect to their source of pollution maps were evaluated at potential pollutants sinks. Adopted methodology proved to be efficient in conducting robust evaluations criteria of OMWW environmental risk in the designated study area. Furthermore, mapping of Olive Mill Waste Tanks will positively improve the adopted methodology in term of assessing the potential risks of soil and groundwater pollution.

Keywords: Crete, Geographical Information System, Oil Mill Waste Water, Risk Assessment, Water Pollution

1. Introduction

The physicochemical characteristics of olive mill waters are quite variable, depending on climatic conditions, olive cultivars, degree of fruit maturation, storage time, and extraction procedure (Fiorentino *et al*., 2003). Nevertheless, OMWW can be characterized as a heavy organic pollutant. The waste load produced by one ton of processed olives produces the equivalent of that of 50 – 100 inhabitants (Niaounakis and Halvadakis 2004). Additionally, OMWW incorporate toxic compounds (i.e. phenols, tannins and dyes). Of the latter compounds, phenols have the highest concentration. Regarding phenols, the group of specific interest is that of the tyrosols.

The derivatives of the tyrosol (hydroxytyrosol) are characterized by major bio – antioxidant activity, but from an environmental point of view, they are resistant to air/oxygen, bacterial and enzymatic degradation and are of a highly polluting nature (Haichar *et al*., 2014). All of the inorganic compounds are found to be bound to the organic polymeric fraction, which is composed of polysaccharides, polymeric polyphenols and proteins. OMWW has a higher concentration of potassium and similar concentrations in the inorganic fraction (i.e. nitrogen, phosphorus, calcium, magnesium and iron) compared with other organic wastes.

A possible toxic substance, incorporated in OMWW, is copper (in the form of cuprite – Cu_2O). Copper is toxic to fungi, algae and other lower vegetation, in concentrations of one tenth of what has been found in OMWW (Kapellakis *et al*., 2015). Additionally, in OMWW, a high number of bacteria, molds, yeasts and fungi can be found, most of which use the OMWW as a growth substrate and help in biodegrading the waste.

The first observation that can be made in a water stream polluted by OMWW is the discolouring of the water. This change in colour is attributed to the oxidation and subsequent polymerization of tannins giving coloured polyphenols, which is difficult to remove from the effluent (Mahmoud *et al*., 2012).

Multi-Criteria Analysis is a decision-making tool developed for complex multi-criteria problems that include qualitative and/or quantitative aspects of the problem in the decision-making process (Mendoza, Macoun *et al*. 1999). It can also be stated that Multi Criteria Analysis is a tool based on the use and manipulation of two types of information: Hard information and Soft information (Malczewki 1999).

The main aim of this work was to assess and map the pollution risk to surface water resources caused by olive mill's wastewaters, in Kolymvari, Crete. It was assumed that M.C.A. with the help of GIS and Remote Sensing tools can quantify and map the aforementioned risk.

2. Materials and Methods

2.1. Study area

The area of study is the Municipality of Kolymvari, comprising 17 communities and located in the Prefecture of Chania (Fig. 1). The landscape can be characterized as mountainous, resulting in plain only near the coast. Olive mills in the area are 3–phase ones. Conventionally, anaerobic digestion is the preferred treatment process for OMWW, since aerobic processes tend to be inhibited by the presence of certain organic compounds such as caffeic acid, tyrosol, hydroxyltyrosol and p-coumaric acid, which are known to be present in OMWW.

Figure 1: QuickBird image of the area after pansharpening. In the inset, a close-up view.

Additionally, the sedimentation of suspended solids creates a non–penetrable layer that covers the basement of the tank, thus preventing possible groundwater contamination. The olive mill owners can use the sediment produced from the tanks to produce fertilizer for their olive fields. Unfortunately, the fate of the solid wastes produced in the tanks after the evaporation of the diluted constituents is left to each owner to decide. Moreover, the waste tanks that are built, due to the legislative requirements, are sometimes at quite a distance from their corresponding olive mills. Consequently, olive mill owners are reluctant to transport of OMWW to them due to the costs involved.

2.2. Data Set

The dataset for the study were collected as follows:

- QuickBird, spatial resolution 0.60 m, dated from 16/Nov/2012.
- 20 by 20 m point elevation grid. The 20x20m point elevation grid was provided by the Greek Ministry of Agriculture.
- Meteorological data (temperature and rainfall data). The meteorological data were provided by two meteorological stations in the area for a time period of 22 years, i.e. 1991 – 2013.
- Land cover vector data, e.g. land cover, road network, protected areas, hydrology, and geology on a scale of 1:100,000. Vector data, such as land cover, road network, protected areas, hydrology, and geology were obtained from the dataset stored in CORINE.

2.3. Basic Methodology

The basic methods incorporated in risk assessment are:

2.3.1. Image analysis (Visual photo - interpretation). Delineation of the source points of pollution was assessed by locating them by using visual photo – interpretation. This procedure made use of the QuickBird Image due to its high spatial resolution.

2.3.2. DEM construction and assessment. Since the raw ground elevation data were available in a 20 by 20m grid format for the Municipality of Kolymvari, the use of a DEM for representing the topography of the study area was considered appropriate. Similarly, the DEM that was produced for this case study was assessed for its accuracy, using trigonometric points as a reference, provided by the Geographic Service of the Hellenic Army.

2.3.3. Hydrological modelling. The methodology used involved locating the steepest descent neighbour for each pixel of the DEM. This method is able to define the direction of movement of a water drop from each pixel of the DEM. Therefore, it is possible not only to create a digital representation of the hydrological network of the area, but also to simulate the surface movement of the OMWW according to the topology of the area.

According to a sensitivity analysis carried out by Garbrecht and Martz (1999), a DEM should have a grid area of less than 5% of the network reference area to reproduce the selected drainage features with an accuracy of about 10%. Therefore, by establishing formula (1), it was possible to calculate the area needed for producing a drainage network with an accuracy of about 10%.

$$\text{Grid area} = 0.05 * \text{Network Reference Area} \quad (1)$$

Where: Grid area: The pixel area, and Network Reference Area: Mean Catchment area

2.3.4. MCA using GIS analysis

The MCA method used was the Simple Additive Weighting (SAW) method. Risk assessment was approached on two different scales, i.e.:

1. On a micro scale, by assessing the risk at each source point of pollution,
2. On a macro scale, by assessing the risk at the watershed level.

The criteria used on the micro scale level were the following:

1. Pollution capacity,
2. Distance of the point sources of pollution from the drainage network,
3. Stream order of the affected drainage network segments,
4. Type of source of pollution,
5. Distance between sources of pollution.

All criteria, apart from criteria numbers 5 and 6, were standardized using linear functions on a scale of 0 to 1. According to the SAW method, each criterion was multiplied by an individual weight of importance assigned on the basis of local expert opinion. The sum of the entire set of weighted criterion – layers was selected as a decision rule (Malczewki, 1999).

3. Results and Discussion

3.1. Source Points of Pollution Validation

Location of the source points of pollution (i.e. olive mill waste tanks and mill factories) was initially assessed using visual photo – interpretation on the QuickBird Image, given its high spatial resolution. The geodatabase created was validated and a field trip to all of the identified or indicated points. Although waste tanks were identified on the digital image with satisfying overall accuracy success (80%, 16 waste tanks were validated out of 20 identified from QuickBird Image), the identification of olive mills was less successful (73%, 11 olive mills were validated out of 15 identified from QuickBird Image), due to their similarity with nearby buildings (Nassar *et al*., 2014). Eventually, it was possible to link the source points of pollution with ownership status.

3.2. DEM Construction

DEM of the area was produced using the Non-linear interpolation method. The pixel size of the raw elevation data was resampled to 4m. This size was considered to be adequate for deriving a detailed hydrological model. Finally, the output elevation values were given real number accuracy. The Random Mean Square Error of the DEM was found to acceptable at 3.21 m (RMSE = 3,21m) according to JRC (2003).

3.3. Construction of the Hydrological Model

The accuracy of the hydrological model can be assessed using the QuickBird Image. A new vector file was created by digitizing the river network on the image through techniques of visual interpretation. The hydrological network of the area and their watersheds extend beyond the borders of the municipality. Therefore, during the analysis, a stratum based on the watersheds of the study area was assessed. These discrepancies occurred because DEM on which the production of the hydrological model was based had a resolution 4x4 m, while the satellite image had a resolution of 0,60m. Therefore, these inaccuracies are the result of the coarser resolution of the DEM.

3.4. Multi Criteria Analysis Implementation

3.4.1. Criteria used on a Micro Scale

3.4.1.1. Pollution Capacity

Pollution capacity of each source of pollution was standardized according to the formula:

$$\text{Stnd (PC)} = \frac{\text{PC}}{\text{PC(max)}} \tag{2}$$

Where: Stnd (PC): the standardized Polluting Capacity, *PC:* Polluting Capacity of each source point of pollution and PC (max): The maximum Polluting Capacity found in the dataset.

3.4.1.2. Distance of the point sources of pollution from the drainage network

The greater the distance of a tank or factory from a stream, the less the drainage network is affected by OMWW pollution. The above was achieved in two steps. The first step was to map the pollution flowpaths using rain drop analysis. The second step was to calculate the 3D lengths of the separate flow path polylines by interpolating heights from the surface and summing the results per flow path. Finally, the calculated distances were standardized using the following formula:

$$\text{Stnd (D)}= \frac{\text{D(min)}}{\text{D}} \tag{3}$$

Where: Stnd (D): the standardized Distance of each source point from nearby streams, D: Distance of each source point of pollution from nearby streams and D (min): The minimum Distance that is found in the dataset.

3.4.1.3. Stream order of the affected drainage network segments

Bigger rivers are able to dilute the pollutants and spread them across their flow line, reducing in such a way their pollution effects. Conversely, when OMWW are discharged into smaller rivers, the pollution effects are greater. The environmental risk was assumed to be inversely analogous to the Strahler order of the aforementioned river segments. Consequently, the Strahler values were standardized from 0 to 1 according to the formula:

$$\text{Stnd (Order)}= \frac{\text{Order(min)}}{\text{Order}} \tag{4}$$

Where: Stnd (Order): the standardized Stream Order of the impacted streams, Order: Stream Order of the impacted streams and Order (min): The minimum Stream Order of the impacted streams.

3.4.1.4. Type of Source of Pollution

Impact of each source of pollution on river ecosystems was considered to be associated with the nature of the source. Consequently, the risk assigned to each olive mill was the maximum (1) and that assigned to each waste tank was less (0,5).

3.4.1.5. Distance between sources of pollution

The distance between the waste tank and its corresponding olive mill is an indication of how much the waste tank is used by its owner. The risks assigned to the olive mills and their corresponding waste tanks were as follows: a- If the distance is greater than 1 Km, it was considered more probable that the greatest amount of waste is discharged, a risk factor of 0,3 was assigned to the waste tanks and a factor of 0,7 to the olive factory and, b- If the distance is less than 1 Km, it was considered more probable that the greatest amount of waste is supplied to the waste tanks, a risk factor of 0,3 was assigned to the olive factories and a factor of 0,7 to their corresponding waste tanks

3.4.1.6. Risk Map Production

According to the Simple Additive Weighting method (SAW), the weighting of the criteria was based on the following formula:

$$X_{ij}\ (w_i)= w_i x_{ij} \tag{5}$$

Where: $X_{ij}(w_i)$: the weighted jth attribute of the ith criterion, w_i: the weight assigned to the ith criterion and x_{ij}: the un - weighted jth attribute of the ith criterion. The weights used for each criterion were as follows:

Table 1: Weights assigned to each criterion

Criteria	Weight
Pollution Capacity	0,27
Distance of the source points of pollution from the drainage network	0,20
Stream order of the affected drainage network segments	0,18
Type of source of pollution	0,27
Distance between sources of pollution	0,08
Sum	1

3.4.2. Criteria used on a Macro Scale

3.4.2.1. Existence of possibly impacted stream segments

The most affected areas in the drainage network was defined as areas of possible sedimentation of the pollutants. The possible sedimentation areas were defined as Flat areas and areas long enough to cause sedimentation of the pollutants.

1. Flat areas. These areas were mapped using the Stream Power Index (SPI), which was defined as follows:

$$\text{S.P.I.} = \ln(\text{Specific Catchment Area} * \tan b) \qquad (6)$$

Where: Specific Catchment Area = A/d, A = upslope drainage area and d = unit contour width
tanb = Slope.

Small values of SPI indicate areas with small slope and a small specific catchment area. Therefore, relatively flat areas are characterized by small values of SPI, abrupt areas are characterized by bigger values.

The SPI values were classified into two classes using the natural breaks algorithm. The 1st class represented the flat surfaces in the drainage network of the study area.

2. Areas long enough to cause sedimentation of the pollutants. To define these areas it was necessary to calculate, the surface flow lengths of river segments that traversed flat areas (Zagklis *et al*., 2013). Subsequently, the surface length distances were classified into three (3) classes (Table 2) using the natural breaks algorithm and the class with the biggest values was selected as the most suitable for sedimentation (Pierantozzi *et al*., 2012).

Table 2: Classification of flow distances that traverse flat areas.

Classes	Surface Length Distances (m)
1st Class	4,01 - 60,12
2nd Class	60,12 - 204,28
3rd Class	204,28 - 581,58

The majority of the selected 3rd class areas were located near the coastline, where the terrain is usually flat enough for the pollutants to sediment.

3.4.2.2. Pollution risk of possibly impacted segments

The risk of OMWW pollution to each sedimentation area was assessed via the waste flow paths of each source point of pollution (Tsiknia *et al*., 2014). Consequently, the accumulated pollution risk in a sedimentation area was equal to the sum of the risks, on a micro scale, of the source points of pollution that supply OMWW to this area (Fig. 2). Finally, the environmental risk on a macro scale was equal to the sum of the accumulated pollution risk of sedimentation areas located in the spatial extent of each watershed (Fig.3).

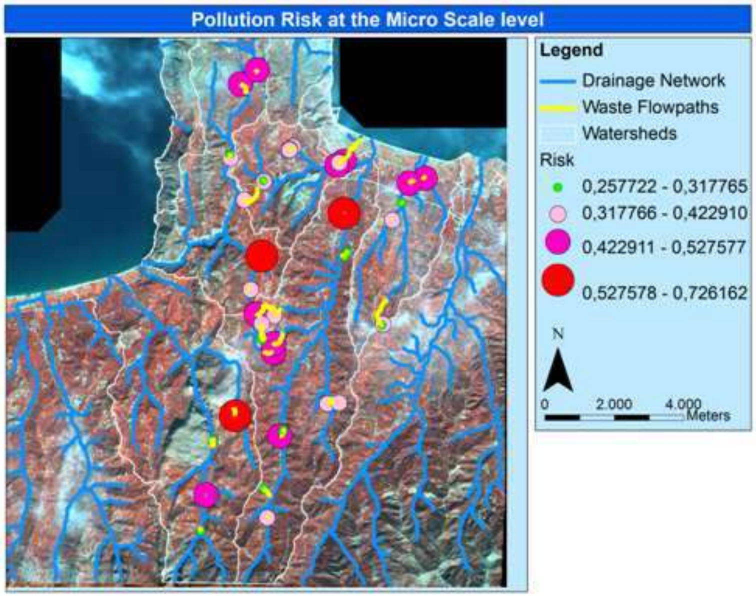

Figure 2: The risk of pollution at each source point of pollution.

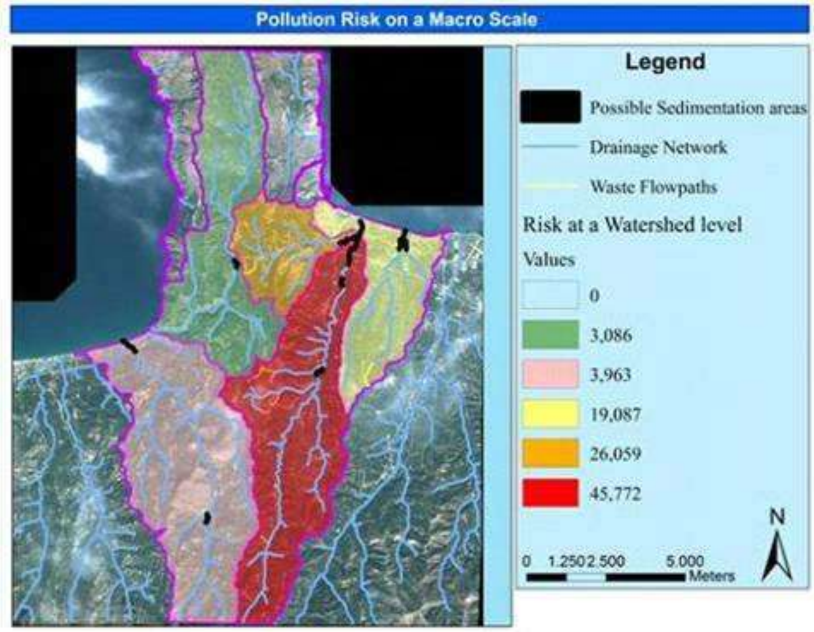

Figure 3: Pollution Risk at a Watershed level.

4. Conclusions

Olive mill wastewater pollutants accumulate in areas of possible sedimentation. Therefore, highly risky areas were defined as areas of possible sedimentation in the drainage network. The location of these areas in a GIS environment was realized by using the Stream Power Index (SPI) in order to map relatively flat areas. By calculating the surface flow lengths of the selected flat areas, it was possible to determine the longest ones, where a sedimentation effect is more probable. Mapping and quantification of the environmental risk from OMWW was implemented in this study in a GIS environment. On a micro scale, it was proved that the implementation of M.C.A. can quantify the environmental risk to surface water resources caused by olive mill wastewaters. On a macro scale, risk mapping was implemented by establishing spatial connection between the source points of pollution and the possible sedimentation areas. Subsequently, it was possible to calculate the accumulative pollution risk in each sedimentation area according to its corresponding source points of pollution. Finally, at a watershed level, the risk was equal to the sum of the sedimentation area's risks in each catchment area. In conclusion, the methodology used in this study proved to be a practical, fast and inexpensive means of evaluating the environmental risk posed by OMWW discharge in the surface water resources of the area of Kolymvari.

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