Minimum dataset for risk management of water pollution caused by olive oil factories in Crete

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ABSTRACT: Liquid waste from olive oil factories comprises an important environmental threat for river ecosystems in Crete. Determining Pressure indicators and relevant Minimum Datasets, within the DPSIR framework, is a crucial step before managing the risk of discharging this waste to the drainage network by accident or due to inappropriate management. By employing the expert opinion, the Minimum Dataset (MDS) was determined comprising 6 GIS layers. These layers were derived via visual photo-interpretation of a QuickBird image, hydrological modelling from a DEM, digitisation of a geological map, and collection of polluting capacity attributes.

1 INTRODUCTION

The broad picture for the olive oil sector in Mediterranean Europe is that of intensified production leading to certain negative effects on the environment, which however, could be reduced considerably by means of appropriate management practices (Beaufoy 2001). In many areas, such as in the island of Crete, Greece, olive cultivation is mostly oriented to oil production. The consequent intensification of the cultivation increases olive oil production and the amount of waste by olive oil factories (Yassoglou et al. 2002; Kosmas 2005).

Olive factories became a source of pollution when technology allowed massive production of olive oil at much faster rates than before. The transaction from the traditional procedure to the 3-phase centrifugation is considered responsible for the increased environmental pollution which was witnessed in Crete from the early 1980’s. The major component of the contemporary olive mill waste is the liquid waste, which is the most hazardous in terms of environmental impact. Sixty five (65) to 175 kgr of liquid may be extracted from 100 kgr of olives. According to the environmental rules and legislation these residues are collected in special evaporation tanks; the sediment from the tanks then can be utilized for producing fertilizer for olive fields. However, in many cases farmers do not maintain the protection measures enforced by the law, e.g. waste tanks, if they exist at all, are often smaller than they should be, or flooded during the winter, rendering discharge of the waste to the neighbouring torrents inevitable, thus causing a serious environmental risk (Karydas et al. 2005c).

In the context of environmental issues, risk assessment is the attempt to quantify risk by determining a Minimum Dataset (MDS) for analysis and management (Schierow 2001). Currently, the best way to cope with risk management is within the concept of ‘DPSIR’, i.e. ‘Driving forces – Pressures – State – Impact – Responses’, framework. Driving forces are the underlying causes, which lead to environmental pressures. Pressures in turn affect the state of the environment, which refers to the quality of environmental elements, such as air, soil, water, and the landscape and thus have impact on ecosystem functioning. Responses influence Driving forces, Pressures and States, thus completing
a feedback loop (Zalidis et al. 2004). This disciplinary context is commonly dealt with by Multi-Criteria Analysis (MCA) methods in the steps of Environmental State and Impact (Giupponi 2002). With regard to risk management of water pollution, examination must be made at the watershed level (Zalidis et al. 2004).

The aim of this work was to determine the Minimum Dataset (MDS), from which proper criteria can be setup for risk management of water pollution by olive oil factories. The basic hypothesis of the work was that a dataset comprising very high resolution imagery, such as QuickBird, a DEM, a geological map, and polluting capacity attributes are necessary and efficient in order to derive proper indicators for a complete risk management of water pollution by olive oil factories.

2 MATERIALS AND METHODS

2.1 Study area

The agricultural area of the municipality of Kolymvari, which is located in the NW part of Crete, was selected as a typical example of an olive oil production area in Crete. The island of Crete is located in the Eastern part of the Mediterranean Sea (Fig. 1). The landscape of the area is characterized as roughly flat, mountainous and semi-mountainous, containing areas which enjoy special protection under the NATURA 2000 programme (Directive 92/43/EEC, Greek Habitat Project Natura 2000) (Baourakis et al. 2003). Tree crops cover an area of 4,445 ha, the most extensive part of which are olive plantations. Currently, 18 olive oil factories operate in the area.

![Figure 1. The area of Kolymvari is located in the NW part of Crete.](image)

2.2 Determination of P Indicators

Following the DPSIR framework, functioning of olive oil factories in the area was characterised as an 'Industry/Energy' Driving force. Among other pressures which may be derived from this activity, 'Emissions to water' by olive oil mill waste was recognised as the main pressure. It has been showed that biodiversity reduction due to waste effluents was 71.4% for medium and small rivers in Crete and 41.6% for big rivers (Voreadou 1994).
According to the experts’ opinion, knowledge such as density and status of olive mill waste tanks, proximity of waste flows to the torrents and geological discontinuities, and inappropriate solutions given by some mill owners is crucial when examining potential accumulative effects by olive oil factories at the watershed level (Zalidis et al. 2004; Karydas et al. 2005b). For the systematisation of the above knowledge, a set of P (Pressure) indicators expressing environment – olive oil factory complex, was proposed as follows:

- number of pollution sources per watershed;
- polluting capacity of each olive oil factory;
- proximity of pollution sources to the drainage network;
- stream order;
- relief curvature;
- proximity of pollution sources to geological ridges.

In order to apply the aforementioned indicators in any attempt of Decision Support with Multi-Criteria Analysis, they were broken down into elementary GIS layers. For constructing these layers, a basic dataset was setup and several techniques were considered.

2.3 Basic dataset

Pollution sources, i.e. waste tanks or olive oil factories (where waste tanks did not exist or waste was discharged to the streams directly from the factory), could be allocated using a very high resolution (VHR) image or alternatively by fieldwork, e.g. using a GPS receiver. However, the latter approach would require a lot of labour and would result in high degree of uncertainty where for instance, a pollution source might not be discovered in the field. On the contrary, the use of a VHR image could guarantee allocation of all sources through visual examination of the entire area. Moreover, a VHR image could contribute to the estimation of polluting capacity by calculating waste tanks’ open surface and could be used for correction of the drainage network where necessary. For the above reasons a VHR image, namely a QuickBird, was selected for allocating and evaluating the sources of pollution in the area.

Panchromatic mode (PAN) and Multi-Spectral mode (MS) of a QuickBird image covering approximately 16.5 km by 16.5 km were acquired on November 16, 2002 with a 14° off-nadir angle. The imagery was provided as Basic product level 1B and was orthorectified in the lab (Fig. 2). The spatial resolution was 0.64 m. in the PAN mode and 2.50 m. in the MS mode (Eurimage). Orthophotos with a spatial resolution of 1 meter covering the study area were also available and were used for Ground Control Point (GCP) and Check Point collections. Rational Polynomial Coefficients (RPC) modelling and first order polynomial refinement were applied and a Root Mean Squared Error (RMS Error) of 0.676 and 0.706 pixels was obtained, i.e., 0.45 m. and 1.69 m. for the PAN and the MS image, respectively. This geometric accuracy satisfied the standards for the very high resolution satellite imagery, i.e. less than 2.5 m. final accuracy, set by the European Commission for mapping products to be used for agricultural monitoring and control (JRC 2003). Correction of the relief displacement was performed using a Digital Elevation Model (DEM) of the area with 4 m spatial resolution.

The Digital Elevation Model (DEM) of the study area was created from available point raster elevation files with 20 m. spatial resolution, i.e., (x, y, z) files. The interpolation method was selected for non-linear Rubber sheeting and the resampling pixel size was 4 m. The z-accuracy (elevation) of the DEM was tested using 33 trigonometric points and found to be 5.212 m. as RMS error. A 10-meter contour-lines layer was created from the DEM and was overlaid on it. The contours were also overlaid on the QuickBird image, in order to support its photo interpretation, e.g. allocation of sloped sites.

After orthorectification, fusion of the two modes (sharpening of the MS mode by the PAN mode) was carried out with Principal Component Analysis (PCA) as a fusion technique and bilinear interpolation as a resampling technique. The resulted product (pansharpened image) extended the application potential of the original dataset (Fig. 3).
Figure 2. The QuickBird image of the area after pansharpening. In the inset, a close view is shown.

Figure 3. An example of advanced image potentialities for interpretation of the QuickBird image: a newly established olive plantation as is shown in the MS mode (up-left), in the PAN mode (up-right) and in the pansharpened result (bottom).
2.4 Techniques

Since QuickBird images are comparable to aerial photographs in spatial resolution, their visual photo-interpretation was based on the same recognition elements as those of aerial photography. Visual photo-interpretation was carried out using a false-colour image composition, i.e. two bands from the optical and one from the Near Infrared (NIR) spectral range. In order to improve the appearance of the image, its histogram was enhanced and a $3 \times 3$ high pass filter was applied. Visual photo-interpretation targeted olive factories (e.g. buildings) and olive oil waste tanks. To identify the features of interest, the following photo-interpretation keys were established (Fig. 4) (Karydas et al. 2005b):

- olive mills: larger than normal buildings, usually with a yard on an accessible road;
- olive oil waste tanks: very dark smooth objects / elliptic or orthogonal shape.

![Image of olive mill waste tanks](image)

Figure 4. A group of olive mill waste tanks located near a torrent (blue line) are identified in a subset of the enhanced image.

Validation of findings of the visual photo-interpretation was based on local residents’ excellent knowledge of the area. A 1-day field survey assisted photo-interpretation and the collection of ancillary data (Gitas et al. 2003).

Given the fact that no other information sources existed, e.g. paper or digital maps, the hydrological layers, i.e. the watersheds and the drainage network, were derived from a Digital Elevation Model (DEM) using the method of ‘the steepest down slope neighbour’ or ‘raindrop analysis’. Raindrop analysis describes how a water drop will travel throughout a landscape from each pixel of the DEM. A classification of the cells according to their flow accumulation is used to identify stream channels and delineate watersheds. The volume of the accumulated flow in each pixel can define if it belongs to a river or to a hill slope. Therefore under a user-defined threshold of a number of cells or a drainage area in square kilometres, the delineation of rivers and their watersheds was carried out in a combined approach. The drainage network in the watersheds of interest was corrected based on
visual photo interpretation of the QuickBird image, more specifically spatial matching of identified streams in the image with stream vector lines (Strahler 1957; Maidment 2003).

Flow paths of waste material, i.e. the shortest route of a flow from a certain point pollution source to the sea (or alternatively, to the closest stream), and the Stream Power Index (SPI) as an expression of areas of probable sedimentation of pollutants (Karydas et al. 2005a) were derived from the DEM for all pollution sources using raindrop analysis, as well. The flow paths of waste material in the study area were estimated by setting as starting points all the locations of the validated olive mills. The Stream Power Index is defined as:

\[ \text{SPI} = \ln(\text{SCA} \times \tan b), \]  

(1)

where: SCA: Specific Catchments Area, tan b: slope. Specific Catchments Area is defined as:

\[ \text{SCA} = \frac{A}{c}, \]  

(2)

where: A: upslope drainage area, c: unit contour width.

Last, the geological ridges were derived by digitising paper geological maps on a scale of 1:50,000, the only available.

3 RESULTS

The aim of this work, i.e. to determine the Minimum Dataset (MDS), from which proper criteria can be setup for risk management of water pollution by olive oil factories in Crete, was achieved. The following GIS layers constitute the proposed MDS (in brackets, the GIS format) (Figs 5 and 6):

Figure 5. A hydrological model of the study area (yellow: watersheds of interest, cyan: drainage network).
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• sources of pollution (point, vector layer) containing points of 11 olive oil waste tanks (validated by the local experts) with their attributes, such as ownership, dimensions of the tanks and waste capacity; also, two cases of olive mills without waste tanks are included in the file; there are another 5 cases non validated yet (Karydas et al. 2005b);
• watersheds (polygon, vector layer) containing nine (9) watersheds;
• drainage network (line, vector layer) containing a 5-order drainage network;
• geological ridges (line, vector layer) containing numerous ridges;
• pollution flow paths (line, vector layer) containing all flow paths starting from waste tanks or olive oil factories (two cases) to the drainage network;
• Stream Power Index (grid, raster layer) containing values for all the study area in raster of 4 m spatial resolution.

4 CONCLUDING REMARKS

Different approaches for risk management may be found, due to the complexity of environmental problems and the fact that when experts deal with a problem, they do a qualitative pre-selection of the context, considering only the aspects of the problem that, according to their judgment, allow them to solve it (Uricchio et al. 2004). An approach can be either a multi-attribute or a multi-objective one. Attributes are properties of elements of a real-world geographical system, while
objectives are statements about the desired state of the system under consideration (Malczewski 1999). In this work, a single-objective and multi-attribute approach was followed, i.e. protection of the streams in Crete from liquid waste effluents using a combination of environmental and anthropogenic parameters.

Independently of approaches, several techniques have been described as means of extracting information about environmental indices. Fieldwork, including field-based GIS, is a common technique in an infinite number of studies, while Remote sensing techniques comprise another huge inventory (Carver et al. 1995). However, application of integrated models in environmental management and risk assessment is quite limited because of the difficulty of preparing input data and interpreting model outputs (Carver et al. 1995; Wanga et al. 2005). In this context, determination of P indicators and quantification of them into a MDS are considered as main and crucial steps towards any following Decision Support System modelled using Multi-Criteria Analysis (MCA).

The basic hypothesis of this work, i.e. a dataset comprising very high resolution imagery, such as QuickBird, a DEM, and a geological map are necessary and efficient in order to derive proper indicators for a complete risk management of water pollution by olive oil factories, was validated. Based on the results of this work, a full potential application using Multi-Criteria Analysis is currently taking place in order to model the risk of water pollution by olive oil factories in Crete.

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LITERATURE


Giupponi, C. 2002. From the DPSIR reporting framework to a system for a dynamic and integrated decision making process. European policy and tools for sustainable water management, Venice.


Karydas, C.G., Sekuloska, T. & Sarakiotis, I. 2005c. Use of imagery to indicate landscape features important when assessing environmental risk caused by olive farming and olive oil production. 2005 IASME/ WSEAS International Conference on Energy, Environment, Ecosystems and Sustainable Development, Athens, Polytechnic School of Athens. (CD)


