Spatial modelling of risk indicators for stream pollution caused by inappropriate function of olive oil factories in Crete

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Abstract: In many areas, such as in the Mediterranean island of Crete, Greece, olive cultivation is mostly oriented to olive oil production. In the last two decades, olive oil factories became a serious source of pollution for streams, because technology allowed massive production of olive oil at much faster rates than before. The major component of the contemporary olive mill waste is the liquid waste (OMWW), which is the most hazardous substance in terms of the environmental impact. Waste tanks -if they exist at all- are often smaller than they should be, or flooded during the winter, rendering discharge of waste to the neighbouring torrents inevitable with a substantial negative impact on the biodiversity. Therefore, monitoring pollution risk of the streams in an olive oil production area by OMWW and moreover a set of quantifiable monitoring parameters (indicators) is necessary. The main aim of this work was to construct a geo-database adequate in order to support risk assessment of stream pollution by OMWW in Crete, through a set of quantified risk indicators. A QuickBird (QB) satellite image visually photo-interpreted, a DEM, the hydrological network and tabular olive oil factory data derived-validated by local expert's support comprised the dataset. Vector-based analysis was selected as the basic GIS-technical approach. The specific objectives, i.e the selection of a set of appropriate risk indicators and then their quantification in the spatial domain were confirmed by the results, which consisted of tabular or digital map datasets linked in a common geo-database and expressing all the selected risk indicators.

Key-Words: OMWW, DPSIR, QuickBird imagery, DEM, Vector-based analysis

1 Introduction

The broad picture for the olive oil sector in the 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 . In many areas, such as in the Mediterranean island of Crete, Greece, olive cultivation is mostly oriented to olive oil production. The consequent intensification of the cultivation increases olive oil production and the amount of liquid waste by olive oil factories . These factories became a source of pollution for streams 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 pollution of streams and torrents which was witnessed in Crete from the early 1980's .

In the context of environmental issues, the probability of occurrence of a particular adverse effect on human health or the environment as a result of exposure to a hazard is defined as environmental risk. Then, risk assessment is an attempt to quantify the risk, while risk analysis is referring to the quantitative and qualitative evaluation of adverse risks associated with a hazardous substance, activity, lifestyle or natural phenomenon that may detrimentally affect the environment and/or human health. On a broader scale, the term risk management refers to the responses of society with regard to the hazard, the population exposed or adverse effects, implementing decisions, and evaluating results. In such a decision making procedure, construction of Geo-Databases with the use of Geographical Information Systems (GIS) has been proved inevitable, because only a GIS can provide the tools for visualizing and analysing quantitative and qualitative data with spatial extent and allow the estimation of uncertainty and imprecision of the information incorporated in the used data.

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 .

Although the objectives of sustainable development are very broad, one still needs a set of quantifiable parameters (indicators) to measure and monitor important changes and progress towards the achievement of these objectives. Therefore, it is necessary to have a tool for environmental assessment and monitoring of the state of the environment, which would comprise an adequate set of indicators (Minimum Dataset) to be surveyed and the defining of a functional scheme to describe cause-effect linking the state of the various indicators .

Following the DPSIR framework, functioning of olive oil factories in Crete 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 liquid waste (i.e. the Olive Mill Waste Water, OMWW) 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 .

The **main aim** of this work was to set up a Geo-Database for monitoring risk, caused by olive oil factories to the streams of Crete's olive oil production areas. More specific objectives were:

- To select appropriate indicators in order to formulate a Minimum Dataset for risk analysis in the case of OMWW.
- To quantify risk indicators for OMWW discharging caused by olive oil factories on to the drainage network in the spatial domain.

2 Problem Formulation

2.1 The environmental problem

In Crete, Greece olive cultivation is mostly oriented to oil production and as a result the more intensive the cultivation the larger the oil production and the amount of waste by olive mills. Olive mills became a source of pollution when technology allowed the massive production of olive oil at much faster rates than before. The transaction from the traditional procedure to the 3-phase centrifugation procedure has been 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 the environmental impact. Generally, 65 to 175 kgr of liquid is extracted from 100 kgr of olives. Moreover, not only is the production of waste high, but in many cases farmers do not maintain the protection measures enforced by the law. For example, waste tanks if they exist at all are often smaller than they should be, or flooded during the winter, rendering discharge of waste to the neighbouring torrents inevitable with a substantial negative impact on the biodiversity. It has been shown that biodiversity reduction in the rivers due to the discharge of olive mill waste is 71.4% for medium- and small-sized streams and 41.6% for big streams . Therefore, determination of the precise allocation of olive oil factories and waste tanks with regard to the drainage network and other important attributes of them, such as their polluting capacity, is prerequisite when assessing environmental risk at the individual and the watershed level as well (Fig.1) .

Fig.1. A waste tank in the study area filled up with OMWW while being allocated on the map with a GPS receiver.

2.2 Study area

The island of Crete is located in the Eastern part of the Mediterranean Sea. The agricultural area of the municipality of Kolymvari, located in the NW part of Crete, was selected as a typical example of an olive oil production area in Crete (Fig.2).

The agricultural area is in the south part of the Municipality and comprises mainly tree crops, which cover an area of 4,445 ha. Olive groves, with deep historical roots, are the most extensively grown crops. Almost total olive crop is driven to olive oil production; currently, 18 olive oil factories operate in the area resulting in around 65,000 tons of olive oil per year. As a result, more than 40,000 tones of OMWW is produced as a by product (Fig.3).

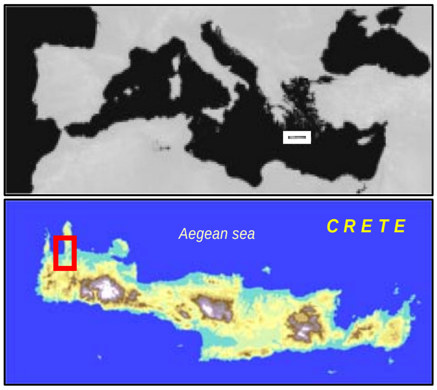


Fig.2. The area of Kolymvari is located in the NW part of Crete.

3 Problem Solution

3.1 Dataset and pre-processing

The dataset and necessary pre-processing included the following:

- A QuickBird (QB) satellite image, which was acquired on 16 November 2002 and covered approximately 16.5 km by 16.5 km with a 14° off-nadir angle (Fig.4). It was provided as Basic product level 1B in separate Panchromatic (PAN) and Multi-Spectral (MS) modes and was orthorectified and fused in the lab resulting in a 0.67 m pixel MS image. The achieved Root Mean Squared Error (RMS Error) of the orthorectification was 0.45 m. and 1.69 m. for the PAN and the MS image, respectively. The fused product extended substantially the application potential of the original dataset. This image was used for allocating olive factories and waste tanks throughout the study area, fully validated after fieldwork and interviews with local experts [4].
- A Digital Elevation Model (DEM) created from a 20 m point elevation grid with interpolation resulting in a pixel size of 4 m (Fig.5). The z-accuracy (elevation) of the DEM was tested using 33 trigonometric points and found to be 5.2 m as RMS error . The DEM was used for deriving all necessary topographic and surface-hydrologic information.
- The drainage network of the study area derived from the DEM with raindrop analysis. Raindrop analysis describes how a water drop will travel throughout a landscape from each pixel of a 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 is taken in a combined approach [6]. The drainage network in the watersheds of interest was corrected based on the visual photo-interpretation of the QuickBird image, more specifically identification of streams in the image [4].
- Tabular data about the annual production, ownership and other properties of the olive oil factories in the study area. This data was collected from the Municipality agencies and by interviewing some local experts [4].

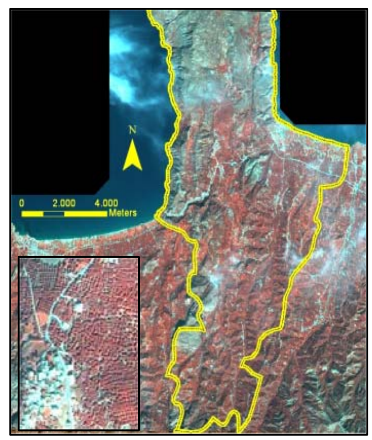
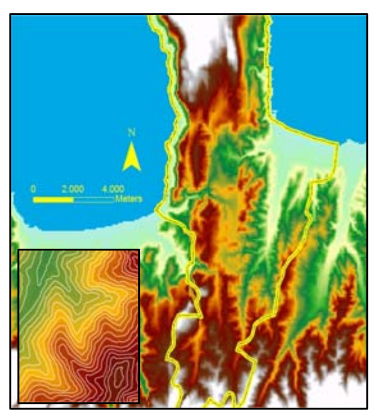


Fig.3. A QuickBird image of the area after implementation of the fusion technique. A close view is shown in the inset.



- Fig.4. A Digital Elevation Model (DEM) of the study area.

3.2 Methodology

The methodology was applied in two steps: first, analysis of risk and selection of risk indicators; second, spatial modelling of the selected indicators with GIS functions. More specifically, the indicators selected were :

- Polluting capacity
- Distance of point sources of pollution from the drainage network
- Distance of point sources of pollution from the NATURA 2000 (protected) area
- Stream order of the affected drainage network segments
- Type of point source of pollution; two types were considered, i.e. the olive factory and the waste tank
- Distance between the olive factory and its waste tanks

All the above indicators were modelled by using the vector-based analysis; more specifically:

- Point vector type was applied for mapping and recording the location and all necessary attributes of the point sources of pollution, i.e. olive factories and waste tanks. The background for allocating the sources was the QuickBird image (as mentioned above).
- Line vector type was applied for mapping and recording the necessary attributes of streams and flow-paths of pollution on the terrain. The background for line vector analysis was the drainage network derived from the DEM after corrections based on the QuickBird image.
- Joint and related tables served as link for information transfer between specific files.

A detailed description of spatial modelling of the selected indicators follows.

3.2.1 Polluting Capacity

The marketing and processing abilities of an olive factory give the volume of olives that are processed in its facilities every year and consequently the volume of the produced OMWW. Based on this principle, polluting capacity of each olive factory was defined as proportionally to the annual production of OMWW. In order to determine the portion of polluting capacity corresponding to a single waste tank (in many cases one olive oil factory had more than one waste tanks) the annual production of the olive factory was divided equally by the number of waste tanks. It was assessed by visual photo-interpretation of the satellite image that all tanks of an olive factory had almost the same size. It was also known by interviews that they had the same depth. As a result, all tanks of an olive factory were assumed to be of equal volume.

Finally, the polluting capacity of each source of pollution (i.e. olive factory or waste tank) was standardized according to the formula:

$$SPC=PC/MPC \quad (1),$$

where SPC: the Standardised Polluting Capacity, PC: Polluting Capacity of each source point of pollution, MPC: The maximum Polluting Capacity found in the dataset.

3.2.2 Distance of the point sources of pollution from the drainage network

The distance of a point source of pollution was considered proportional to the risk that this source will reach the drainage network. For a more true assessment of this distance, the surface lengths of all source points of pollution from their nearby segments of the network (streams, torrents) were calculated. These pollution flow-paths were mapped using raindrop analysis, a technique which determines how the water flows through the landscape from a selected starting point (Fig.5). The ‘flow direction’ grid (an intermediate step when delineating hydrological network) was the input of mapping the flow-paths. This time, the flow-paths were standardized according to the formula:

$$SD=MinD/D \quad (2),$$

where SD: Standardized Distance of each source point of pollution from the drainage network, D: Distance of each source point of pollution from the drainage network, MinD: The minimum Distance that is found in the dataset.

Fig.5. Flow-paths of OMWW from waste tanks to the drainage network.

3.2.3 Distance of the source points of pollution from protected areas

Quantification of the risk related to the NATURA 2000 protected area was based on the length of the flow-paths of the point sources of pollution from the edges of the protected area. Actually, a small part of the agricultural area is within the protected area and only one olive oil factory; however, pollution travelling through the drainage network of the protected area is always a threat for the protected species. Therefore, the length of the flow-paths was related to the probability that OMWW will reach the protected area. Then, the risk was taken as inversely proportional to the length of the flow-paths.

More specifically, the olive factory and its related tanks found within the protected area were given the maximum risk (i.e. risk=1), while the rest (outside the protected area) were standardised between 0 and 0.9 (0.9 was given to the source point of pollution that was found closer to the edges of the protected area). In other words, the following formula was used:

$$SD=1, \text{ if point in the protected area}$$
$$SD=(MinD/D)*0.9, \text{ if point outside the protected area} \quad (3),$$

where SD: the Standardized Distance of each source point from the protected area, D: Distance of each source point of pollution from the protected area, MinD: The minimum Distance found in the dataset.

3.2.4 Stream order of the affected drainage network segments

Stream order was related to the capability of a stream to dilute OMWW, because –as is the case with liquid pollutants- the impact of OMWW on river ecosystems is highly correlated with their dilution at the point of entrance. Therefore, it was considered that bigger rivers, able to dilute OMWW and spread it across their flow line reducing in such a way their pollution effects, were less risky in accepting OMWW. Conversely, when OMWW was discharged into smaller rivers, the risk should be taken higher.

There are three main systems of stream ordering, namely Strahler, Shreve and Horton, among which Strahler system is the most commonly used. In Strahler system, the smallest headwater segments are assigned order 1. Order increases downstream by 1 whenever two streams of equal order join. For example, two streams of order two (2) join to form a third-order (3^{rd}) stream. However, the order number does not increase when a higher-order stream is joined by a lower-order stream (Fig.6) .

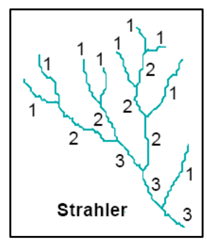


Fig.6. Strahler stream ordering system.

For the needs of risk quantification, the stream segments of the drainage network intersected by pollution flow-paths were assigned values of stream order according to Strahler system. As it was discussed earlier, the risk was assumed to be inversely proportional to Strahler order of the aforementioned river segments. Finally, Strahler values were standardized according to the formula:

$$SO=MinO/O \quad (4)$$

where SO: Standardized Stream Order of the impacted stream segments, O: Stream Order of the impacted stream segments, MinO: minimum Stream Order of the impacted stream segments in the dataset.

3.2.5 Type of source of pollution

The risk of each source of pollution for harming the river ecosystems was associated with the type of the source, i.e. the fact that the source would be either a waste tank or the olive oil factory itself. This was justified by the fact that in some cases olive factory owners did not make use if their tanks but instead they discharge OMWW directly into nearby streams [4]. This case –when known or assumed- was given a high risk values because the impact to the ecosystem is high. On the opposite, existence and use of waste tanks, where OMWW is discharged and stored reduces environmental threat, because the pollutant is evaporated to a large proportion and diluted in rain water before it is discharged to the nearby stream due to a flooding effect.

Because not more details were known about every olive oil factory separately, the two cases were simplified by assigning a risk value of 1 for an olive factory and a risk value of 0.5 for a waste tank.

3.2.6 Distance between sources of pollution

Similarly to the previous indicator (type of pollution source), this indicator was also linked to the OMWW discharge policy pursued by the mill owners, i.e. probability of olive mill owners discharging OMWW directly to the nearby stream. This probability was considered higher when the distance of the olive factory from its waste tanks was big, because use of pumps for transferring OMWW implies a high cost. Note that waste tanks were found usually in higher locations that their corresponding factory.

After interviewing local experts, the risk values for this indicator were assigned as follows:

- If the straight distance between the waste tanks and the corresponding factory was bigger than 1 km, a value of 0.7 was assigned to the factory and a value of 0.3 was assigned to its waste tanks. Because in this case it was considered more probable that the greatest amount of the waste would be discharged in the nearby stream than being transferred to the waste tanks.
- Inversely, if the straight distance was found less thank 1 km a risk value of 0.7 was assigned to the tanks and a risk value of 0.3 was assigned to the factory.

3.3 Results and discussion

The results comprised a complete geo-database with all data selected and pre-processed and a set of tabular data or digital vector maps each of which was related to a risk indicator (Fig.6). More specifically:

- The indicator ‘polluting capacity’ was recorded as tabular data and linked to the point vector of factories and waste tanks.
- The indicator ‘distance from the drainage network’ was initially estimated as graphics (flow-path), then by calculating the surface distance and finally modified to a line vector file; finally, a relevant map was produced.
- The indicator ‘distance from the protected area’ followed the same technique as the previous one, while only the flow-paths that crossed the protected area were considered; a relevant map was produced, too.
- The indicator ‘stream order’ was calculated in a tabular format after intersecting all flow-paths of pollution with the drainage network and then selecting the order of the intersected segment of the network.
- The indicator ‘type of source’ was assigned directly to the attribute table of the factories and waste tanks’ vector file.
- The indicator ‘distance between sources of pollution’ was recorded as a tabular dataset after measuring the straight distances between all factories and their corresponding waste tanks.

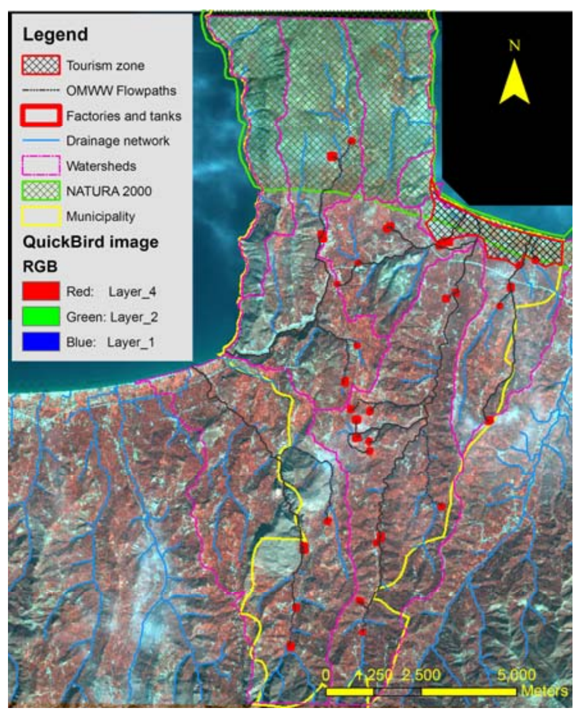


Fig.6. The geo-database of risk indicators constructed.

4 Conclusion

Visual photo-interpretation of the QuickBird image carried out commonly with local experts set off the major potentialities of the image to validate image interpretation prior conducted in the lab and to reveal particular cases, such as lack of waste tanks and other non-environmentally friendly solutions. Note that interpretation of this type of imagery is based on principles similar to aerial photography interpretation, thus making it familiar to non-experts.

Hydrological modelling and more specifically, drainage network mapping and flow-path tracing from waste tank locations towards a corrected stream network resulted in a vector file and digital maps that can assist qualitative and quantitative analysis of pollution risk of streams by OMWW. More specifically, the highly precise mapping of the drainage network achieved supported quantification of 3 out of 6 selected risk indicators.

Vector-based analysis, which was selected for recording and mapping the risk indicator attributes, was proved adequate to express all considerations that were taken into account in this modelling approach.

The role of local experts was proved necessary in modelling the pollution risk realistically. More specifically, the local experts supported substantially modelling at all stages, i.e. allocation and validation of pollution sources, collection and interpretation of olive oil factory data, selection of set of indicators, and assigning values to the selected risk indicators.

Summarising the above, it can be stated that the main aim of this work was achieved, because a complete geo-database adequate for monitoring the pollution risk of streams by OMWW was constructed. This geo-database comprised raster and vector datasets, while fieldwork with GPS and interviews played an important –mostly validating-role. More specifically, the first objective, i.e. the selection of appropriate risk indicators was achieved, based on the good knowledge of the area by the local experts and an adequate dataset (the Minimum Dataset); the second objective, i.e. quantification of the selected risk indicators, was also achieved, based on vector-based analysis.

It must be stated that the achieved spatial model can be further corrected and refined through its validation with additional fieldwork focused on in situ measurements of OMWW in the drainage network. Currently, a full assessment procedure of the pollution risk of the streams by OMWW in the study area is being carried out using Multi-Criteria Analysis with GIS and based on the selected and quantified risk indicators developed in this work.

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