DEVELOPMENT OF GIS BASED METHOD FOR RISK ASSESSMENT OF OLIVE MILL WASTE WATER IN CRETE, GREECE

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ABSTRACT

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, Olive Mill Waste Water (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. The research presents the proposed criteria and calculations required to estimate sub-catchment risk significance. This research combines elements from risk assessment frameworks, Multi Criteria Analysis (MCA), and GIS. 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

Over two thirds of Earth's surface is covered by water and less than a third is taken up by land (Woodford, 2006). The largest volumes of freshwater are stored underground as groundwater, accounting for about 0.6 per cent of the total. Only a tiny fraction (0.01 per cent) 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 & 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).

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 development of modeling systems. In this context, researchers and policy makers rely more and more 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 the nature and how these interactions influences water resources in a watershed. 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 framework for decision support of point source water pollution risk assessment and management and more specifically to develop a quantitative risk assessment method for OMWW pollution.

2. Materials and methods

2.1. Study area

The hydrological basin of Keritis is located in the north part of Chania Prefecture, on the island of Crete, Greece. 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 (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. 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). 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.

2.2. Soil Sampling

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.

2.3. Multi Criteria Analysis (MCA)

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

2.3.1. Development of risk evaluation criteria

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;

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 & Macoun, 1999).

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.

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 can be achieved by weighted linear combination (WLC) procedure wherein standardized criteria are combined by mean of a weighted average (Eastman, 2003).

3. Results and Discussion

3.1. 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. 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.

3.2. Assignment of criterion weights

The relative importance of the criteria used for the third group is given according to the degree of harm resulting from each element or compound which can be found in the literature as listed in Table 1. 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. The relative importance of the compared criteria was taken in 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 in order to achieve a more accurate estimation for every criterion weight.

3.3. Applying an aggregation rule

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. 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. 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 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 are very low. The obtained risk values in sub-catchment four and five were 0.25 and 0.18, respectively. This indicates, according to the Natural Breaks classification, a relatively moderate risk. These two sub-catchments have 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 shown by Fig. 1 that hazardous chemicals may be transported in sub-catchments 4 and 5 through streams of 4th and 5th order, respectively. This results in a quick dilution process of the chemicals possibly entering those streams which is reflected in the calculation model by the results of chemical tests.

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 decrease 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 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 aforementioned 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 (Fig. 1).

Regarding the results of the risk on NATURA sites, calculations resulted in various risk values which have been classified into five classes. 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 (Fig. 2). 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. 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 OMW on NATURA sites is the highest of all. This high risk value is a result from relatively high probability of consequences to which large NATURA areas are exposed (Fig. 2).

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.

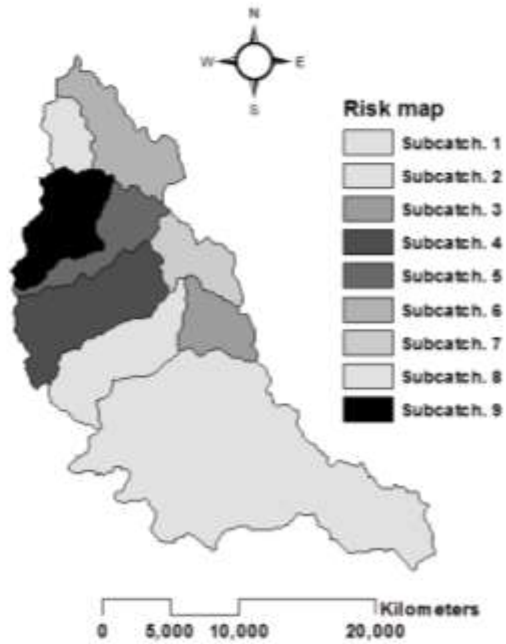

Figure 1: Risk map on human health in Keritis watershed caused by OMW

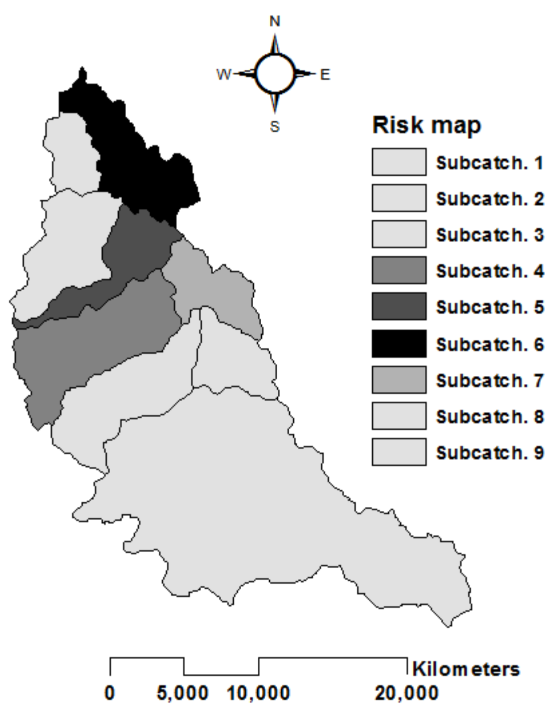

Figure 2: Risk map on NATURA sites in Keritis watershed caused by OMW.

Table 1: List of developed criteria classified according to their components.

Component	Criterion	Derived weight
1st probability component	Precipitation	0.500000
	Ratio	0.250000
	Condition	0.250000
	Sum	1.000000
2nd probability component	Flow path length	0.751880
	Runoff properties	0.248120
	Sum	1.000000
3rd probability component	pH	0.042961
	Magnesium	0.042961
	Potassium	0.042961
	Sodium	0.042961
	Sulphates	0.042961
	Bicarbonate	0.042961
	Nitrates	0.084700
	Copper	0.084700
	Iron	0.084700
	Zinc	0.084700
	Manganese	0.084700
	Phosphorus	0.084700
	Phenols	0.234034
	Sum	1.000000

4. Conclusions

Research objectives aimed in development of a detailed quantitative methodology to assess the
The developed methodology was implemented on the case study of Keritis watershed and was pursued by means of the 4th objective of this research. This implementation 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. In other words, different cases, for the same environmental problem, may be subjected to different factors which require a modification of the criteria and their weights for more accurate results. Moreover, this method can be widely applied. 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.

REFERENCES

1. Barbera, A. C., Maucieri, C., Cavallaro, V., Ioppolo, A. and Spagna, G. (2013), Effects of spreading olive mill wastewater on soil properties and crops, a review. Agricultural Water Management, 119: 43–53.
2. Billington, K. (2005), River Murray and Lower Lakes Catchment Risk Assessment Project for Water Quality - Mannum to Mypolonga Trial. Environment Protection Authority.
3. Dietz, R. (2000),The Use of GIS for Integrated Watershed Analysis: Integration of Environmental Models with GIS in the Upper Roanoke River Watershed. Virginia Polytechnic Institute and State University. USA.

4. Eastman, J. R. (2003), IDRISI Kilimanjaro Guide to GIS and Image Processing. Clark Labs, Clark University,USA.
5. Goula, A. M. and Adamopoulos, K. G. (2013), A Method for Preparing a Novel Solid Product from Olive Mill Wastewater: Wastewater Characterization and Product Recovery. Drying Technology, 31(3): 339-349.
6. Kalogerakis. N., Politi, M., Foteinis, S., Chatzisymeon, E. and Mantzavinos, D. (2013), Recovery of antioxidants from olive mill wastewaters: a viable solution that promotes their overall sustainable management. Journal of Environmental Management, 128: 749-758.
7. Kapellakis, I., Tzanakakis, V. A. and Angelakis, A. N. (2015), Land Application-Based Olive Mill Wastewater Management. Water, 7: 362-376.
8. Mendoza, G. A. and Macoun, P. (1999), Guidelines for Applying Multi-Criteria Analysis to the Assessment of Criteria and Indicators. Center for International Forestry Research (CIFOR), Jakarta, Indonesia.
9. Mendoza, G. A., Anderson, A. B. and Gertner, G. Z. (2002), Integrating Multi-criteria Analysis and GIS for Land Condition Assessment: Part I - Evaluation and Restoration of Military Training Areas. Journal of Geographic Information and Decision Analysis, GIDA 6(1): 1-17.
10. Nassar, N. N., Arar, L. A., Marei, N. N., Abu Ghanim, M. M., Dwekat, M. S. and Sawalha, S. H. (2014), Treatment of olive mill based wastewater by means of magnetic nanoparticles: Decolourization, dephenolization and COD removal. Environmental Nanotechnology, Monitoring and Management, 1(2): 14–23.
11. Niaounakis, M. and Halvadakis, C. P. (2006), Olive Processing Waste Management, Literature Review and Patent Survey. Second edition. Elsevier.
12. Papafilippaki, A., Gasparatos, D., Haidouti, C. and Stavroulakis, G. (2007), Total and bioavailable forms of Cu, Zn, Pb and Cr in Agricultural soils: a study from the hydrological basin of Keritis, Chania, Greece. Global NEST Journal, 9(3): 201-206.
13. Soupios, P. M., Kouli, M., Vallianatos, F., Vafidis, A. and Stavroulakis, G. (2007), Estimation of aquifer hydraulic parameters from surficial geophysical methods: A case study of Keritis Basin in Chania (Crete - Greece). Journal of Hydrology, 338: 122-131.
14. Woodford, C. (2006), Water pollution, an introduction. The UK Rivers Network.
15. Zagklis, D. P., Arvaniti, E. C., Papadakis, V. P. and Paraskeva, C. A. (2013), Sustainability analysis and benchmarking of olive mill wastewater treatment methods. Journal of Chemical Technology and Biotechnology, 88(5): 742-750.