Science of the Total Environment 497–498 (2014) 38–49

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Effects of olive oil wastes on river basins and an oligotrophic coastal marine ecosystem: A case study in Greece

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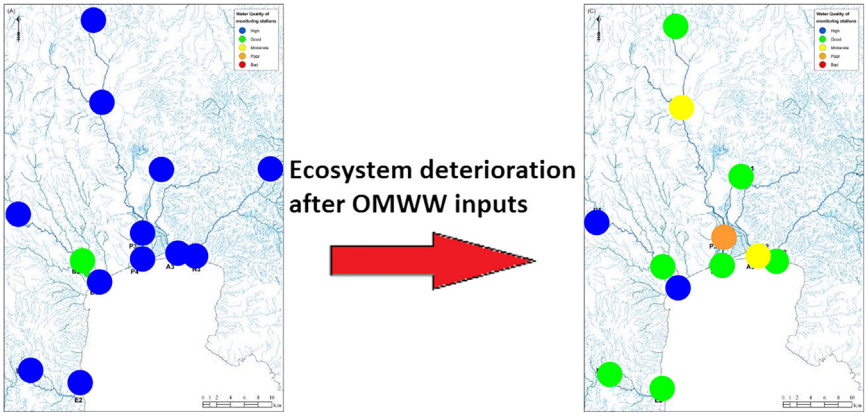
HIGHLIGHTS

- Release of untreated olive oil wastes in the riverine ecosystem of Messinia
- High toxicity of olive oil effluents on stream macroinvertebrates
- Olive oil wastes enrich the area in ammonia, phenols, organic carbon and metals.
- The olive oil wastes have downgraded the ecological status of the ecosystems.
- A period more than five months is needed for the ecosystem recovery.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 4 June 2014
Received in revised form 11 July 2014
Accepted 11 July 2014
Available online xxxx

Editor: D. Barcelo

Keywords:
Olive oil wastewater
Ecological status
Messiniakos
Toxicity
Palaemonidae shrimp

ABSTRACT

This work aims to contribute to the knowledge of the impacts of olive oil waste discharge to freshwater and oligotrophic marine environments, since the ecological impact of olive oil wastes in riverine and coastal marine ecosystems, which are the final repositories of the pollutants, is a great environmental problem on a global scale, mostly concerning all the Mediterranean countries with olive oil production.

Messinia, in southwestern Greece, is one of the greatest olive oil production areas in Europe. During the last decade around 1.4×10^6 tons of olive oil mill wastewater has been disposed in the rivers of Messinia and finally entered the marine ecosystem of Messiniakos gulf. The pollution from olive oil mill wastewater in the main rivers of Messinia and the oligotrophic coastal zone of Messiniakos gulf and its effects on marine organisms were evaluated, before, during and after the olive oil production period. Elevated amounts of phenols (36.2–178 mg L^{-1}) and high concentrations of ammonium (7.29–18.9 mmol L^{-1}) and inorganic phosphorus (0.5–7.48 mmol L^{-1}) were measured in small streams where the liquid disposals from several olive oil industries were gathered before their discharge in the major rivers of Messinia. The large number of olive oil units has downgraded the riverine and marine ecosystems during the productive period and a period more than five months is needed for the recovery of the ecosystem. Statistical analysis showed that the enrichment of freshwater and the coastal zone of Messiniakos gulf in ammonia, nitrite, phenols, total organic carbon, copper, manganese and nickel was directly

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http://dx.doi.org/10.1016/j.scitotenv.2014.07.088

correlated with the wastes from olive oil. Toxicity tests using 24 h LC_{50} Palaemonidae shrimp confirm that olive mill wastewater possesses very high toxicity in the aquatic environment.

1. Introduction

Olive oil production is of great economical importance in many Mediterranean countries, i.e., Spain, Italy, Greece, Turkey, Tunisia and Morocco (Duarte et al, 2013; Mohawesh et al., 2013). It has been estimated that more than 30×10^6 m^3 of oil mill wastes is produced annually in the Mediterranean region, with Spain, Italy and Greece being the largest producers (Karaouzas et al., 2011; Justino et al., 2012).

It is well known that the production of olive oil generates large volumes of wastes, varying in composition, depending on many factors such as the local and seasonal nature of oil production, the climatic conditions, the cultivation methods etc. (Justino et al., 2012; Mohawesh et al., 2013). The dark colored liquid wastes are a significant environmental problem, since they contain high quantity of organic load and pollutants like phenols, potentially dangerous for the environment and human health. Olive Oil Wastewater (OMWW) is also rich in nitrogen and phosphorus and contains trace metals (Fe, Cr, Pb, Cu, Ni, Cd, Zn, Mn) (Paredes et al., 2005). It is also enriched with organic forms of plant growth promoting factors (auxins, cytokinins) (Chatjipavlidis et al., 1996). Disposal of OMWW causes significant environmental pollution with unforeseeable effects on the quality of soil, surface and ground water and poses a serious risk to aquatic and marine ecosystems (Mekki et al., 2008; Karaouzas et al., 2011).

Despite the significant contribution of many Mediterranean countries in olive oil world production, very few studies have focused on the environmental impact of the OMWW on the Mediterranean aquatic environment such as rivers and coastal marine ecosystems. The already published work on olive oil wastes focuses mainly either on the OMWW characterization and quality, or is restricted on the effects of OMWW on aquatic systems located very close to olive oil industries and directly affected by the OMWW. Moreover, the environmental impact of OMWW may vary among the different areas, as the toxicity of the OMWW could be related with its phenolic content, depending on the local and seasonal nature of oil production, the climatic conditions and the cultivation methods (Kapellakis et al., 2006; Karaouzas et al., 2011; Justino et al., 2012; Ntougias et al., 2013).

The aim of the present work is to study the impact of the olive oil wastes to aquatic ecosystems of Messinia. This work contributes to the knowledge of the impacts of OMWW pollution to freshwater and marine environments. Specifically, the objectives of this study are to: (a) assess the spatial and temporal effects of OMWW to chemical characteristics (nutrients, phenols, total organic carbon, trace metals) of streams, rivers and the coastal marine environment, (b) evaluate the toxicity of the OMWW on Palaemonidae shrimp, (c) study the impacts of OMWW to the ecological status of riverine and coastal marine ecosystems using a nutrient classification system and benthic communities data, (d) indentify which of the chemical pollutants are directly correlated with the OMWW and (e) investigate the capability of the ecosystems affected by the OMWW to recover.

2. Materials and methods

2.1. The study area

The area of Messinia, which is located in Peloponnese at the southern part of Greece, is the second major olive oil production area in Greece. 21% of the Messinian land (620 km^2) is covered by olive trees. More than 250 oil factories are operating in Messinia and about 70% of them use the three-phase process, whereas only about 30% use the two-phase decanter system which is able to operate without water and thus dramatically reduces the amount of wastewater produced. It is noteworthy, that 41% of the olive oil industries are located close to the rivers, whereas 60 industries (olive oil, wineries, etc.) are located alongside the major river of Messinia, the Pamisos River (Fig. 1). The operation of olive oil mills is seasonal and usually lasts 3 to 4 months (November–February) which is defined as productive period. It has been estimated that more than 350×10^3 m^3 of olives and 56×10^3 m^3 of olive oil are produced annually. The olive oil production and consequently wastewater vary temporally, probably depending on the local annual climatic changes. During 2005–2011, the annual olive oil production varied between 33×10^3 and 59×10^3 tons producing from 163×10^3 to 346×10^3 tons of water wastes per year. The great fires of 2007 in Peloponnesus also affected the olive productivity, since it has been estimated that about 3000 km^2 of cropland, mostly covered by olive trees, was burned.

However, olive oil industries are probably the most important, but not the only sources of pollution for the study area. The 76% of the industrial activity is held by olive oil industries, 14% by wineries and 7% by dairy factories. Many livestock units are also located near the rivers. Additionally, a biological wastewater treatment plant operates at the capital city of Kalamata, processing 12,000–13,000 m^3 of wastes per day, which is discharged directly in Messiniakos gulf and does not impact the water quality of the rivers.

The OMWW is disposed, in most of the untreated cases, in water bodies although disposal of untreated OMWW in aquatic compartments is not allowed in Greece and each district is responsible to adopt the appropriate practices for olive oil mill wastewater management. In the case of Messinia, the management of OMWW is based on the conversion of three-phase to two-phase olive processes. During 2010 the three-phase olive oil mills were 172 and the two-phase olive oil mills were 27 in Messinia, but the percentage of two-phase olive oil mills increased over the years. The three-phase olive oil mills transport only the squashed olive stone part to the seed industries while the OMWW is being discharged on the ground and the streams after a minor treatment with $Ca(OH)_2$ in order to reduce the acidity. Finally, the wastewater is spread through canals and small streams into the major rivers of Messinia during the productive period and outflow in Messiniakos gulf (Kapellakis et al., 2006). It is noteworthy, that during the last decade around 1.4×10^6 tons of OMWW has entered the rivers of Messinia and ultimately the marine ecosystem of Messiniakos gulf. On the contrary, in other olive oil production countries such as Italy and Spain, the wastes are properly treated either with the combustion method, the compost method, or by co-treating the wastes from the two and three-phase olive oil mills after the appropriate adjustment of the equipment at the seed oil factories.

According to the evaluation of the ecological status of the water bodies of Greece based on the European Framework Detective (2000/60/EC), parts of the major rivers in Messinia (Pamisos, Nedon and Aris Rivers) are significantly disturbed (Skoulikidis et al., 2004). However, the pollution concerning the OMWW discharges to the aquatic environment of the Prefecture of Messinia exists for a great number of decades, but the last 20–25 years the problem has become very intense due to the fact that the procedure of the olive oil extraction has changed. The olive oil industries use the new centrifuge system which produces huge quantities of olive oil at a very short period of time, instead of the old press type system. Thus, the quantities of OMWW that are being generated annually are approximately 60% higher compared to the ones that were produced in previous decades. For this reason the pollution has become evident relatively recently and the consequences are very strong and a have a great impact on the local society in general requiring immediate action.