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Abstract: Plastic materials used in agriculture mostly derive from synthetic petro-chemical polymers; they require, at the end of their lifetime, a suitable management system, for the collection and treatment. A research was carried out in order to define a GIS methodology for assessing the agricultural plastic waste quantity and localization. The use in agriculture of plastics in Barletta-Andria-Trani Province - Apulia Region - was investigated by applying orthophotos analysis and remote sensing survey. Specifically purposed Plastic Waste Indexes were created. The data were organized in a specific geo-database. The analysis showed that the estimation of agricultural plastic waste yearly produced from covering films was over 627 kg ha-1, from the anti-hail nets was up to 159 kg ha-1, from nets for crop protection was up to 192 kg ha-1, from shading nets was up to 131 kg ha-1, from irrigation pipes was up to 104 kg ha-1. Through GIS, the areas with high density of plastic wastes were pointed out and the suitable location of temporary storage areas or collecting points was defined. The produced maps and the GIS database can be always updatable tools, useful for optimizing and monitoring the collection of agricultural plastic waste from the farms and their transport to the recycling companies.

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To the Editor

Resources, Conservation and Recycling

Subject: Agricultural Plastic Waste Mapping using GIS. A case study in Italy.

Authors: R. V. Loisi, I. Blanco, C. Sica, E. Schettini, G. Vox

Dear Editor,

I would like to submit an original research article entitled "Agricultural Plastic Waste Mapping using GIS. A case study in Italy." for consideration by Resources, Conservation and Recycling. I confirm that this work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere.

This paper defines a GIS methodology for assessing the agricultural plastic waste quantity and localization. The evaluation and localization of agricultural plastic waste is a growing environment problem in waste management. This paper shows a novel methodology addressed to the scientific community. The produced map and the GIS database can be always updatable tools, useful for optimizing and monitoring the collection of agricultural plastic waste from the farms and their transport to the recycling companies.

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Sincerely,

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Bari, 21/02/2018

Agricultural Plastic Waste Mapping using GIS. A case study in Italy.

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Abstract

Plastic materials used in agriculture mostly derive from synthetic petro-chemical polymers; they require, at the end of their lifetime, a suitable management system, for the collection and treatment. A research was carried out in order to define a GIS methodology for assessing the agricultural plastic waste quantity and localization. The use in agriculture of plastics in Barletta-Andria-Trani Province - Apulia Region - was investigated by applying orthophotos analysis and remote sensing survey. Specifically purposed Plastic Waste Indexes were created. The data were organized in a specific geo-database. The analysis showed that the estimation of agricultural plastic waste yearly produced from covering films was over 627 kg ha^{-1}, from the anti-hail nets was up to 159 kg ha^{-1}, from nets for crop protection was up to 192 kg ha^{-1}, from shading nets was up to 131 kg ha^{-1}, from irrigation pipes was up to 104 kg ha^{-1}. Through GIS, the areas with high density of plastic wastes were pointed out and the suitable location of temporary storage areas or collecting points was defined. The produced maps and the GIS database can be always updatable tools, useful for optimizing and monitoring the collection of agricultural plastic waste from the farms and their transport to the recycling companies.

Keywords: GIS, land use management; landscape planning; sustainability; environmental management; waste disposal.

Introduction

The use of plastics in agriculture represents about 2% of the over 265 million tons of plastics produced per annum worldwide, nevertheless this use is globally growing due to an ever more diffusion of intensive and semi-intensive agricultural practices (Delbert and Hemphill, 1993; Picuno, 2014; Briassoulis et al., 2013). Plastic films can be employed for greenhouse, tunnel and direct covering, silage covering, soil mulching and solarization. Plastic nets can be used for crop shading and protection, for harvesting and post-harvesting operations. Moreover, irrigation and drainage pipes, packaging containers and sacks, pots, trays and seedling containers, strings and ropes can be made from plastics (Picuno, 2014; Vox et al., 2010; Markarian, 2005). The benefits of plastic materials are: light weight and good mechanical resistance, easy installation, use and management, lower costs in relation to other materials (Hopewell et al., 2009; Markarian, 2005). Crops quality and yield can be increased taking advantages of plastics, as well as resource efficiency can be improved, use of farm land can be optimized, favorable conditions for an optimal development and growth of the plants can be created, harvest periods can be extended, irrigation and water consumption can be decreased which results in water savings. Plastic nets and covering films can protect crops from adverse weather conditions, birds and aphids, and plastic mulches can reduce the use of chemicals to kill weeds (Briassoulis and Schettini, 2003; Briassoulis et al., 2013; Picuno et al., 2012a; Mistriotis and Castellano, 2012; Deng et al., 2006).

The growing diffusion of plastics in agriculture is also stimulated by the constant research for innovative materials to be used (Sica et al., 2015b; Levin et al., 2007; Espí et al., 2006; Castellano et al., 2016). Colored nets as well as photoselective and photoluminescent plastic films can modify the spectral wavelength distribution and the quantity of the transmitted solar radiation; their use can be functional for increasing consistently the product yield, quality and homogeneity in protected cultivation (Schettini et al., 2011; Castellano et al., 2008; Gulrez et al., 2013; López-Marín et al., 2008) and for controlling plant height in tree cultivation in greenhouses, thus facilitating the cultivation and avoiding the use of growth regulators.

Agricultural plastics, mostly derived from synthetic petro-chemical polymers, generate a strong impact in areas where protected horticultural crops are intensively spread, as in the Mediterranean countries and in developing countries, such as in China (Scarascia Mugnozza et al., 2011). The Chinese greenhouse industry started growing rapidly since 80s, thus China is actually one of the major nations in the world where plastic mulches are used on large scale; during only 2010 China has used about 2.2 million tons of thin plastic film as mulch (Lu et al., 2015; Ramos et al., 2015).

Plastic materials used in agriculture are turning into a growing environmental issue which requires efficient solutions. The agricultural plastic industry, and in particular that of plastic films, contributes seriously to plastic waste disposal problems and has other several negative environmental impacts such as negative aesthetic impacts, decrease of local biodiversity due to the natural habitat modification, alteration of natural water runoff/retention of soil, increased energy consumption related to the production of plastics (Levin et al., 2007). Actually greenhouse and high tunnel films represent the highest part in volume of agricultural plastics material (Espí et al., 2006); these films need to be frequently replaced being subject to mechanical and radiometric properties decay due to the limited thickness, to the exposition to solar radiation, chemical pesticides, wind and hail storms, variations in temperatures and relative humidity (Picuno, 2014; Schettini and Vox, 2012; Scarascia Mugnozza et al., 2011). Their frequent replacement generates large amounts of post-consumer material (Al-Maaded et al., 2012; Briassoulis et al., 2012, 2013, 2014; Delbert and Hemphill, 1993). The quantity of plastic employed can be limited by using thicker plastic materials with a higher durability (Picuno, 2014; Schettini et al., 2014; Stefani et al., 2014; Espí et al., 2007; Stefani et al., 2011; Schettini and Vox, 2012).

In the last decades, several environmental-friendly novel materials have been produced and experimentally tested in order to limit the use of fossil fuel derived plastics. Innovative biodegradable in soil or compostable materials have been manufactured using raw materials from renewable origin and having mechanical and physical properties analogous to plastics derived from petrochemicals (Santagata et al., 2014; Vox and Schettini, 2007; Briassoulis et al., 2015; Malinconico et al., 2008; Vox et al., 2010; Schettini et al., 2012; Sartore et al., 2013).

Agricultural plastic waste (APW) is mostly made of geographically concentrated and seasonally dependent materials (Simboli et al., 2015); APW is mainly composed by low-density polyethylene (LDPE), linear low-density PE (LLDPE), high-density PE (HDPE), polypropylene (PP), ethylenvinylacetate (EVA), polyvinyl chloride (PVC), polycarbonate (PC), polymethyl methacrylate (PMMA) and glass reinforced polyester (GRP) (Scarascia Mugnozza et al., 2011; Simboli et al., 2015; Briassoulis et al., 2013). The volume of APW globally generated varies greatly in the literature from 2 to 6.5 million tons per year (Meng et al. 2016; Muise et al. 2016). At the end of their useful life, only a small percentage of APW is recycled: in EU the amount of plastic materials used in agricultural during 2011 was more than 1.3 million tonnes, the recovery rate of APW has been only 46% and the mechanical recycling rate has been about 23% (Plastics Europe 2012; González-Sánchez et al. 2014). The average annual consumption of agricultural plastic materials in Italy amounts to about 350000 tons which in turn generates about 200000 t/year of APW, of which 55% derives from greenhouse and low tunnel covering films, soil mulches, vineyards films and nets (Picuno et al., 2012a). APW is often improperly disposed of through open field burning, abandonment in the fields or along watercourses, burial in the soil, and disposal in the landfills. An inappropriate disposal of APW produces an environmental and economic problem: it causes aesthetic pollution, agro-ecosystem degradation, soil and water contamination, release of harmful substances and air pollutants, food contamination; APW is moreover contaminated with pesticides and fertilizers (Briassoulis et al., 2013). APW can be suitable for an economically feasible mechanical recycling and could be used even for producing other plastic materials, such as street furnitures, or used as matrix for eco-composite materials reinforced with cellulosic materials and coupling agents, in order to reduce the quantity of plastics produced with non-renewable petrochemicals and to prevent waste production (Picuno et al., 2011, 2012b; Picuno, 2014; Sica et al., 2015a; González-Sánchez et al., 2014). The recyclability of the APW is influenced by several factors such as thickness, ageing, the presence of inert contaminants and pesticides, the contamination with organic matter and with other polymers (Briassoulis et al., 2012). Some APW fractions cannot be recycled, thus the energy recovery can be a way of using the non-recyclable plastic waste, exploiting its high heating value, as alternative option to the disposal in the landfills (Delbert and Hemphill, 1993; Scarascia Mugnozza et al., 2011). The APW ability to be used as alternative solid fuel (ASF) in energy recovery units is influenced by factors such as the content of chlorine, sulphur, heavy metals, volatiles and moisture, physical properties, and quantity of ashes (Briassoulis et al., 2012). A novel and interesting application consists in the use of waste of agricultural plastic films together to swine solids for producing value-added biochar and power through a co-pyrolysis process; the resulting pyrolyzing manure technology is energetically sustainable (Ro et al., 2014).

The inefficiency of the few systems of APW management existing in European countries, the little input/output data on the use of plastics in agriculture and the APW contamination with soil and several polluters make too expensive and complicated their collection, cleaning, sorting and processing (Martínez Urreaga et al., 2015; Briassoulis et al., 2013). There is a lack of a standardization methodology for identifying the types, the quantities and the flows of APW in an agricultural area in order to create a geo-referenced database useful to overcome the problem of APW management. The knowledge on how much waste are present in an agricultural area and the identification of the areas with the greatest APW concentration in this geographical area make possible the development of a sustainable APW management plan. In Europe, the cooperation between governments and academic researchers within the projects AgroChePack (AgroChePack, 2013) and AWARD (AWARD, 2016) has led to the development of draft of different APW management plans.

In literature, spatial modeling, Geographical Information System (GIS) studies and image processing can be useful techniques to be applied in land use and land cover monitoring in evaluating rural built environment and peri-urban landscapes changes (Arcidiacono and Porto, 2010b; Diti et al., 2015; Tassinari et al., 2010; Novelli and Tarantino, 2015; Scarascia Mugnozza et al., 2016; Loisi et al., 2017; Rogge et al., 2008). The application of GIS studies permits to create a dedicated geo-referenced database able to manage the complete geo-referenced information on the APW. GIS can be also used for analyzing, quickly and carefully, the suitable disposal site selection, considering geographical, geomorphological, socio-economic and land use factors (Suresh and Sivasankar, 2014). Through GIS a great amount of data can be efficiently stored, retrieved, analyzed, and displayed, in relation to user-defined specifications, thus lowering the cost of the land-fill site-selection procedure (Shamshiry et al., 2011; Onunkwo at al., 2012).

The aim of this paper is to quantify the agricultural plastic waste related to each crop type and plastic application by defining a specifically purposed set of plastic waste indexes (PWIs). A planning procedure using GIS is implemented to provide a complete geo-referenced information on the quantities and typologies of APW produced in the territory of the Barletta-Andria-Trani Province (BAT), in Apulia Region, South Italy. The GIS database, easily updatable and manageable, will constitute a useful instrument for the Authorities and the Stakeholders for monitoring the APW production and properly manage the APW flows;

this instrument can promote sustainable solutions in landscape planning within the wider issue of the land conservation (Picuno et al., 2011; Díaz-Palacios-Sisternes et al., 2014; Vox et al., 2016a; Vox et al., 2016b).

Materials and methods

The area of study is delimited by the administrative boundaries of the Barletta-Andria-Trani Province (BAT), in Apulia region, Southern Italy (Fig. 1); it has an extension of about 1530 km^2, more than 390000 inhabitants and is divided into 10 municipalities (Andria, Barletta, Bisceglie, Canosa di Puglia, Margherita di Savoia, Minervino Murge, San Ferdinando di Puglia, Spinazzola, Trani, Trinitapoli). The agricultural area is characterized by an intense production of plastic waste linked to the massive presence of vineyards, olive groves, orchards and vegetables cultivations. The cereals (mainly wheat) are cultivated in the south area of the Province; olive groves are particularly concentrated in the North-East; orchards and vegetables in the West. Vineyards, widely distributed throughout the whole agricultural territory, are mostly located in the North-West of the territory. The local Authority of the BAT Province has intended to solve the APW management problem through the introduction of modernization actions for the farms in the area as dealt with in the "Agricultural Waste valorisation for a competitive and sustainable Regional Development - AWARD" project (AWARD, 2016).

A GIS database was created according to the following work phases:

(1) Creation of a set of plastic waste indexes (PWIs) for each crop type and plastic application;

(2) Preparation of the land use map in ArcMap;

(3) Selection and highlighting on the land use map of the crops generating plastic waste;

(4) Detection on the map of plastic materials used for crop protection (film and nets);

(5) Attribution of the PWIs for each crop and plastic application to the different features in the land;

(6) Quantitative evaluation and geo-referring of APW;

(7) Creation of a geo-database summarizing the complete information on the APW;

(8) Realization of the APW maps;

(9) Identification of the suitable location of the APW collection centers.

The typologies of crops producing plastic waste in the BAT Province territory were defined by analyzing the data gathered during the 6th Italian Agricultural Census (ISTAT, 2011); the census data permitted to define the main crops cultivated in the study area and to make a first hypothesis on the different agricultural plastic materials used. Afterwards a survey among the farmers in the territory of the BAT Province was carried out, within the AWARD project activities, by the University of Bari and the Confagricoltura growers association (AWARD, 2016). Direct questions and a questionnaire, specially developed for this purpose, were submitted to farmers located in the territory of the Province of BAT. The questionnaire permitted to collect data on: the cultivated surface and the crop typology; the different kind of plastic materials used for each crop; the polymer type, thickness, weight, size, the connected quantities per hectare, their useful lifetime; the commonly used agricultural practices such as how the farmers use and install plastic films, irrigation pipes, etc.; the number of months during which the materials are used; the way of storing and cleaning the materials after the seasonal use and at the end of their lifetime; the level of dirtiness and the pollution typologies affecting the plastic waste.

The survey showed that vineyards in the study area have the peculiarity of being cultivated according to the traditional “tendone” technique (Fig. 2), which is a grape cultivation system with a supporting structure that may be covered with plastic films or nets (Picuno et al., 2011; Vox et al., 2012). Farmers use the films to anticipate the grape maturation, to postpone the harvest period to late autumn, to protect the grapes by the meteoric elements (rain, hail and wind), virus-vector insects and birds. According to the "tendone" technique films and nets are stretched on the pergola above as to form a double pitched roof on each row; this practice causes an increase of the plastic film consume and huge quantities of plastic waste generated by the vineyard cultivation.

The amount of plastic waste related to each crop type and plastic application was evaluated by using the plastic waste indexes (PWIs) calculated elaborating the responses of the questionnaire delivered to several farmers in the area, taking into account the features and the periodicity of the waste generation mechanism. The indexes were also verified with census and literature data, direct communications from agricultural plastic materials production companies, and the database developed at the University of Bari on the physical properties of agricultural plastic materials (AWARD, 2016; Lanorte et al., 2017).

The plastic consumption values related to the use of films and nets for crop protection were evaluated considering their thickness and density (kg m^{-3}), dependent on the specific application: films and nets for greenhouse and low tunnel covering; mulching films; nets for crop protection from hail, wind, birds and virus-vector insects; shading nets; nets for olive collection. The slope, the overlapping, the ratio between the area occupied by the films/nets projected on the horizontal surface and the useful life in months were also taken into account. The plastic consumption values related to the use of irrigation pipes were evaluated considering their length, cross section, weight and the useful life in months. The plastic consumption values related to the use of fertilizer bags and agrochemicals containers were estimated based on the survey consumption data and on the utilized agricultural area.

Table 1 summarizes the Plastic Waste Indexes (PWIs) with the values of the parameters used to calculate them. This set of indicators shows the typology of the produced APW and the estimated yearly average values of the APW quantities per cultivated area (kg

ha^{-1} yr^{-1}), coming from the most widespread crops in the Province of BAT. The data were collected from 75 questionnaires and the statistical analysis was carried out with CoStat software (CoHort Software, Monterey, CA, USA) (Lanorte et al., 2017).

PWI for fertilizer bags and agrochemical containers were directly provided by the farmers.

PWI for the plastic application (PA) "films" can be computed by:

$$PWI = S_{cr} \cdot \rho \cdot TK \cdot life^{-1} \cdot UF_{cvc} \qquad (kg\ ha^{-1}\ yr^{-1}) \qquad (1)$$

where: S_{cr} is the surface correction factor which takes into account the increase of material surface due to the coverage slope (S_{cr} is equal to 1.2, 1.45 and 1.35 for vineyards, orchards and greenhouses, respectively); ρ is the plastic density (kg m^{-3}); TK is the plastic thickness (μm); *life* is the plastic useful lifetime (month); UF_{cvc} is the covering unit conversion factor for converting the result in kg ha^{-1} yr^{-1} unit (UF_{cvc} = 0.12 m^3 μm^{-1} month yr^{-1} ha^{-1}).

PWI for the PA "nets" can be computed by:

$$PWI = S_{cr} \cdot AM \cdot life^{-1} \cdot UN_{cvc} \qquad (kg\ ha^{-1}\ yr^{-1}) \qquad (1)$$

where: S_{cr} is the surface correction factor which takes into account the increase of material surface due to the coverage slope (S_{cr} is equal to 1.20 for vineyards, 1.00, 1.45 for orchards and 1.00 for olive groves and greenhouses, respectively); AM is the areic mass (kg m^{-2}) for the HDPE nets); TK is the plastic thickness (μm); *life* is the plastic useful lifetime (month); UN_{cvc} is the covering unit conversion factor for converting the result in kg ha^{-1} yr^{-1} unit (UN_{cvc} = 0.12 m^2 month yr^{-1} ha^{-1}).

Some farmers (60 %) declared to cover vineyards with both plastic film and net; the most of them (82 %) put the net under the film.

All crop types are provided with drip fixed system, consisting of the header HDPE tubes (diameter 100 mm) from which detach secondary HDPE tubes (diameter 25 mm) along the rows. PWI for the PA "irrigation pipes" of all the crop types, is given by (Lanorte et al., 2017):

$$PWI = (PL_{25} \cdot PW_{25} + PL_{100} \cdot PW_{100}) \cdot life^{-1} \cdot U_{cvp} \quad (kg\ ha^{-1}\ yr^{-1}) \qquad (2)$$

where: PL_{25} is the length of the pipe with 25 mm diameter (m ha^{-1}); PW_{25} is the weight of the pipe with 25 mm diameter (PW_{25} = 0.25 kg m^{-1}); PL_{100} is the length of the pipe with 100 mm diameter (m ha^{-1}); PW_{100} is the weight of the pipe with 100 mm diameter, (PW_{100} = 2.5 kg m^{-1}); *life* = 216 months; the U_{cvp} is the pipes unit factor which converts the result in kg ha^{-1} yr^{-1} unit (U_{cvp} = 12 month yr^{-1}).

The sum of the contributions due to the different types of PA defined the total amount of plastic waste for each land feature, characterized by a specific crop.

The base map materials used were:

- Digital colour orthophotos at a scale of 1:5000, having a pixel ground resolution of 50 cm, obtained from aerial flights performed in 2011 and 2013; they are available online (Regione Puglia, 2016)
- Land Use (LUS) Map of the Apulia Region at a scale of 1:5000: it derives from the 2006 orthophotos having 50 cm pixel, updated with the new areas found on the 2011 orthophotos; the legend of the map complies with the European CORINE Land Cover Changes Database with an extension to the fourth level. This LUS map is freely available on the website of the Apulia Region (Regione Puglia, 2016).

The base maps, the municipality boundaries, the infrastructural components and the main agro-environmental components characterizing the territory were managed by the ESRI ArcMap10, a GIS software, for constituting an adequate base map system. The maps were placed in the WGS 84 / UTM zone 33N reference system.

The Apulia LUS map provides the data on the spatial distribution of the different crops. It is available in several shapefiles, depending on the detected area. The selected shapefiles needed to be merged in order to obtain a single shapefile to work on. The resulting shapefile was then clipped on the study area for limiting the amount of data to be handled.

The only crops that generate plastic waste were highlighted on the map by means of a subsequent further processing of the Apulia LUS map. The next phase consisted in detecting additional information (missing on the LUS map) on the typology and characteristic of the plastic covering structures employed for the cultivation, such as the presence or not of a covering system, and the kind of cladding material employed whether film or net. The additional data were obtained through the overlay mapping of the base map material and by means of the simultaneous operation of photo-interpretation of the web-mapping tools Google Maps 2014 and Google Earth 2014.

A Global Navigation Satellite System (GNSS) receiver with a field computer were used to carry out land surveys in the areas with uncertain identification of the land use, especially in presence of covering film or net. A system consisting of a Pro 6H receiver and a Juno 5 handheld computer (Trimble, Sunnyvale, CA, USA) were used for the surveys; Trimble TerraSync and GPS Pathfinder Office software were used for data management.

The database of the GIS software was detailed with additional data and updated to 2014. The land use database was expanded adding 15 fields to the already given 3 fields, which identify the land use polygons. The supplementary 15 fields were populated with data on the PWI for each PA, which is characterised by its CT, carried out in the polygon area.

The total waste for a given i-th feature, including several PAs, is calculated as follows (Lanorte et al., 2017):

$$APW_i = S_i \times \sum_{PA=1}^{N} PWI_{CT,PA} \tag{3}$$

where S_i is the surface of the i-th feature, $PWI_{CT,PA}$ is the plastic waste index for the CT of the i-th parcel and for the specific PA, N is the number of PAs for the CT present in the i-th feature.

Equation 3 was integrated into the GIS database and data of the overall waste production in the feature were added.

The APW total amount per application and the total production of APW generated in the Province of BAT were calculated. Finally, the dedicated geo-database allowed the evaluation of the spatial distribution of the plastic waste through the creation and analysis of purpose-built thematic maps.

The suitable position on the land of the first waste collection center was evaluated by GIS. Each single land area was georeferenced by means of a polygon (feature); the centroid tool of the QGIS software program (QGIS, 2016) was used to localize the geometric center (centroid) of the features. Each polygon was identified by the coordinates of its centroid that were related to the APW production in the feature area. In order to identify the suitable localization of the collection centres on the land for each kind of APW, generated by a specific plastic application, the weighted average value of the coordinates was calculated for each application by:

$$X_p = \frac{\sum_{i=1}^{N_p} S_{p,i} x_i}{\sum_{i=1}^{N_p} S_{p,i}} \qquad Y_p = \frac{\sum_{i=1}^{N_p} S_{p,i} y_i}{\sum_{i=1}^{N_p} S_{p,i}} \tag{4}$$

where the subscript p indicates the kind of plastic application generating a specific APW type, i.e. covering plastic films and nets, irrigation pipes, nets for olive collection, agrochemicals containers and fertilizers bags; $S_{p,i}$ is the weighting function for each type of APW (subscript p) and for each feature (subscript i) that takes into account the quantity of APW produced in the corresponding feature polygon surface for the application “p”; x_i and y_i are the coordinates of each feature centroid; N_p is the number of the features of each APW type. The QGIS mean coordinate(s) tool was used for this purpose.

Results and Discussion

The information on plastics collected by direct questions and questionnaires in the BAT province has revealed that:

- pipes for crop irrigation are mainly in HDPE ;
- films in LDPE and nets in HDPE are mainly used for vineyard (table grape) and orchards protection;
- nets in PP are used for olives collection;
- plastic containers in HDPE are used for agrochemicals (fertilizers and pesticides);
- greenhouses covering films in EVA are used for protected cultivation of vegetables.

From the questionnaires, as regards the management of the APW, the following peculiarities emerged:

- all farmers collect plastic waste manually, leaving them intact, without tearing them (e.g. films or nets) or pressing them (e.g. containers or pots);
- a majority of farmers (97.3%) store APW in temporary farming areas where APW is mixed and not protected by atmospheric agents;
- APW are generally contaminated with soil, plant residues and paper.

Data shown in Table 1 point out that firstly the PA “film”, with a PWI up to 764.15 kg ha^{-1} yr^{-1} for the CT “Orchards”, and secondly the PAs “net” and “irrigation pipes”, with a PWI up to 192.16 kg ha^{-1} yr^{-1} for the CT “Orchards” and 104.17 kg ha^{-1} yr^{-1} for the CT “Greenhouses” respectively, strongly contribute to the generation of APW according to the commonly used agricultural practices in the selected area.

A geo-referenced database on the production of the APW was created by using the base map material in a GIS. Figure 3 shows the crop distribution in the study area: the 16% of the territorial surface is cultivated with vineyards, the 28% with olive trees, the 31% is arable land (cereals and vegetables) and the 2% is cultivated with fruit trees and berry plantations.

The created database allowed the generation of the thematic maps on the spatial distribution of APW in the Province of BAT. Figure 4 depicts the overall density of produced waste resulting from the sum of the obtained values per waste individual types. The waste density ranged from 3.30 kg ha^{-1} y^{-1} for an arable land (cereals) to 868.57 kg ha^{-1} y^{-1} for a greenhouse covered with plastic films and shading nets. The waste generated by the use of irrigation pipes strongly influenced the overall density of APW; other plastic wastes contributed less.

The analysis of the results obtained by applying the average plastic consumption indexes to the land use map (Table 2) shows that the total amount of produced APW per year is about 6200 tonnes, of which the largest contribution (76%) comes from the irrigation pipes of all irrigated crops (vineyards, olive trees, vegetables, orchards). The 18% originates from the plastic covers of the vineyards and fruit trees. The contribution deriving from bags, containers and olive nets is not significant in order to quantify the overall production of APW: the waste produced from bags is about 3%, the APW from containers accounts for about 2% and from olive nets for about 1% of the total waste.

The Andria municipality produces the highest amount of APW due to its large municipal land area. However when considering the produced amount of the APW in relation to the municipality surface, San Ferdinando di Puglia comes out as the municipality with the highest average production of APW per cultivated area.

Figure 5 presents the territorial distribution of the estimated APW generated annually per hectare of cultivated area from the use of irrigation pipes, which mostly contribute to the overall waste production. A high difference in waste production was pointed out between the areas with vineyards or greenhouses and the areas cultivated with olive trees. The waste density, related to the irrigation pipes, ranged from 50 kg ha^{-1} y^{-1} in the case of olive trees to 104 kg ha^{-1} y^{-1} for greenhouses. According to the survey data, all detected vineyards are provided with a drip fixed system, consisting of header HDPE tubes from which detach secondary HDPE tubes along the rows, the vineyards layout being denser than that of olive groves and orchards. The greenhouses are characterized by a greater use of irrigation pipes with respect to the same cultivations in open field.

Figure 6 depicts the distribution of the amount of plastic waste deriving from the use of covering films and nets. The highest densities of plastic waste, related to covering films and nets, are recorded in the areas with vineyards due to the widespread use of films and nets for vineyards protection in the BAT Province; lower values where pointed out in the other cultivated areas. The waste density ranged from 159 kg ha^{-1} y^{-1} in the case of vineyards covered with nets to 773 kg ha^{-1} y^{-1} for the vineyards protected with both films and nets.

A minimum contribution derives from the waste generated from bags, containers and olive nets. Figure 7 and Figure 8 present the distribution of the APW generated annually from fertilizer bags and from agrochemical containers. In relation to the bags, the waste density ranged from 0.5 kg ha^{-1} y^{-1} for olive trees to 2.7 kg ha^{-1} y^{-1} for cereals, while for containers, the density ranged from 0.6 kg ha^{-1} y^{-1} for olive trees or cereals to 4.0 kg ha^{-1} y^{-1} for vineyards. Figure 9 shows the distribution of the APW deriving from the replacement of olive nets, corresponding to all areas planted with olive trees, with a waste density equal to 0.5 kg ha^{-1} y^{-1}.

The APW generation had already been analysed, in the wider European context, but on the basis of statistical data and at the national level, making difficult the localisation of the areas characterised by intense APW production. When no primary data were available, estimated areas of protected cultivations were used for calculating quantities of yearly-generated APW, by applying conversion factors defined on an agricultural film producer experience (Briassoulis et al., 2013). A detailed geographical distribution of main APW quantities was defined on the Greek and Italian territories (Hiskakis et al., 2008; Scarascia

Mugnozza et al., 2008); however, the geographic distribution of crops, which was inferred from statistical sources and from data provided by the Ministry of Agriculture.

Finally, the most suitable location areas for the collection center for each kind of APW were defined in relation to quantity and distribution of waste generated on the land. The position of the collection center was defined with a buffer area (radius of 3 km), in relation with the request of the companies engaged in the waste management. A final suitability map was created (Fig. 10), showing how the collection centers are far from sensitive areas of the landscape assets identified by Apulian Regional Territorial Landscape Plan - PPTR (Alta Murgia National Park, Margherita di Savoia Salt-marshes, Regional Natural Park of the Ofanto River) except that one relating to bags. In this case the collection center could be located in the buffer area for avoiding conflict with sensitive areas. The map is useful in order to make an initial selection of the most suitable areas.

Conclusion

The increasing diffusion of intensive and semi-intensive agricultural practices involves the generation of large amounts of plastic waste that need to be properly managed in order to limit environment and economic damages. The Italian Apulia Region is an area characterized by the consumption of several and many plastics due to the application of intensive agricultural practices. In the BAT Province the most of APW derives from the use of irrigation pipes and from the turnover of films and nets mainly applied for vineyard protection.

The proposed methodology of territorial analysis is based on the use of a GIS and is applicable to rural lands devoted to agriculture; it allows the updating of the official regional land use maps and their enrichment with additional information for the agricultural areas such as the presence of covering systems and their characteristics.

The resulting geo-referenced database, through a continuous monitoring of APW flows and land use changes, provides the Authorities and the Stakeholders with a tool for:

- the quantification of APW produced in every area;
- the localization of the areas characterized by intensive production of APW;
- the localization of the most suitable areas for the collection centers in barycentric zones as regard to the areas that generate high quantities of each kind of APW;
- the analysis of several different development scenarios for the rural land.

The database could help decision makers and planners in selecting the best sites for disposal facilitates and in the implementation of action plans, by increasing the knowledge about the land.

A further development of the proposed territorial analysis technique could be to combine it with multiple criteria analysis in order to the evaluate the site based on a suitability index based on several criteria such as urban centers, infrastructures, pipes, power lines, oil pipes, liquid gas pipes, industrial areas, streams and surface water.

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Table 1: Plastic Waste Index (PWI) per Plastic Application (PA) and Crop Type (CT)

PA	**CT**	**density ($kg\ m^{-3}$)**	**thickness (μm)**	**life (month)**	**PWI ($kg\ ha^{-1}\ yr^{-1}$)**
Films	Vineyards	930.00	165.00	36.00	613.80
	Orchards	930.00	170.00	36.00	764.15
	Greenhouses	930.00	200.00	48.00	627.75
		areic mass ($kg\ m^{-2}$)			
Nets	Vineyards (anti-hail net)	0.07		60.00	159.03
	Olive groves (net for olive collection)	0.07		153.76	0.50
	Orchards (net for crop protection)	0.07		60.00	192.16
	Greenhouses (shading net)	0.12		102.00	141.18
		pipe length ($m\ ha^{-1}$)			
Irrigation pipes		PL_{25}	PL_{100}		
	Vineyards	4001.33	200.13	215.36	83.33
	Olive groves	1600.00	200.00	216.80	50.00
	Orchards	2500.00	200.13	217.28	62.50
	Vegetables	3000.00	200.40	216.16	69.44
	Greenhouses	4500.00	300.00	216.00	104.17
Fertilizer bags	Vineyards				1.60
	Olive groves				0.50
	Orchards				2.20
	Vegetables				2.50
	Cereals				2.70
	Greenhouses				2.00
Agrochemicals containers	Vineyards				4.00
	Olive groves				0.63
	Orchards				1.80
	Vegetables				1.70
	Cereals				0.60
	Greenhouses				3.40

Table 2: Total APW in the study area per waste typology and municipality

Municipality	Irrigation pipes (tonnes per year)	Covering films and nets (tonnes per year)	Bags (tonnes per year)	Containers (tonnes per year)	Olive nets (tonnes per year)	TOTAL (tonnes per year)
ANDRIA	1237.53	166.93	38.77	31.28	8.41	1482.92
BARLETTA	739.87	218.4	15.90	25.02	2.72	1001.91
BISCEGLIE	288.83	150.53	4.20	5.47	2.30	451.33
CANOSA DI PUGLIA	755.02	144.41	19.24	27.18	2.32	948.17
MARGHERITA DI SAVOIA	71.05	0.00	3.28	2.64	0.01	76.98
MINERVINO MURGE	322.06	33.60	40.67	18.86	1.04	416.23
SAN FERDINANDO DI PUGLIA	229.87	70.25	4.60	7.78	0.81	313.31
SPINAZZOLA	19.60	2.61	38.72	8.86	0.15	69.94
TRANI	438.50	218.84	8.54	10.31	2.83	679.02
TRINITAPOLI	607.16	119.20	19.28	25.63	0.92	772.19
BAT	**4709.49**	**1124.77**	**193.20**	**163.03**	**21.51**	**6212.00**

Figure 1: The study area where the GIS modeling was applied.

Figure 2. Vineyards covered above and laterally with coloured LDPE films.

Figure 3: The Land Use map on the study area.

Figure 4: The distribution of the overall density of APW (kg $ha^{-1}yr^{-1}$) in the Province of BAT

Figure 5: The distribution of the amount of plastic waste deriving from irrigation pipes (kg $ha^{-1}yr^{-1}$).

Figure 6: The distribution of the amount of plastic waste deriving from covering films and nets (kg $ha^{-1}yr^{-1}$).

Figure 7: The distribution of the amount of plastic waste deriving from bags (kg $ha^{-1}yr^{-1}$).

Figure 8: The distribution of the amount of plastic waste deriving from containers (kg $ha^{-1}yr^{-1}$).

Figure 9: The distribution of the amount of plastic waste deriving from olive nets (kg $ha^{-1}yr^{-1}$).

Figure 10: The suitable location of the collection centres on the land for each kind of APW.

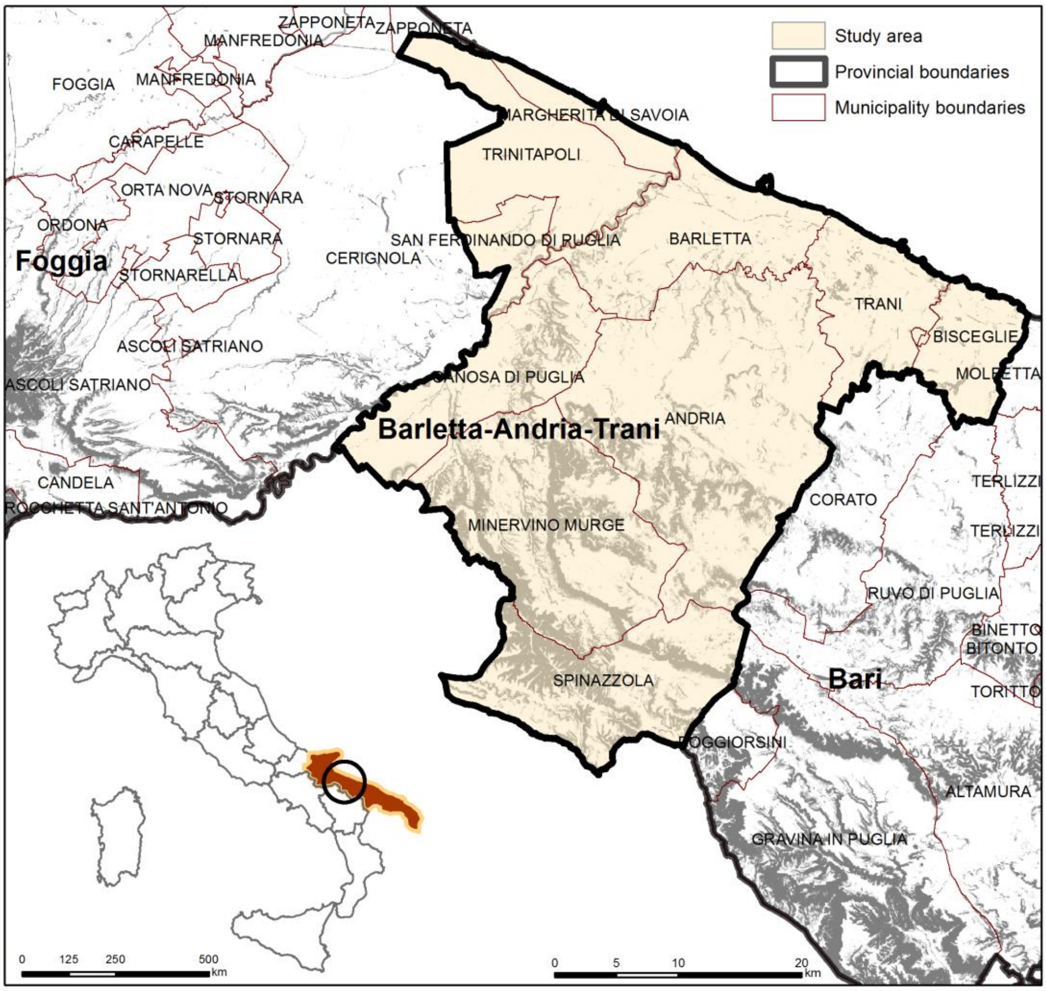

Figure 1: The study area where the GIS modeling was applied.

Figure 2. Vineyards covered above and laterally with coloured LDPE films.

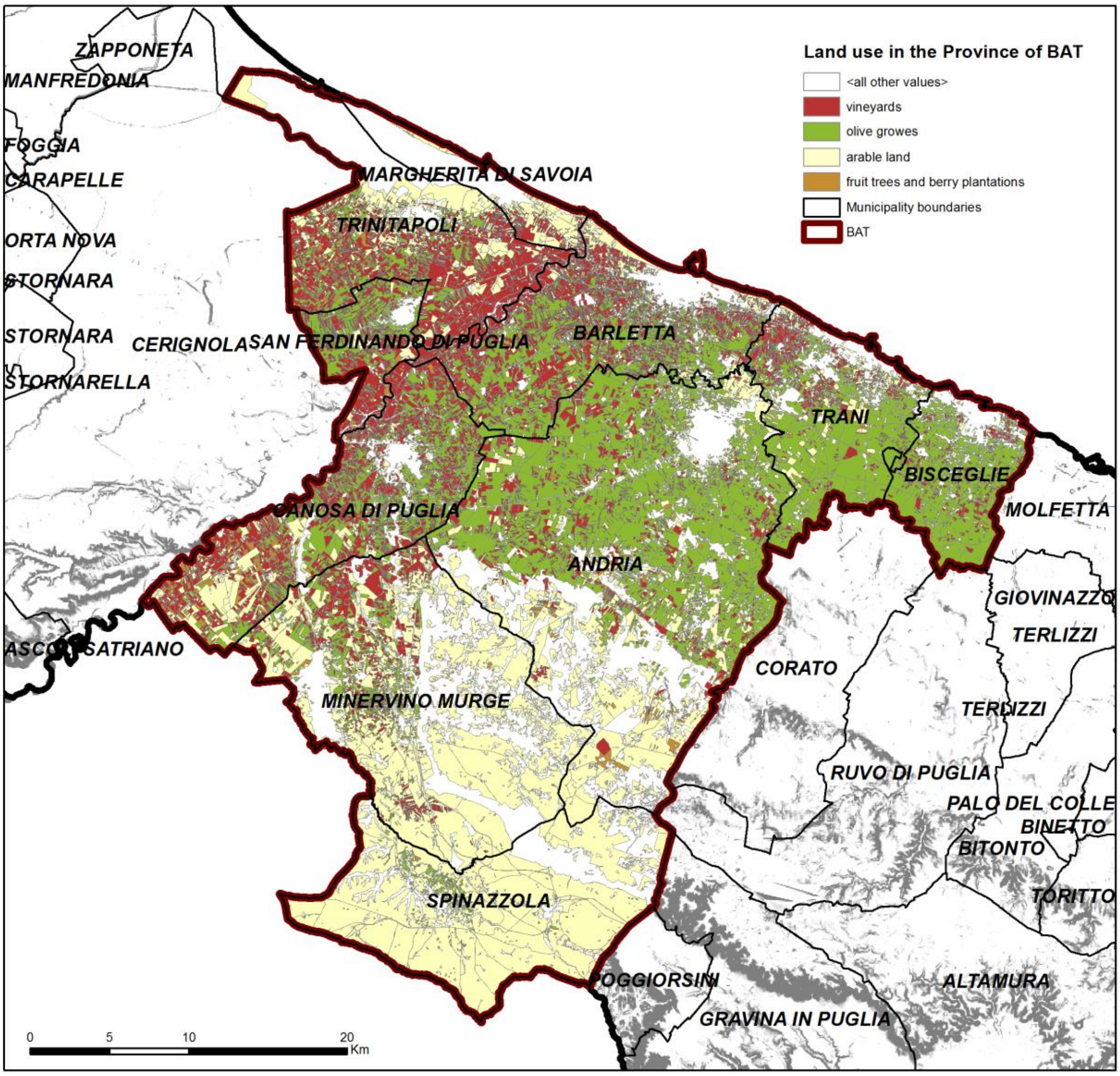

Figure 3: The Land Use map on the study area.

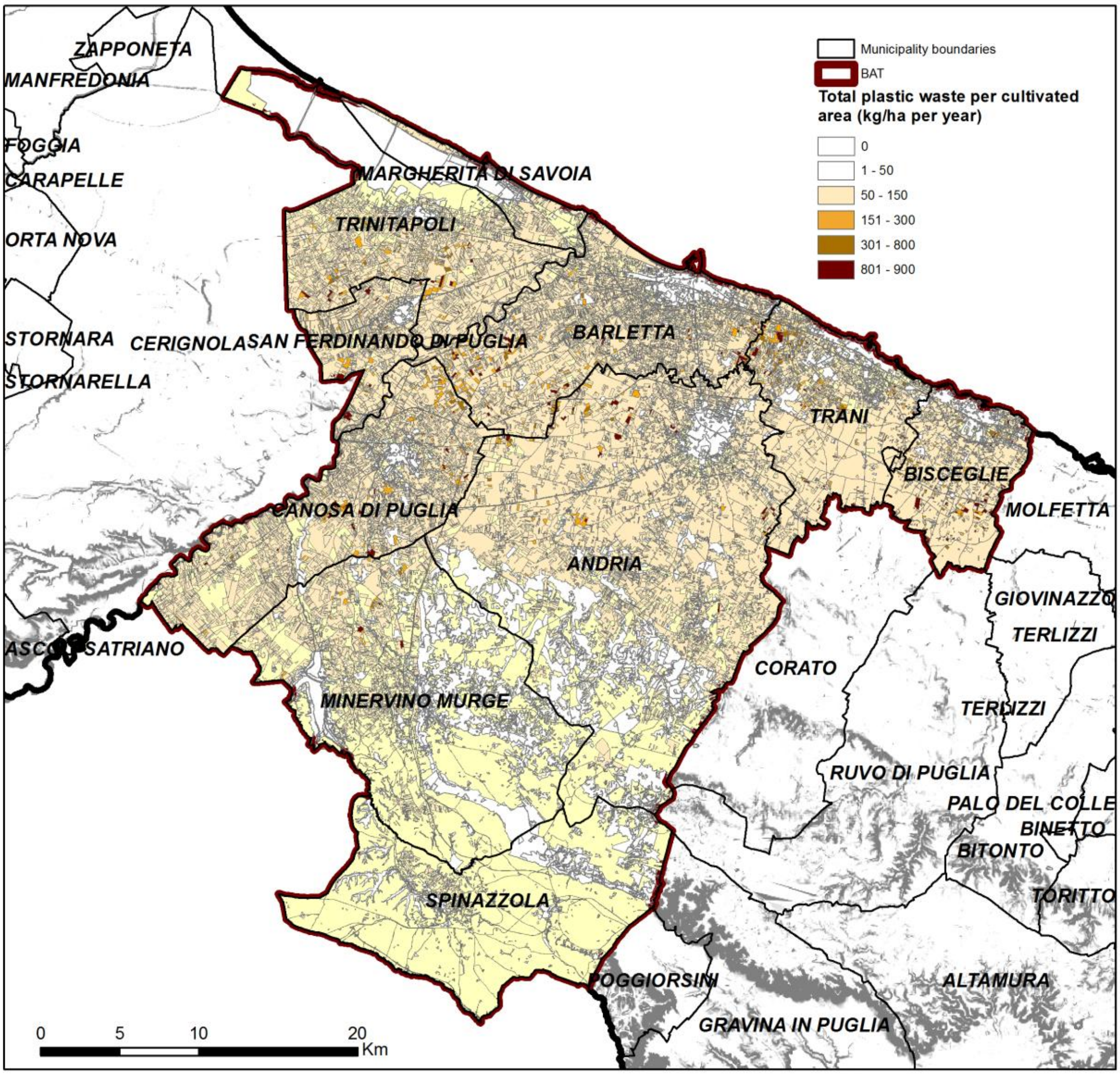

Figure 4: The distribution of the overall density of APW (kg $ha^{-1}yr^{-1}$) in the Province of BAT

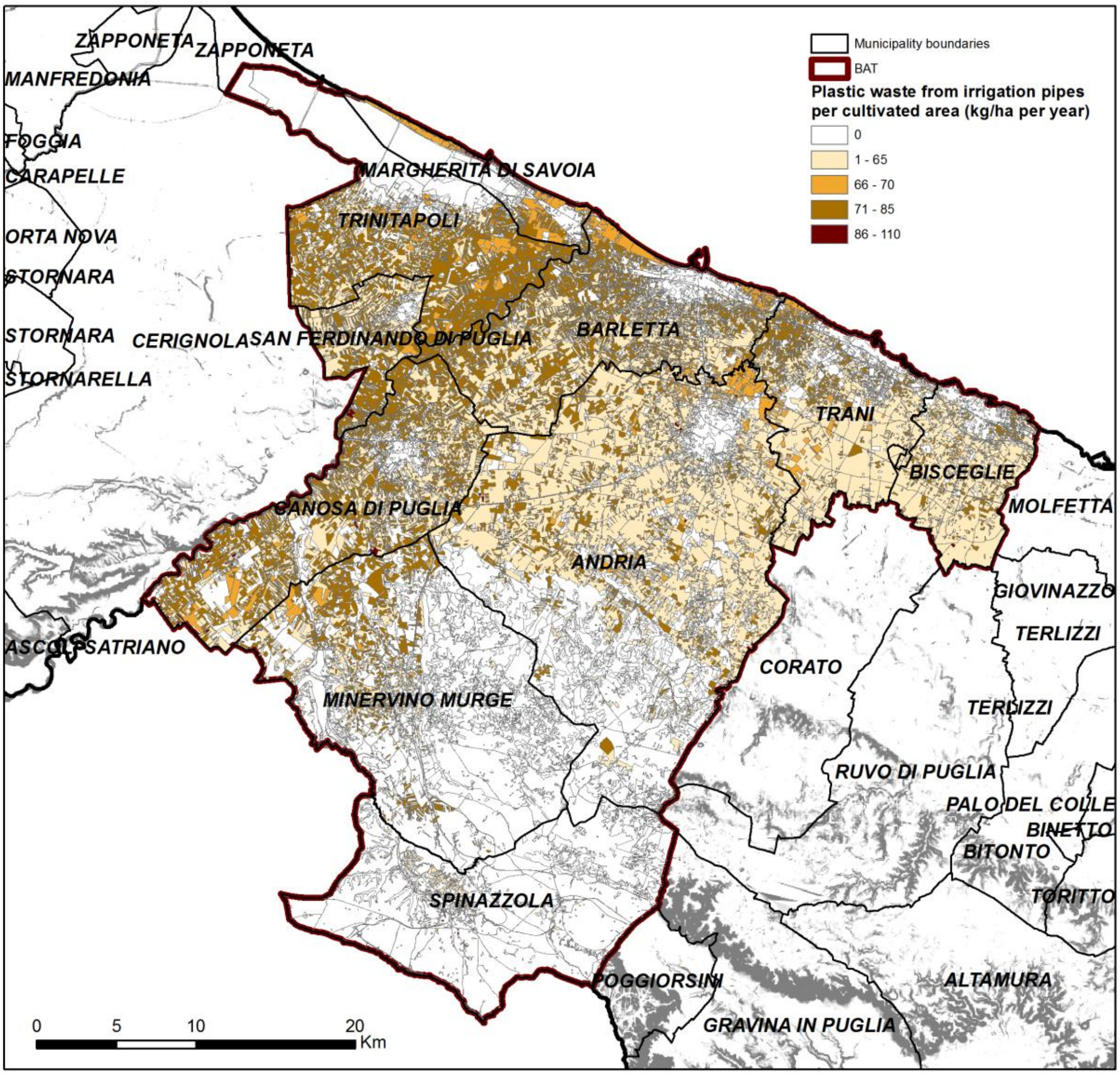

Figure 5: The distribution of the amount of plastic waste deriving from irrigation pipes (kg ha^{-1}yr^{-1}).

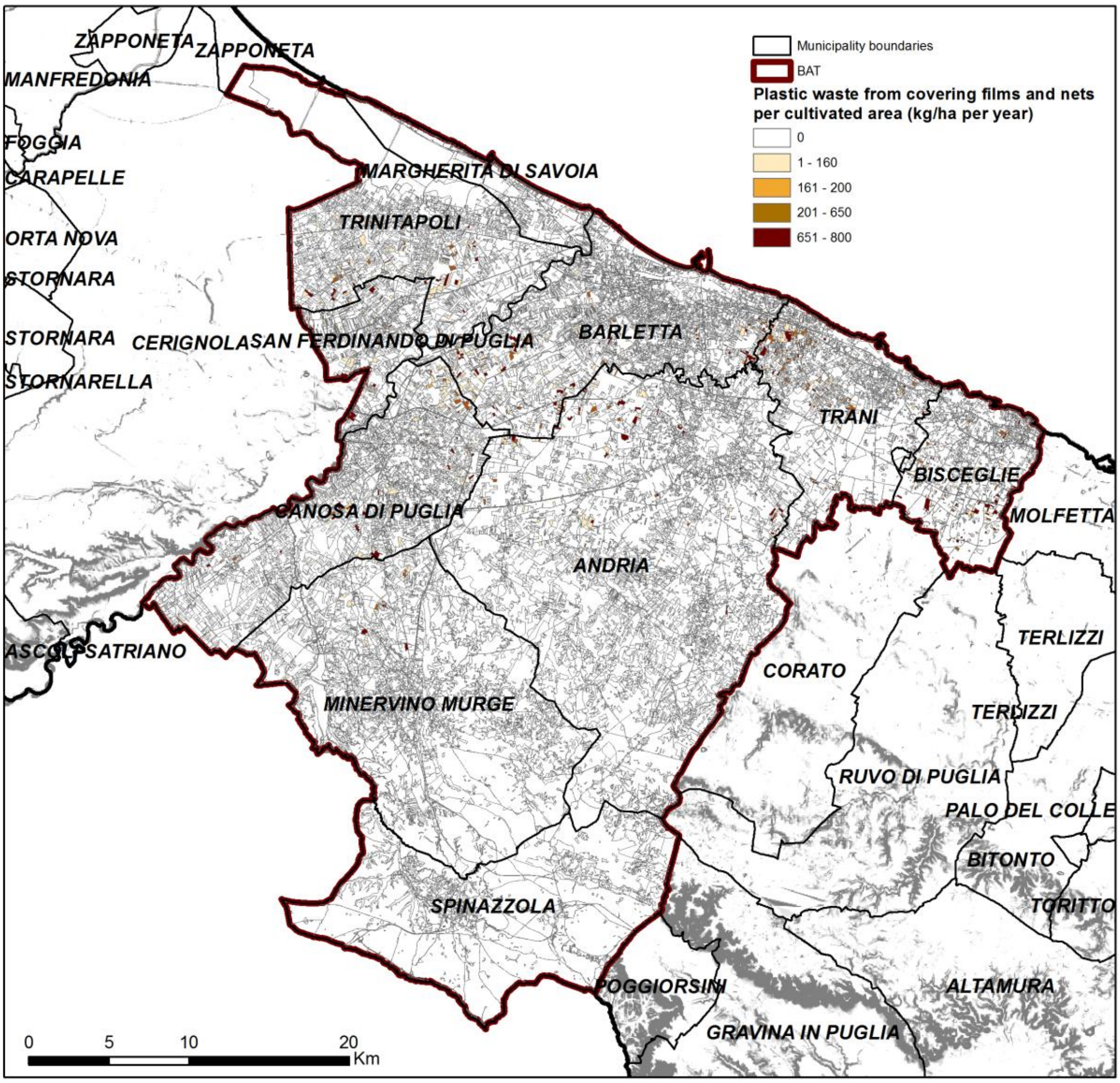

Figure 6: The distribution of the amount of plastic waste deriving from covering films and nets (kg $ha^{-1}yr^{-1}$).

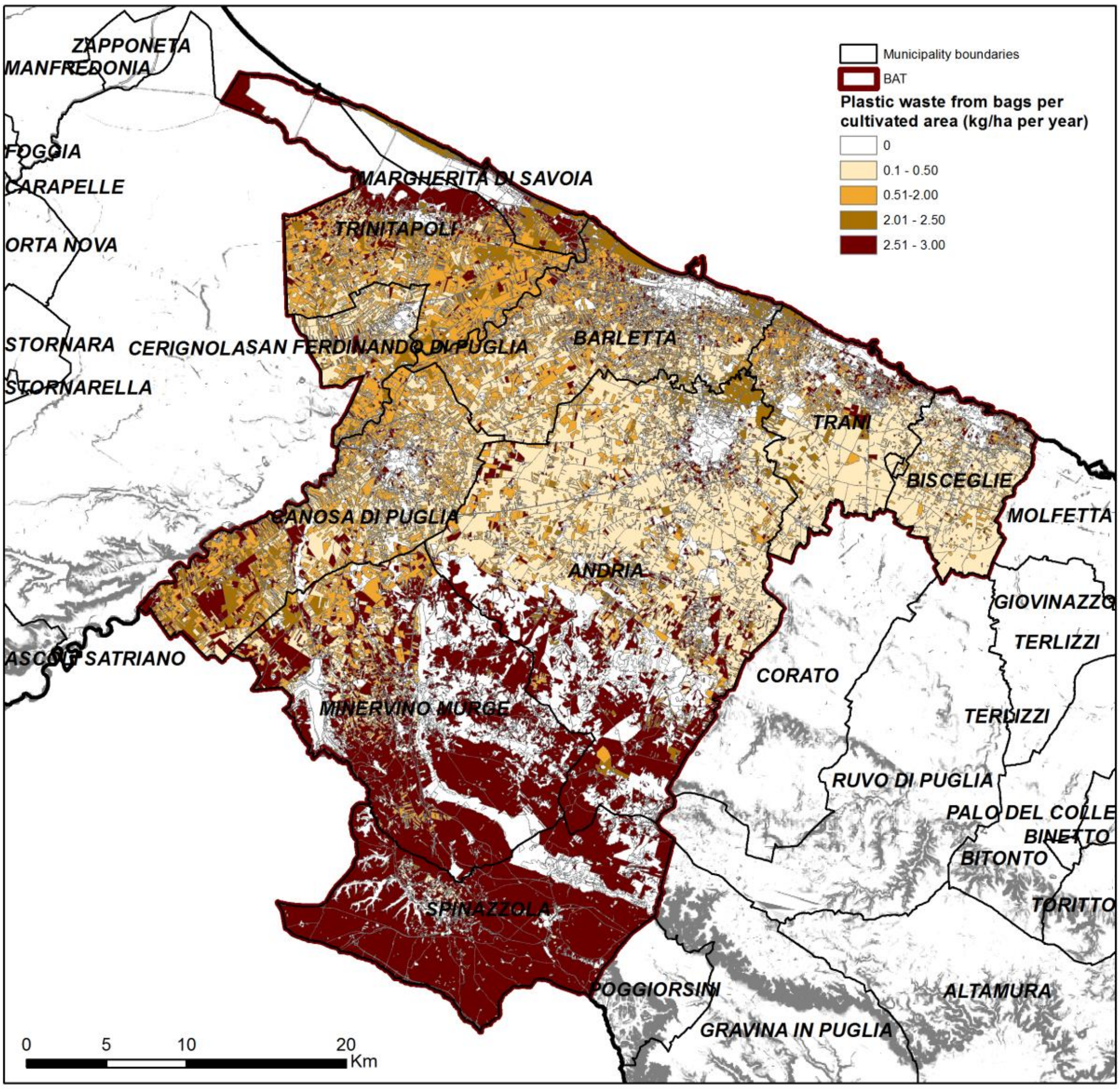

Figure 7: The distribution of the amount of plastic waste deriving from bags (kg $ha^{-1}yr^{-1}$).

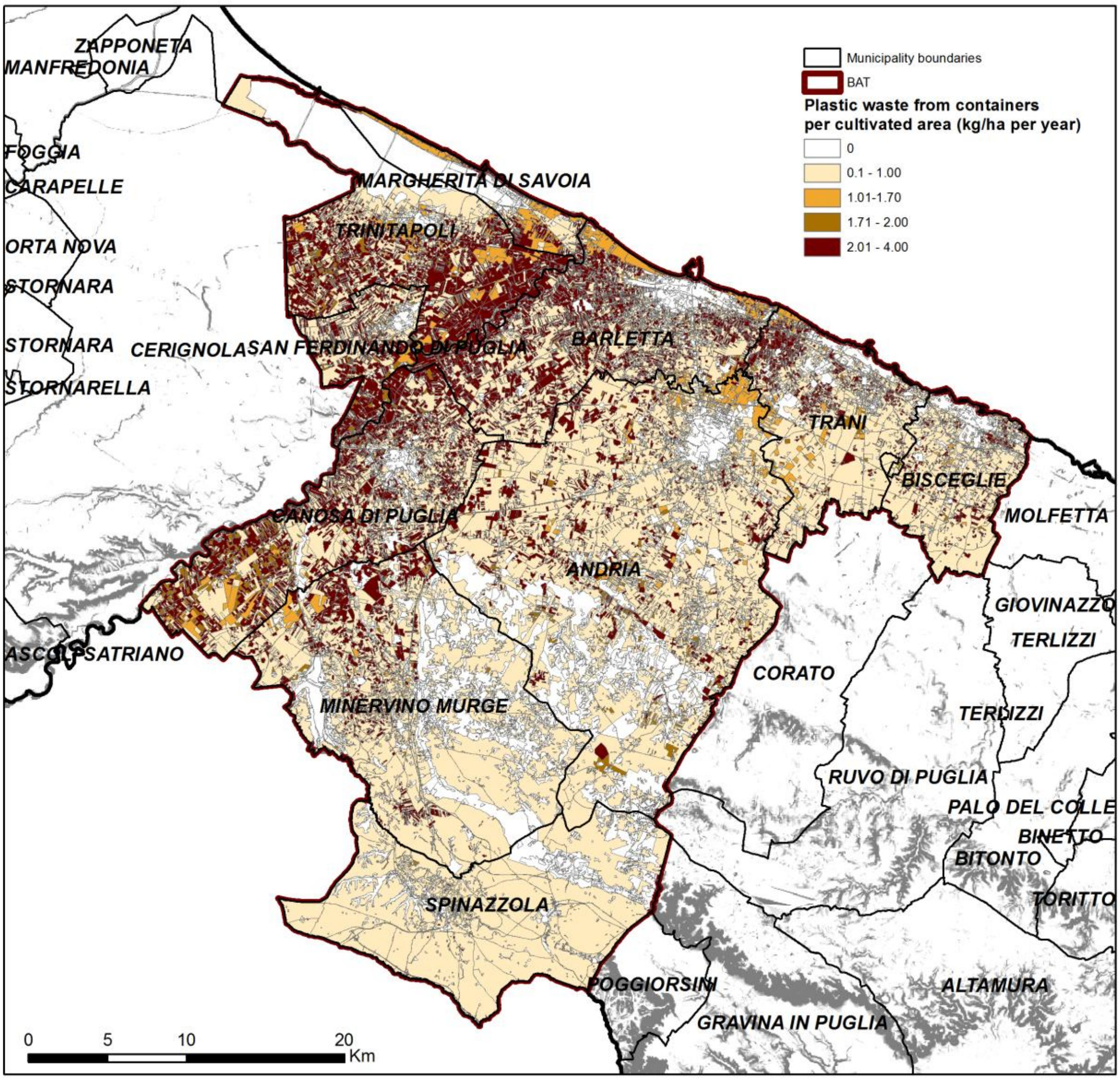

Figure 8: The distribution of the amount of plastic waste deriving from containers (kg ha^{-1}yr^{-1}).

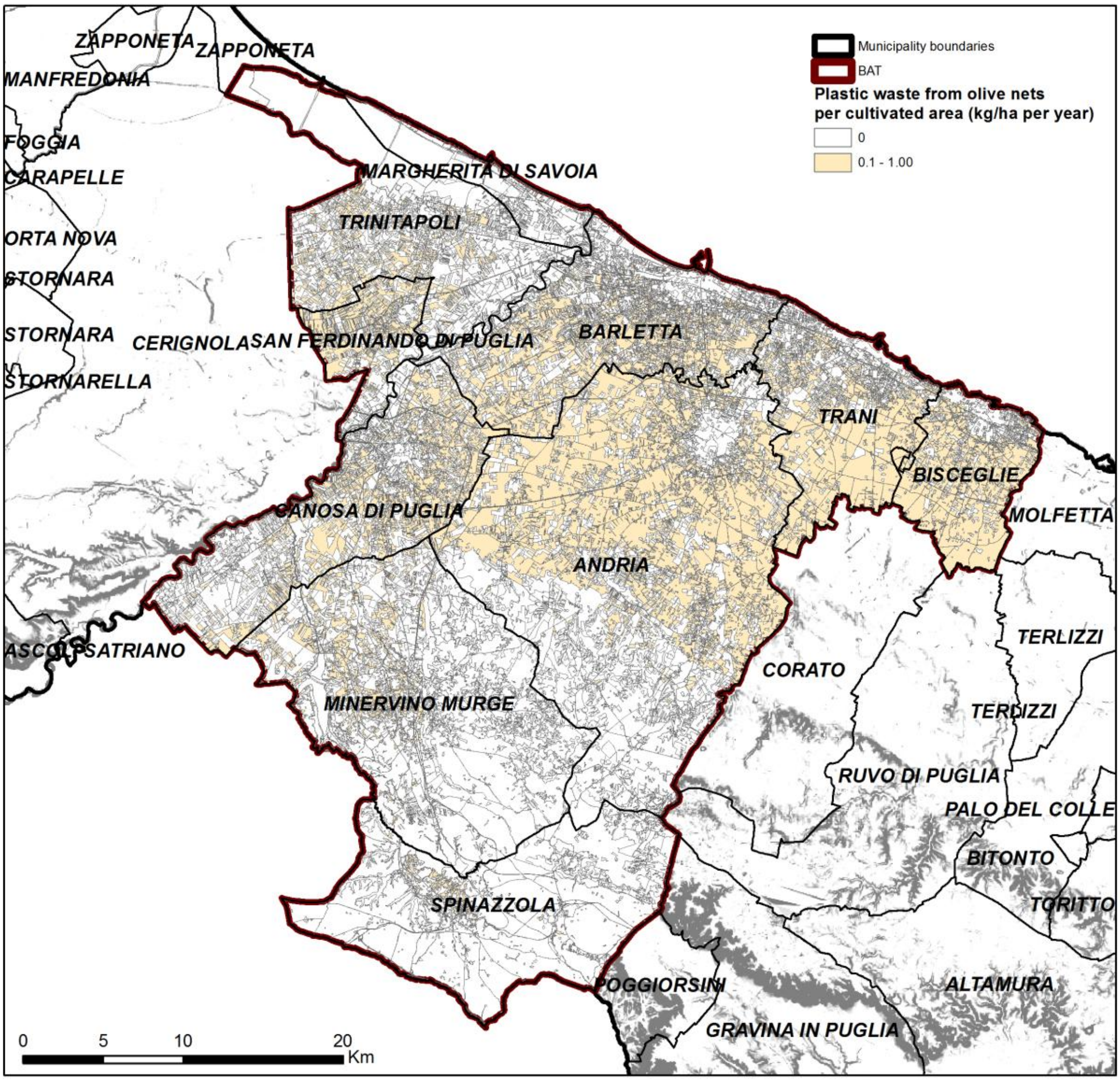

Figure 9: The distribution of the amount of plastic waste deriving from olive nets (kg ha^{-1}yr^{-1}).

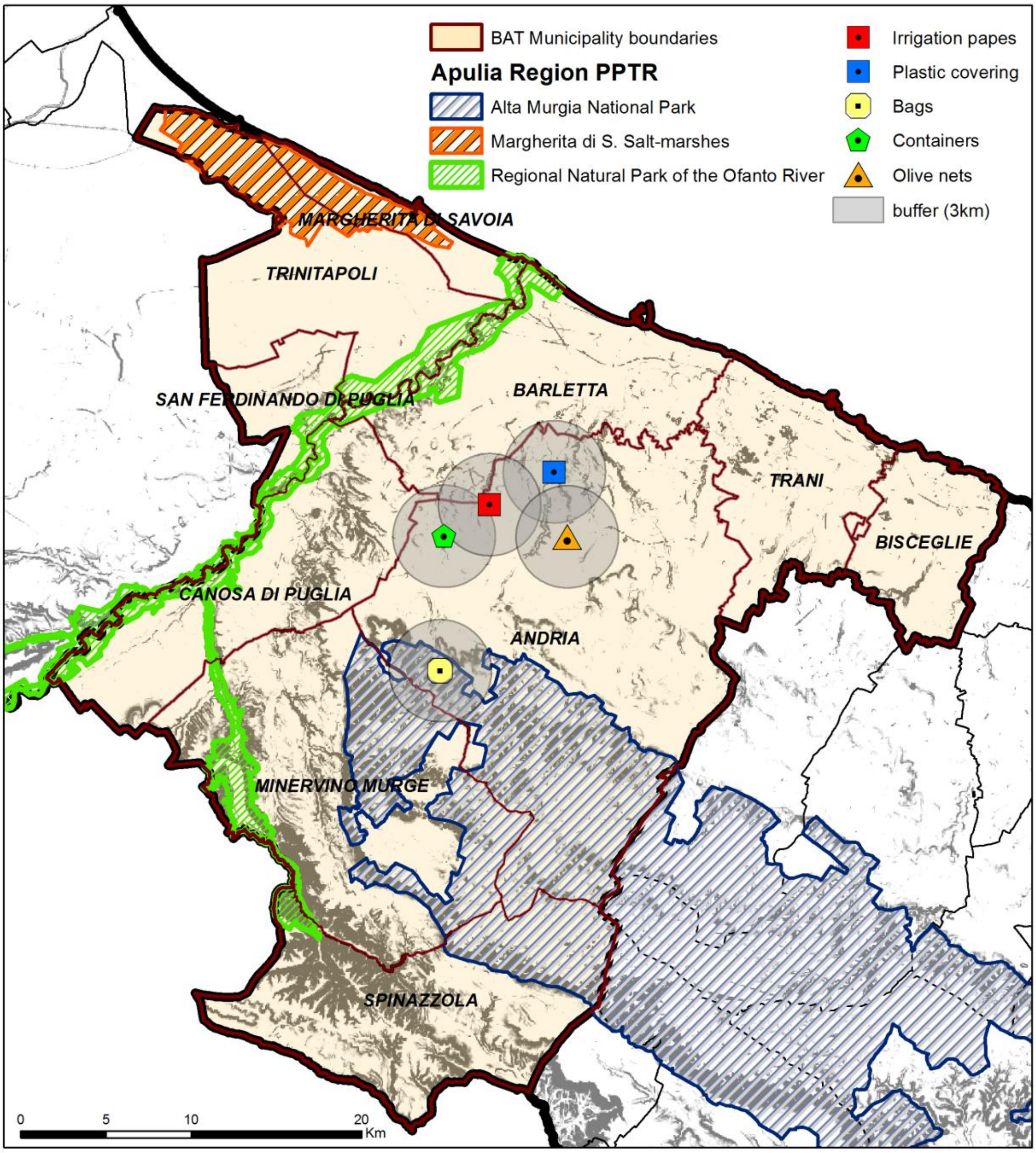

Figure 10: The suitable location of the collection centres on the land for each kind of APW.