A GIS-BASED INDEX TO IDENTIFY CRITICAL HOTSPOTS OF AGRICULTURAL PLASTIC PRESSURE IN VULNERABLE LANDSCAPES

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Abstract
The intensification of plasticulture may generate substantial quantities of agricultural plastic waste (APW), posing increasing risks to ecological integrity and landscape quality, especially in close proximity to protected sites or to areas subjected to mass summer tourism. This study proposes the Landscape Vulnerability to Agricultural Plastic Index (LVAPI), a GIS-based composite index combining the Agricultural Plastic Pollution Risk Index (APPRI) with a Landscape Sensitivity Index (LSI), to map critical hotspots of plastic pressure across an Italian Southern region (*i.e.*, Basilicata). APPRI was computed by integrating plastic waste indices per crop type with relative risk indices, reflecting the micro- and nanoplastic (MNP) generation potential associated with each plastic application. LSI integrates three equally weighted sensitivity components: slope-based soil sensitivity, water sensitivity based on proximity to the regional hydrographic network, and ecological sensitivity based on proximity to Natura2000 protected sites. Applied at 10 m spatial resolution across 435,134 ha of agricultural land, LVAPI identified high-vulnerability hotspots covering 18,716 ha (4.30%), concentrated in some regional areas characterized by intensive agricultural production, ecologically vulnerable landscapes, intensive summer tourism, or close to drinking water watershed. As a proxy-based screening tool, LVAPI supports spatial prioritization of protection measures, rather than predicting field-scale micro- and nanoplastics concentrations.

Key words: Agricultural plastic waste, GIS, Landscape sensitivity, Microplastic risk, Natura2000 sites.

Introduction

Plastic materials are widely used in agriculture, generating significant Agricultural Plastic Waste - APW (Statuto et al., 2024). Italy is among the main APW producers in Europe, with high contributions from Sicily and Apulia (Hachem et al., 2024). In Basilicata, GIS-based studies estimated both plastic-covered areas (2,062.23 ha) and APW quantities (~1,875 tonnes), mainly near sensitive coastal zones (Statuto et al., 2024; Cillis et al., 2022b). Plastic residues degrade into Micro- and NanoPlastics (MNPs), affecting soils and biota (Briassoulis, 2023), and are transported to aquatic systems through runoff and erosion (Picuno C. et al., 2019; Rehm et al., 2021). Landscape features and proximity to protected areas influence contamination patterns (Convertino et al., 2023). Existing tools such as Plastic Waste Index (PWI) and Agricultural Plastic Pollution Risk Index (APPRI) focus on plastic pressure (Lanorte et al., 2017; Hachem et al., 2024) but neglect landscape sensitivity, which is crucial in Mediterranean environments (FAO, 2021). This study addresses this gap by proposing a specific Index (Landscape Vulnerability to Agricultural Plastics Index - LVAPI), which combines APPRI with a Landscape Sensitivity Index (LSI) based on slope, hydrological proximity, and distance from Natura2000 sites. Applied to the Basilicata region at 10 m resolution, it identifies areas where high plastic pressure overlaps with high vulnerability, supporting targeted mitigation and policy actions.

Materials and Methods

The study area is the Basilicata region (≈9,992 km²), a Southern Italian region characterized by diverse topography and agricultural systems dominated by cereals, grassland, and olive groves - with plastic-intensive crops concentrated in the "*Metapontino*" district. The presence of 84 *Natura2000* sites, including some coastal areas subjected to intensive summer tourism that are adjacent to intensive plasticulture, highlights high ecological sensitivity. The analysis was performed in *QGIS 3.44* through: land use selection; identification of plastic applications using the PWI framework (Hachem et al., 2024); area calculation and PWI adjustment with ISTAT (2025) data (Hachem et al., 2024); APW estimation; APPRI computation using risk indices (Briassoulis, 2023; FAO, 2021; Hachem et al., 2026); LSI derivation from slope, hydrological, and ecological factors (Ferrara et al., 2020); and LVAPI calculation and classification (Hachem et al., 2024). The workflow represents a regional-scale screening approach for vulnerability mapping. ISTAT data were used to refine mixed land-use classes (Hachem et al., 2024). Weighted PWI values were calculated for vineyards (363.0 kg ha^{-1} yr^{-1}) and irrigated arable land (268.0 kg ha^{-1} yr^{-1}), accounting for crop distribution and protected cultivation systems. PWI values are reported in Table 1.

Tab. 1: Plastic applications and corresponding PWI values assigned to each Corine Land Cover class (adapted from *Hachem et al., 2024).*

Land Use Class	PWI (kg ha^{-1} yr^{-1})	APPRI (kg RRI ha^{-1} yr^{-1})
Non-irrigated arable land	207.3	2,124
Irrigated arable land	268.0	2,510
Vineyards	363.0	2,827
Orchards	1005.4	6,821
Olive groves	80.3	699
Mixed crops	238.0	2,317
General agricultural areas	268.0	2,510

APPRI was computed to link APW to MNP contamination risk, following Hachem et al., (2024). The Relative Risk Indices RRI values from Briassoulis, 2023 and (FAO, 2021), as consolidated by (Hachem et al., 2026), represent the MNP release potential of each plastic application. APPRI = $\Sigma(APW_i \times RRI_i)$, where APW_i is annual waste and RRI_i the risk index reported in Table 2. Values were normalized (0–1) and classified into low, medium, and high using equal intervals.

Tab. 2: RRI for plastic applications used in the APPRI calculation (Hachem et al., 2026).

Plastic Application	RRI
Agrochemical containers	11.2
Mulching films	10.5
Irrigation pipes	9.5
Vineyard plastic support	9.5
Bags for fertilizers	9.35
Silage films	8.1
Protective nets	8.0
Covering films	6.3

The LSI was derived by combining three equally weighted components at 10 m resolution, each classified on a 1–3 scale. Equal weighting was adopted to avoid bias in the absence of validated schemes. Slope-based sensitivity was obtained from the TINITALY DTM using the MEDALUS framework (Ferrara et al., 2020), with thresholds: low (0–6°), moderate (6–18°), and high (>18°). Water sensitivity was based on distance from the hydrographic network: high (<500 m), moderate (500–2,000 m), and low (>2,000 m), reflecting erosion-driven transport processes (Rehm et al., 2021). Ecological sensitivity was defined by proximity to Natura 2000 areas using the same 500 m threshold, supported by evidence of higher MNP contamination near sensitive environments (FAO, 2021). The three components were then combined as:

$$\boldsymbol{LSI} = (\boldsymbol{S_{soil}} + \boldsymbol{S_{water}} + \boldsymbol{S_{eco}}) / \boldsymbol{3}$$

This simplified approach ensures transparency and reproducibility, with potential refinement through future calibration. LVAPI was calculated as LVAPI = APPRI × LSI and normalized (0–1) by dividing by the maximum value of 3.0, representing the highest hotspot condition. The index was classified into Low (0–0.33), Medium (0.33–0.66), and High (>0.66) using equal intervals, consistent with Hachem et al., (2026).

Results

The LSI showed marked spatial variability across Basilicata. Soil sensitivity (mean = 2.09) reflects the predominantly hilly–mountainous terrain (Ferrara et al., 2020), while water sensitivity (mean = 2.01) highlights widespread proximity to drainage networks, increasing runoff-driven transport (Rehm et al., 2021). Ecological sensitivity was lower (mean = 1.23), as most areas lie beyond 500 m from Natura2000 sites, though these create localized high-sensitivity zones (FAO, 2021). Overall, LSI ranged from 1.0 to 3.0 (mean = 1.83), with higher values along river corridors, steep slopes, and protected areas. The APPRI map (Figure 1) showed clear spatial patterns of plastic pressure, with a mean value of 0.263. The highest values occur in the Metapontino coastal plain (Zone A), dominated by intensive orchards (APPRI/ha = 6,821 kg RRI ha^{-1} yr^{-1}). Moderate values were observed in vineyards of the Vulture area (Zone B; 2,827 kg RRI ha^{-1} yr^{-1}), while olive groves and non-irrigated arable land (Zone C; 699 kg RRI ha^{-1} yr^{-1}) showed the lowest pressure. The LVAPI map (Figure 2) highlights a heterogeneous distribution of landscape vulnerability. Low LVAPI dominates (415,446 ha, 95.47%), mainly in extensive cereal, pasture, and olive systems. Medium LVAPI is limited (972 ha, 0.22%) and reflects transitional conditions. High LVAPI hotspots cover 18,716 ha (4.30%), identifying areas where both plastic pressure and landscape sensitivity are high, concentrated in three main zones.

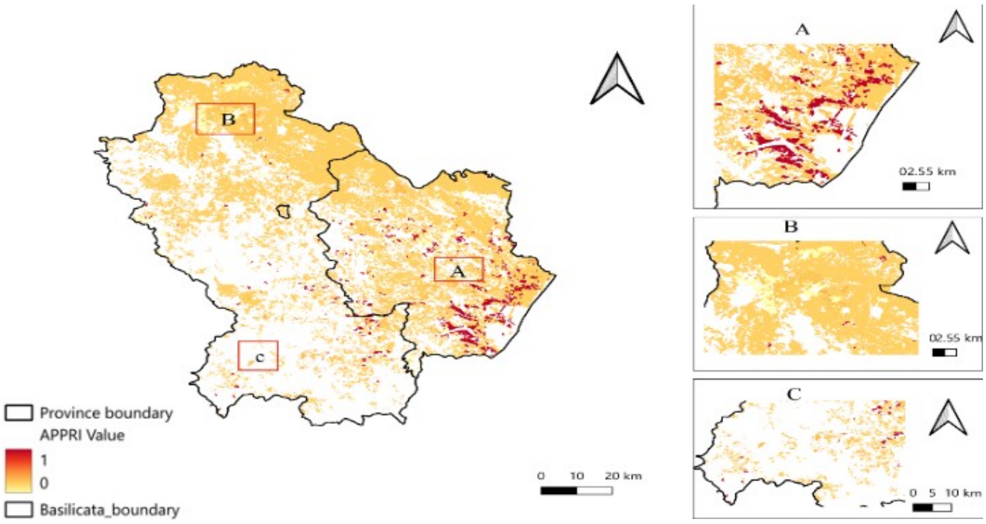

Fig. 1: Agricultural Plastic Pollution Risk Index (APPRI) across Basilicata, with three inset zones. Zone A (Metapontino). Zone B (Vulture) and Zone C (Agri-Pertusillo). White areas indicate non-agricultural land uses receiving APPRI = 0.

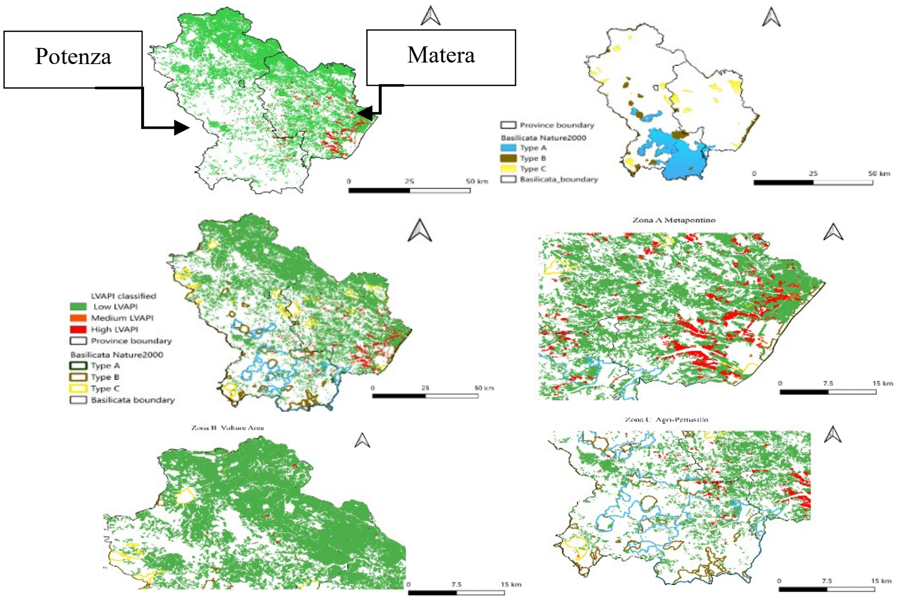

Fig. 2: Spatial analysis of the Landscape Vulnerability to Agricultural Plastic Index (LVAPI) in Basilicata region, Italy, and its relationship with Natura 2000 protected areas. Top left: Spatial distribution of LVAPI across Basilicata classified into three vulnerability classes: Low (LVAPI < 0.33, 415,446 ha, 95.5%), Medium (0.33 ≤ LVAPI < 0.66, 972 ha, 0.2%), and High (LVAPI > 0.66, 18,716 ha, 4.3%). Top right: Spatial distribution of Natura 2000 protected sites in Basilicata (Data source: EEA, 2022). Middle left: LVAPI classified map overlaid with Natura2000 protected site boundaries. Middle right: Zone A — Metapontino (eastern Matera province). Lower left: Zone B — Vulture (northwestern Potenza province). Lower right: Zone C — Agri-Pertusillo (south-central Basilicata).

Zone A — Metapontino Coast shows the highest LVAPI concentration, driven by intensive orchards and protected horticulture (*e.g.*, strawberry tunnels and melon crops). These hotspots lie adjacent to Natura 2000 sites along the Ionian coast, indicating a critical risk for protected habitats (Cillis et al., 2022a).
Zone B — Vulture Viticulture Area exhibits a contrast between low vulnerability inside protected forested areas and localized High LVAPI in surrounding vineyards, highlighting the exposure of protected areas to plastic pressure (Zavattoni et al., 2026).
Zone C — Agri-Pertusillo Watershed represents a key critical area, where High LVAPI zones border the SAC protecting the Pertusillo reservoir, with implications for water security due to erosion-driven MNP transport (Rehm et al., 2021).

Discussion

The LVAPI results show that vulnerability to agricultural plastic pollution depends not only on plastic pressure but also on landscape sensitivity. The identified hotspots confirm that areas where intensive plastic use overlaps with sensitive environmental conditions are the most critical. The Metapontino coastal plain represents the main hotspot, due to high plastic-intensive cultivation combined with proximity to Natura2000 sites, highlighting potential risks for protected ecosystems (FAO, 2021; Zavattoni et al., 2026). In the Vulture and Agri-Pertusillo areas, vulnerability is influenced by landscape factors such as slope, hydrological connectivity, and proximity to sensitive environments, supporting the role of erosion and runoff in MNP transport (Picuno C. et al., 2019; Rehm et al., 2021). Compared to existing approaches (Lanorte et al., 2017; Hachem et al., 2024), LVAPI improves spatial assessment by integrating plastic pressure with landscape sensitivity. However, the model is based on proxy variables and simplified assumptions (*e.g.*, equal weighting), and should be considered as a screening tool. Future research should validate the index with field data and test alternative weighting schemes.

Conclusion

The GIS-based LVAPI index, integrating agricultural plastic pressure and landscape sensitivity to identify vulnerability hotspots applied to Basilicata, highlights critical areas concentrated in some regional areas located particularly close some Natura 2000 sites. The results show that environmental risk depends on both plastic intensity and landscape characteristics. As a proxy-based tool, LVAPI supports spatial planning and targeted APW management, b further validation with field data is required.

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Souhrn
Zemědělský plastový odpad představuje v středomořských krajinách rostoucí zátěž pro životní prostředí, zejména v blízkosti chráněných lokalit nebo oblastí s intenzivním turistickým ruchem. Tato studie představuje index LVAPI, založený na GIS, který identifikuje kritická místa, kde se vysoká zátěž plasty překrývá s vysokou citlivostí krajiny, a který byl aplikován na region Basilicata (≈9 992 km²; 84 lokalit sítě Natura 2000). LVAPI kombinuje APPRI – odhad rizika znečištění plasty pomocí indexů specifických pro jednotlivé plodiny a dat ISTAT (2025) – s LSI, který integruje sklon, blízkost vody a ekologickou citlivost v rozlišení 10 m. Oblasti s vysokou zranitelností pokrývají 18 716 ha (4,30 %), hlavně ve třech zónách: pobřežní nížina Metapontino, vinařská oblast Vulture a povodí Agri-Pertusillo, které se všechny vyznačují blízkostí lokalit Natura 2000. Oblasti s nízkou zranitelností tvoří 95,47 % zemědělské půdy. Rámec LVAPI podporuje cílené strategie řízení a je přenositelný do jiných středomořských regionů.

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