

1 *Proceedings*

2 **A gis-based approach for manure spreading monitoring within** 3 **the digital agriculture framework[†]**

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19 **Abstract:** Livestock manure management, especially related to the soil fertilisation practice, is
20 responsible for most of the emissions in agriculture, in particular ammonia emissions (NH₃) which
21 play a key role in environmental problems, affecting water, soil and air quality. Within the digital
22 agriculture framework, EO data contribute for agricultural practices monitoring such as manure
23 spreading, to mitigate pollutants emission. This study presents a GIS-based tool on an Open-
24 Source platform, developed for susceptibility estimation of sewage spreading occurrence in
25 agricultural areas in Italy. The tool is based on the analysis of multispectral and hyperspectral
26 satellite time series in synergy with field data and ancillary information collected from regional
27 repositories, to produce a series of classified and prioritised spatially explicit information.. Spectral
28 analysis of satellite acquisitions enabled the identification of manure spreading with precision of
29 about 83%. Field campaigns from October to March were carried out to validate the spreading
30 event. The case study demonstrates the ability of the proposed GIS-based tool in supporting the
31 monitoring of manure spreading.

Keywords: agricultural practices; soil fertilisation; monitoring manure spreading; GIS-based tool

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32 **1. Introduction**

33 The agricultural sector has a strong impact on emissions of pollutants, including
34 ammonia from livestock farming and fertilisation of agricultural land.

35 At the European level farmers will be permitted to spread manure in specific
36 temporal windows [1] although monitoring every plot of land is a critical point [2].

37 The approach of integrating Earth Observation acquisitions, ground data and
38 available datasets bring benefits to deal with issue [2]. Within this perspective, the
39 objective of the activity is to develop a tool to support monitoring of manure spreading.
40 The final result is a GIS-based tool that estimates the areas most susceptible to manure
41 spreading.

42 **2. Materials and Methods**

The study area identified to develop and demonstrate tool capacity is the Po Plain (Fig.1), one of the regions most involved in agricultural activity in Italy. The tool was developed using the open source software QGIS.

A number of surveys were conducted in the north-east and in the east of the study area (province of Modena and Bologna) (Fig.1) to collect Ground Truth Points (GTPs).

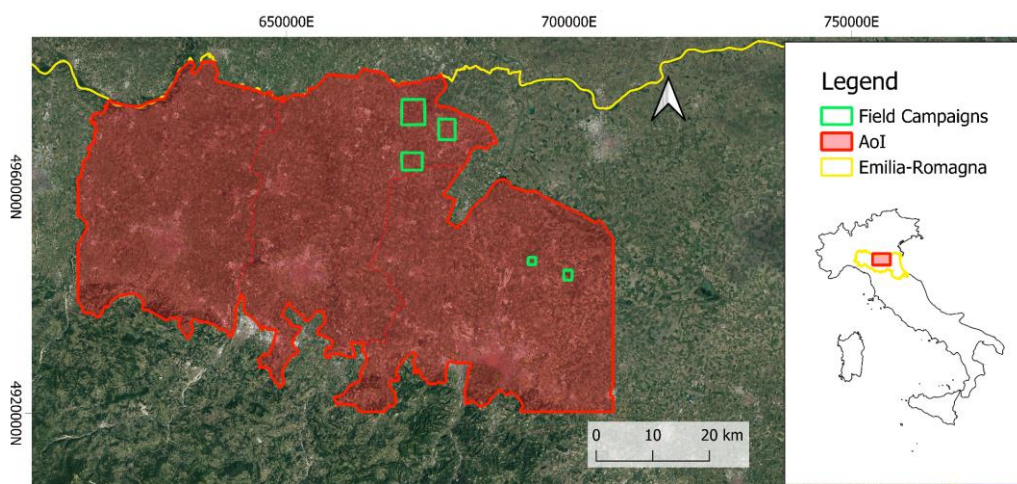


Figure 1. Study area in Po Plain (in red). Surveys carried out in the green-marked areas.

The approach is based on a combination of the following set of relevant spatially explicit variables, combined using a weighted formula:

- Variable 1: Manure spreading frequency;
- Variable 2: Manure spreading areas manually detected;
- Variable 3: Distance from farms and/or bio-digesters.

The data processing approach is shown in Figure 2.

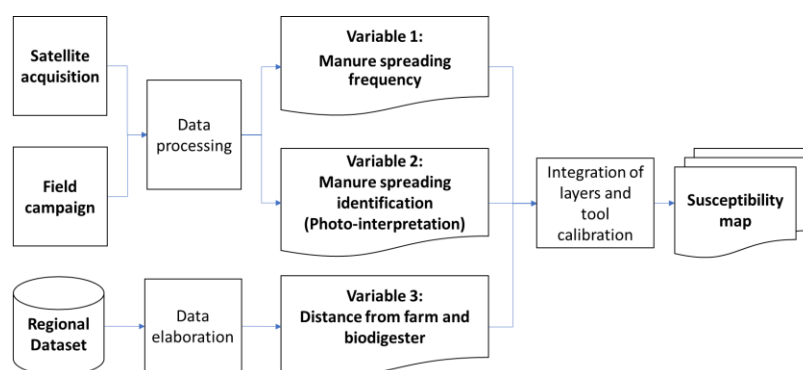


Figure 2. Workflow of the methodology for the GIS-based tool development (Susceptibility map).

2.1. Satellite acquisitions

In this study 46 Sentinel-2 MSI (S2) acquisitions (from February 2020 to February 2023) and 3 PRISMA acquisitions (collected 07/11/2020, 25/11/2020, 26/03/2021), both characterised by a minimal cloud coverage, were analysed. The technical specification of satellite data is summarised in Table 1. The processing operations, for both S2 and PRISMA acquisitions, have been executed using the software ENVI version 5.6.

Table 1. Technical specification of satellite data [3][4].

Agency	Satellite	Type	Resolution	Bands	Sensor	Access
ESA	Sentinel-2	Level 1C	10/20 m	13	Multispectral	Open data
ASI	PRISMA	Level 2D	30 m	240	Hyperspectral	By request

2.2. Field campaigns

Field campaigns were carried out to collect a dataset of GTPs, used to validate the spreading and no-spreading areas (Fig. 3).



Figure 3. Field campaign measures and S2 MSI true colour acquisition over the surveyed site.

Field campaigns were performed in the temporal window from October to March: October manure spreading for winter crops, November - February fertilisation ban, March soil/land prepared for new crops.

Measurements of relative humidity, electrical conductivity and temperature were taken in the fields surveyed. They were carried out both where spillage had occurred and where it had not.

2.3. Satellite data processing

First, the satellite acquisitions were pre-processed by applying raster masks that isolate arable fields by integrating the following ancillary datasets: Soil Map [5] to circumscribe the lowlands; Land Use [5] and Land Consumption [6] to exclude urban and non-agricultural; Crop Map [7] to exclude grassland and alfalfa.

Then, spectral analysis was carried out in order to investigate manure spreading response. Average reflectance values for each spectral band acquired by the satellite sensor were extracted and analysed, in particular for spread areas. Variations in the ShortWaveInfra-Red (SWIR) region of the electromagnetic spectrum (corresponding to bands B11 and B12 of S2 MSI data) have been considered to be more suited in manure spreading detection, according to scientific literature [2, 8].

Finally, a spectral index calculated from the combination of SWIR, near-infrared (NIR) and red spectral bands of S2 MSI was employed to map manure spread regions in each satellite acquisition:

$$\text{Manure Spectral Index} = \frac{(SWIR1 + SWIR2) - NIR}{RED} \quad (1)$$

The separation between manure and other land cover has been reached with a threshold of 3, which represents the optimal performance according to the overlapping rate test for the pure pixel detection. Furthermore, the pixel aggregation procedure has removed the noise. These steps constitute a semi-automatic processing that provides the raw dataset utilised for the development of two different independent products: Variable 1 and Variable 2.

The manure spectral index, with the selected threshold, provides a precision of about 83% in the manure spread class; the statistical robustness is supported by a kappa coefficient value of 0.86. The test dataset consists of 1090 pure pixels (corresponding to about 11 hectares) that have been selected on two S2 MSI acquisitions, temporally

consistent with the field campaign dates. Such accuracy evaluations, however, have been only performed over the surveyed sites.

2.4. Variable 1: Manure spreading frequency

The analysis of the preliminary output of the satellite data processing has shown that some areas were more often involved by manure spreading events; thus, the spreading frequencies have been investigated. Firstly, the data redundancy has been mitigated, realising a 350 m buffer for each candidate “manure spread” area. Later, each buffer was assigned the value 1, while the background was set to value 0. Then, manure spread rates have been obtained by summing up the manure spread maps generated from each satellite acquisition. Ultimately, the obtained values were converted into 5 classes, each of which was assigned a susceptibility value (as reported in Table 2). Manure spreading frequencies lower than 5 have been excluded, since they could represent a low impact fertilisation practice.

Table 2. Susceptibility values depending on the automatic frequency computation.

Number of spreads	Susceptibility value
<5	0
5-6	0.25
7-8	0.50
9-10	0.75
>10	1

2.5. Variable 2: Manure spreading manual identification areas

Using photo-interpretation, an expert operator confirmed manure spreading areas identified by semi-automatic processing, in order to refine the product by removing false positives. The resulting product consists in a spatially explicit variable in which manure spreads regions are identified by a 350 m radius buffer. Buffer operation has enabled the aggregation of contiguous manure spreads areas. Buffer areas and background pixels have been assigned the values 1 and 0, respectively.

2.6. Variable 3: Distance from farms and/or bio-digesters

Spray fields are typically located in close proximity to animal houses and manure lagoons due to the high cost of hauling the liquid [9-13]. Positions of livestock farms and biodigester (main manure storage points in Po Plain) were identified using information on the characteristics of farms and biodigesters in the Emilia-Romagna region found in regional datasets [14]. Only cattle farms with more than 80 animals/farm and pig farms with more than 600 animals/farm were selected.

A spatial analysis was then performed to assign each pixel in the study area a distance value from farms and biodigesters.

The last step was to reclassify the distance values into discrete classes by assigning each ring a susceptibility value between 0.2 and 1, as reported in Table 3. The assigned values were agreed upon with the stakeholders.

Table 3. Spreading susceptibility values assigned for distance from livestock farms and biodigesters.

Distance	Susceptibility value
0-1000 m	1
1000-2000 m	0.8
2000-3000 m	0.6
3000-4000 m	0.4
>4000 m	0.2

2.7. Integration of variables and tool calibration

In order to prioritise and integrate the three variables, a set of weights, agreed upon with the primary users, were assigned to combine variables according to formula:

$$\text{Susceptibility} = (0.4 * \text{Variable 1}) + (0.2 * \text{Variable 2}) + (0.4 * \text{Variable 3}). \quad (2)$$

Within the variables integration process, statistical indicators have been evaluated. Among the coefficient combinations following a normal distribution, the one that better shows the balance between the three variables has been selected. Thus, very high susceptibility rates are detected uniquely in the areas where the three variables reach a maximum value.

3. Results

The product of the formula (2) is the susceptibility tool (Fig. 4), which ranges 0 to 1.

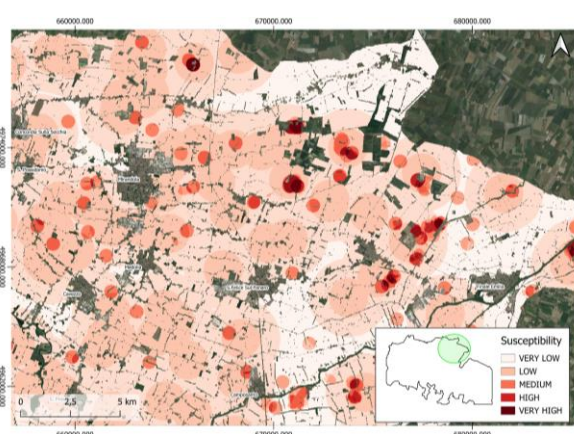


Figure 4. Susceptibility tool, zoom on the north-east portion of the Modena province.

The values were converted into 5 classes (from very low to very high) to enhance the readability (Tab. 4).

Table 4. Classes of susceptibility according to values obtained.

Value	Class
< 0.28	very low
0.28 - 0.46	low
0.46 - 0.64	medium
0.64 - 0.82	high
>0.82	very high

4. Discussion and Conclusion

Regarding the parameters measured in field campaigns, no evidence was found between the spreading and the non-spreading areas. However surveys have been essential in evaluating the correspondence between the satellite and the ground data. New field campaigns could be carried out together with soil chemical analyses to better investigate any differences and to enhance the accuracy of the monitoring of the area. In this study the accuracy of the manure spectral index is calculated on test areas and will be implemented simultaneously with the aforementioned field campaigns.

The tool could be tailor-made to users' needs for different geographic areas modifying the weights used for each variable in the formula (2). In addition, the manure spreading frequency could be provided annually, estimated from satellite time series analysis updated.

169 It is important to note that the study presents obstacles such as it still needs for an
170 operator to validate the data, and the critical point to identify spreads in vegetated land.

171 Despite the above mentioned limitations, the proposed approach has been proved
172 to be a valid and innovative digital method to produce the susceptibility map. This GIS-
173 based tool could serve as an information instrument for territory management, for the
174 area monitoring system (AMS) to be adopted by 2024 as foreseen in article 70 (1) of
175 Regulation (EU) 2021/2116 and for the achievement of the new Air Quality Directive
176 2008/50/CE targets for ammonia emissions.

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