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GIS-based analysis to assess biogas energy potential as support for manure management in Southern Italy

Ester Scotto di Perta[1], Elena Cervelli[1], Raffaele Grieco[2], Antonio Mautone[1], Stefania Pindozzi[1]

[1] *Department of Agricultural Sciences University of Naples Federico II, Portici (NA), Italy*
[2] *Department of Agricultural and Food Sciences, University of Bologna, Bologna, Italy*

ABSTRACT
Anaerobic digestion can provide a valuable aid to manure management while producing renewable energy. Biogas production is highly dependent on the size and composition of livestock farms, and the availability of fresh manure can vary throughout the year, limiting reliable assessment of potential production. The aim of this study is to develop an affordable GIS-based analysis to support manure management, based on a highly detailed livestock farm database. Databases refer to the years 2013 and 2019 and report the herd consistency and the age of each class head. Kernel density (KD) was used to identify emerging hotspot areas with potentially high concentrations of nitrogen applied to the field. Three KD classification methods were compared: defined interval (DI) into 3 classes (0-170, 170-340, > 340 kg N/ha), quantile (Q) and natural break (NB). The results show that the DI and NB areas correspond to 40 % and 84 % of the total N of buffalo origin in the Campania region, with a N surplus in the hotspot areas localized in nitrate vulnerable zones of 55 and 6 % respectively. The biogas produced from 50 % of the buffalo manure in these areas generates sufficient energy to allow the removal of the N surplus.

Section: RESEARCH PAPER

Keywords: N surplus; anaerobic digestion; kernel density; manure treatment

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Corresponding author: Ester Scotto di Perta, e-mail: ester.scottodiperta@unina.it

1. INTRODUCTION

The livestock sector is responsible for the production of a huge amount of slurry every year. Table 1 summarizes the amount of manure annually produced in the European Union and the UK. Generally, cattle breeding is the main responsible for manure production, except for Denmark, where the pig sector is equally important [1].

In the last decade, there has been a growing interest in the effects of agricultural practices on environmental quality and it has been assessed that the produced manure needs to be handled with the right precautions in order to avoid negative environmental implications. Livestock manure composition in particular nitrogen (N) content can have an impact on terrestrial and aquatic ecosystems with a detrimental effect on air, soil, and water [2]. Because of the huge amount of nutrients, manure management is considered a crucial step in agriculture and livestock production worldwide [3], [4]. As stated by [5], [6], when farms are sited within a limited and confined geographical region, and animals are fed with highly intensive feeding strategies, there is a more intense pollutant effect due to the elevated concentration of nutrients that are excreted in that area. As a consequence, the focus of recent research has been on the utilization of sustainable agricultural practices as well as resources and nutrient circulation and reuse [7]. Indeed, it must be considered that nitrogen (N) plays a fundamental role in agricultural production, important as water [8]. Livestock manure is a low-budget source of nitrogen largely used by farmers as fertilizer [9].

In order to regulate farm activities related to N manure management, several European legislative measures have been adopted in Italy such as the Nitrates Directive, the NEC Directive, IPPC Directive [2]. According to Nitrate Directive,

Table 1. Annual manure production (million tonnes) in the European Union and UK and distribution according to main animal types (period: 2016-2019). Source: [1].

Country	Annual manure production (million tonnes)
Italy	103.19
France	276.19
Spain	135.3
Portugal	26.38
Ireland	84.25
United Kingdom	140.1
Belgium	41.13
Netherlands	72.99
Denmark	35.8
Germany	196.99
Poland	107.61
Sweden	21.1
Finland	13.42
Estonia	3.61
Latvia	5.77
Lithuania	9.97
Czech Republic	20.92
Hungary	18.63
Austria	28.66
Slovenia	6.83
Croatia	6.62
Slovakia	7.27
Romania	36.87
Bulgaria	9.03
Greece	10.48
Cyprus	1.52
Malta	0.29
Luxembourg	2.54

some limitations in the amount of N to be applied to the field are introduced. Thus, finding available lands where is possible to apply the manure can lead to an increase in direct or indirect costs, since they can be far from the location of the farms. Therefore, the direct agronomic utilization of manure compels the application of treatments reducing the manure N content. On the other hand, the need to find an alternative source of energy is gaining more and more importance and recently many researchers have studied how to produce renewable energy from the utilization of different biomasses, agricultural and livestock wastes suitable to be used as different feedstock for the anaerobic digestion (AD) treatment [10]. In addition to the advantage of biogas production, AD provides a digestate effluent, which can be used as a good quality fertilizer [11] and the reduction of GHG emissions which occur during the decomposition of manure if not properly stored [12]. Generally, AD can provide valuable support for manure management while producing renewable energy, which can be addressed by following N treatment.

The production of biogas is highly dependent on the size and composition of livestock farms, moreover, the availability of fresh manure can change over the year limiting the reliable evaluation of the potential production [13]. Moreover, it must be considered that when biogas investments are planned there is the need to apply a spatiotemporal analysis to define how the feedstock and biomasses required from the biogas plants are distributed [14]. In this paper, the authors offer an analysis of buffalo manure management in the Campania region carried out with GIS software support. The studied area is the main hotspot

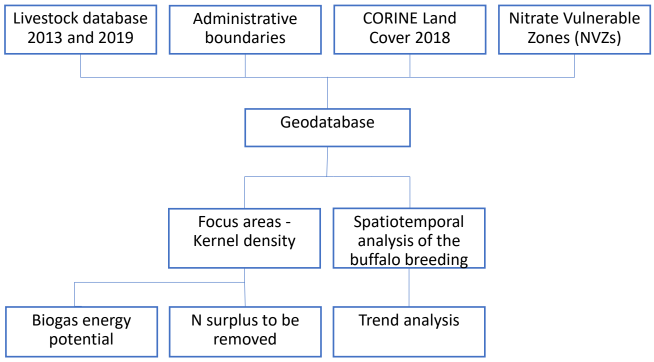

Figure 1. Study framework.

of manure nitrogen concentration before and after field application. Based on livestock size and the amount of produced manure it has been evaluated the effective nitrogen applied to the crop when manure is applied as fertilizer and the possible utilization of the remaining slurry as feedstock to feed biogas plants.

2. MATERIALS AND METHODS

2.1. The study area

The selected area in this study is the Campania region with a surface of 13.590 km², located in Southern Italy. This region is characterized by the highest number of buffalo heads (more than 290 000 in 2019) reared in the whole of Italy. Typically, buffalo breeding farms are concentrated in two main provinces, Caserta and Salerno with 2.651 km² and 4.954 km² wide, respectively. These together correspond to 56 % of the total region area.

2.2. The framework

Based on the spatiotemporal analysis between 2013 and 2019, this work aims at determining the growing trend of buffalo farming and the emerging hot spots for N management. On the other hand, the potential valorisation of the livestock effluents is supposed at a regional scale, in order to support N reduction strategies (Figure 1). The GIS processing entails different operations carried out by means of ArcGIS 10.5 software (ESRI, Environmental Systems Research Institute).

This study is characterized by five main steps:

1) The creation of the geodatabase, which includes Buffalo consistency and composition, administrative boundaries, Nitrates Vulnerable Zones (NVZ), and existing biogas plants.
2) The quantification of nitrogen applied to the field and the methane and energy potential production, derived from the consistency and composition of the herds in the study area.
3) Trend analysis of buffalo farming, based on previous data.
4) Definition of the focus areas (FA), which are regional areas with potentially high concentrations of nitrogen applied to the field.
5) Definition of energy potential requirements for the N treatment and energy potential from livestock manure valorisation.

2.3. Creation of the geodatabase

In this phase, different data were collected for the geodatabase design. Specifically, the Buffalo database was obtained from the Italian National Zootechnical Register

(INZR). It reports different information for each farm, such as type of housing, type of products (i.e., milk, meat, etc.), number of total heads and the number of heads for each age class. Moreover, it indicates farm geographic coordinates expressed in WGS 84 reference.

Administrative boundaries and Nitrates Vulnerable Zones (NVZ) were obtained from the Campania region website (https://sit.2.regione.campania.it/content/download). All data were transformed to World Geodetic System 1984 (WGS 1984) Universal Traverse Mercator (UTM) Zone 33 projected coordinate system to preserve the integrity of the spatiotemporal analyses.

2.4. N quantification and Methane and energy potential production

In order to quantify the potential N produced from buffalo farming, a specific algorithm was used [3] in Microsoft Excel:

$$N_t = \sum (n_a \cdot N_a)_i \,, \tag{1}$$

where N_t is the estimated nitrogen to the field, (t y^{-1}); n is the number of animals; N is the nitrogen per year to the field (t y^{-1}); a is the animal age (younger than 6 months, between 6 months and 1 year or older than 1 year); and i is the production orientation/type of production in a function of age.

Table 2 of Italian Ministerial Decree 5046/2016 concerning the Nitrogen produced by livestock, was employed for the value of nitrogen produced by buffalo head according to the age and the housing system.

The potential methane produced from buffalo manure and slurry was evaluated by means of the following equation [10]:

$$GM = Y_m \cdot A_b \cdot G_m \,, \tag{2}$$

where GM is the methane production in one year (Nm^3 CH_4 y^{-1}); Y_m is the methane yield from fresh buffalo manure (Nm^3 CH_4 kg$_{\text{fresh manure}}^{-1}$); A_b is the availability factor of fresh buffalo manure (%) [10] and G_m is the is manure production in one year of a specific farm (kg$_{\text{fresh manure}}$ y^{-1}).

The Electric generation potential (kW h y^{-1}) is calculated with equation (3) [10]:

$$EP = GM \cdot LHV \cdot n \cdot D \,, \tag{3}$$

where LHV is lower heating value of the CH_4 than 13.69 kW h kg^{-1}; n is the conversion efficiency value of 0.28 that is the result of the combination between gas engine (30–40 %) and generator (80 %) efficiency and D is methane density of nearly 0.657 kg m^{-3}.

2.5. Trend analysis

Buffalo consistency and composition, and farm location were analysed and compared between 2013 and 2019, in order to determine the buffalo farming trend.

2.6. Definition of the Focus Areas and N surplus

Focus Areas (FA) are the areas with potentially high concentrations of nitrogen applied to the field, which can exceed the maximum N load, established from the Nitrate Directive. For this reason, these areas are potentially more affected by environmental issues related to N losses and where to concentrate the mitigation strategies. For their determination, the Kernel Density tool of ArcMap ESRI® GIS was used [3]. The FA can act as a guide for identifying an area with an N management issue, whether it is site N removal or recovery treatment plants. In order to find the most proper KD classification methods, three methods were applied and three ranges of values were considered, i.e. low, medium and high N values areas:

i) defined interval (DI) classification, which divides the range of values into 3 classes (0-170, 170-340, >340 kg N/ha);
ii) quantile (Q) classification, which divides the classes considering the same number of features;
iii) natural breaks (NB) classification, which maximizes the differences between classes and minimizes the within-class differences [3].

Moreover, the N load on these areas was calculated by intersecting them with the suitable areas for spreading. To build this layer, the Corine Land Cover 2018, 3rd level classification was integrated with the Campania Region land use map, that is CUAS 2009 Map (scale 1: 50,000) and the Nitrates Vulnerable Zones (NVZ). Specifically, only the agricultural areas were considered. Moreover, the following limitations were applied according to DGR n. 585/2020 of Campania Region (Table 2).

Table 2. Areas not suitable for spreading.

Nitrates Vulnerable Zones	Common Zones
2.1.3 (Rice field) – Corine Land Cover	2.1.3 (Rice field) – Corine Land Cover
< 10 m from surface water courses	< 10 m from surface water courses
< 100 m from urban settlements	< 100 m from urban settlements
< 30 m from lakes and coastal areas	< 10 m from lakes and coastal areas
< 10 m from roads	< 10 m from roads
Land with a slope greater than 10 %	Land with a slope greater than 10 %

2.7. Energy potential from livestock effluents and Energy required for the N treatment

After the FA definition, N load, GM and EP were estimated for each of them. Finally, it was evaluated the energy consumption for surplus N removal, by referring to the energy required per kg N removed from some treatments in the literature [15]. Among them, nitrification/denitrification (N/D) Anaerobic ammonium oxidation - anammox (A) are usually used to remove nitrogen from wastewater, mostly requiring energy for the aeration of the liquid matrix. A is similar to N/D and involved microorganisms that convert NH_4^+ to N. Electrodialysis (ED) is generally applied for desalination purposes by means of the use of electric current and ion-permeable membranes.

3. RESULTS AND DISCUSSION

3.1. Trend analysis (2013-2019)

Table 3 and Table 4 summarize buffalo consistency in the region and in the NVZ. By analysing the dataset of 2013 and 2019, some interesting aspects arose. The number of farms decreased in recent years, but the number of heads increased.

On the other hand, in 2019 more farms (81 % of the total) are involved in the NVZ, which has doubled their extension.

3.2. Definition of the Focus Areas and N surplus

Figure 2 shows the three different KD classification methods for 2019 with medium and high N values areas. The number of involved farms is 464, 1016 and 1310, for DI, NB and Q, respectively. These areas correspond to 40 %, 84 % and 100 % of the total N of buffalo origin of the Campania region. In this context, Q (Figure 2c) did not allow a proper definition of the

Table 3. Buffalo farms' characteristics in 2013 and 2019.

Parameter	2013	2019
Farms	1,757	1,317
Heads	285,058	291,722
Farms with heads > 500	94	125
Farms with heads > 200	425	540
N production (t y^{-1})	$14.2 \cdot 10^3$	$14.4 \cdot 10^3$
GM (m^3 y^{-1}), Nm^3 CH_4	$112 \cdot 10^6$	$114 \cdot 10^6$
EP (GW h y^{-1})	282	286

Table 4. Buffalo farms' characteristics in NVZ in 2013 and 2019.

Year	N. Farms	N. Heads	N production (t y^{-1})	Area (ha)
2013	177	32,898	$1.6 \cdot 10^3$	150,599
2019	1,062	241,097	$11.9 \cdot 10^3$	316,692

focus areas since it included all the areas where the farms are located. For this reason, the Q classification method was not considered in further evaluations of this study.

The higher detail of DI and NB allowed identifying focus areas (which include both the medium and high values areas highlighted in Figure 2a and Figure 2b) with a total N surplus, which corresponds to 55 % (3205 t N y^{-1}) and 6 % (758 t N y^{-1}), respectively. This resulted from the intersection of the KD areas with NVZ and regional land cover (Figure 3), corresponding to the regional lands which are suitable for manure spreading. These lands represent 15302 and 62062 ha in the DI and NB focus areas, respectively (Figure 4). As consequence, the amount of N that can be spread on the available lands located in the focus areas is 2620 and 11360 t N y^{-1} for DI and NB, respectively. Moreover, as shown in Figure 4, the major part of both focus areas falls into the NVZ, specifically 99 % and 92 % for DI and NB, respectively. This result suggests the effectiveness of the Kernel analysis in identifying the areas characterized by a higher probability of having a huge N load, where consequent environmental issues could occur, such as nitrate leaching.

Overall, the regional lands which are suitable for manure spreading account for 21 % (284176 ha) of the entire Campania surface and they are located mainly in the provinces of Caserta and Salerno.

3.3. Energy potential from livestock effluents and Energy required for the N removal in NVZ in 2019

By hypothesizing to treat 50 % of the total amount of buffalo manure in focus areas (DI and NB) in 2019 with AD, it is possible to use a portion of the energy potential production for the N surplus removal with three different treatments: electrodialysis (ED), denitrification (N/D), and anammox (A) (Table 5).

These findings suggest that N/D proved to be the most energy-requiring compared to A and ED. Nonetheless, in both

Table 5. The electrical energy (EE) required for N surplus removal in 2019.

Parameter	DI	NB
EE N/D (GW h)	11.3	2.7
EE A (GW h)	4.6	1.1
EE ED (GW h)	7.6	1.8
Energetic surplus N/D	80 %	98 %
Energetic surplus A	92 %	99 %
Energetic surplus ED	87 %	99 %

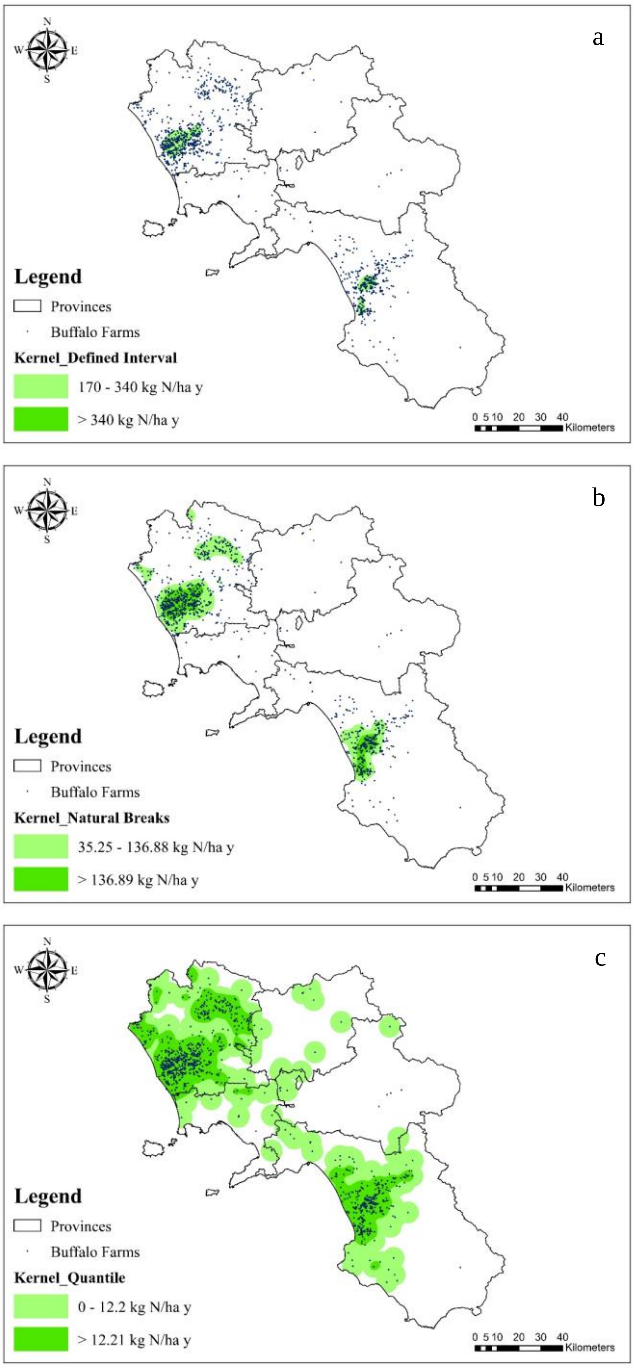

Figure 2. KD classification methods for 2019: (a) Defined Interval, (b) Natural Breaks, (c) Quantile.

DI and NB, the theoretical energy produced by AD is sufficient for the manure treatment, showing a remaining EE higher than 80 %. On the other hand, using treatments allowing a lower energy consumption, together with N recovery, is needed for more sustainable livestock breeding.

4. CONCLUSIONS

This study aimed at supporting the buffalo manure management in the Campania region, by identifying focus areas with potentially high concentrations of nitrogen applied to the field, where it is necessary to find other available spreading lands or to concentrate the N removal treatments. To this purpose, three KD classification methods were compared: DI, NB and Q.

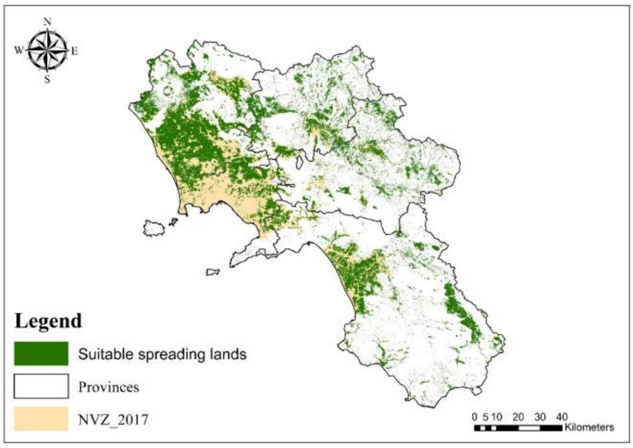

Figure 3. Suitable lands for manure spreading in 2019.

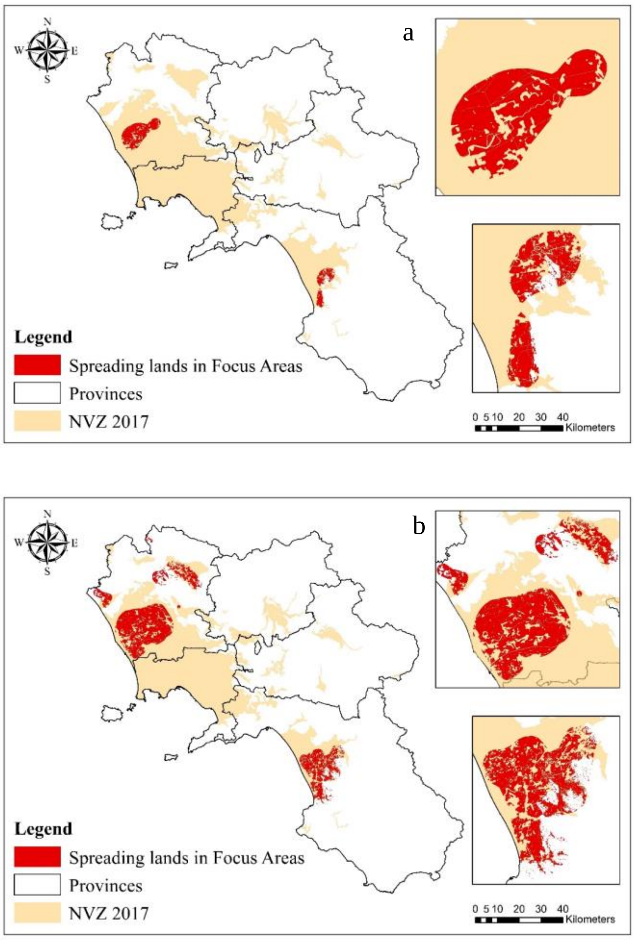

Figure 4. Spreading lands in the Focus areas for 2019: (a) Defined Interval, (b) Natural Breaks.

Q did not allow a proper definition of the focus areas since it included all the areas where the farms are located. Whereas 40 % and 84 % of the total N of buffalo origin of the Campania region fall into DI and NB areas, with a surplus of N by 55 and 6 %, respectively. This means that the resulting N surplus of 3205 (DI) and 758 (NB) t N y^{-1} needs to be managed. One possibility is manure application into the fields outside the focus areas, taking into account the manure transport feasibility and the suitable lands for manure spreading, which are affected by different factors: land cover and the related maximum N per crop, NVZ limitations and the presence of other livestock breeding. On the other hand, another option is the manure treatment adoption for the removal of the N surplus in the focus areas. In this case, assuming to treat with AD process 50 % of the total amount of buffalo manure in these areas, the resulting biogas production is sufficient to allow the removal of the N surplus evaluated in these areas with one of the following treatments: N/D, ED and A.

This paper presents an analysis methodology and problem quantification to support proper manure management, which can apply to higher scales and include more livestock species.

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