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RECOVERY OF SEWAGE SLUDGE ON AGRICULTURAL LAND IN LOMBARDY: CURRENT ISSUES AND REGULATORY SCENARIOS

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Abstract

Issues concerning the treatment and the recovery/disposal of sludge derived from the municipal WWTPs (Wastewater Treatment Plants) are gaining importance both in Italy and abroad. In Lombardy Region this aspect is particularly relevant due to both the amount of sludge produced and its remarkable reuse in agricultural soils. This paper discusses different strategies for land application of sludge in order to provide technical and regulatory guidance at regional level. The work is based on a survey concerning qualitative and quantitative characteristics of sewage sludge (derived from WWTPs and sent to Sludge Treatment Plants – STPs – authorized for the treatment on behalf of third parties) reused for agricultural application. Then, the effects of six different regulatory scenarios (considering the rules of the European Commission, national legislation and the laws of regions neighbouring to Lombardy) on the qualitative characteristics of sludge reused in agricultural soils have been evaluated. The results of this work have been incorporated into regional guidelines that were approved with Decree of Regional Government (DGR) n. X/2031 dated 1 July 2014. On the basis of this work, the principles of the regional guidelines are: 1) improvement in the quality of the sludge spread on agricultural land; 2) protection of the high-quality sludge (ingoing to the STPs), avoiding its mixing with other sludge suitable for agricultural reuse, but with qualitative characteristics closer to the regulatory limits; 3) minimization of the problems concerning the odour emissions (one of the main critical issue).

Key words: agricultural use, heavy metals, Regional Guidelines, sewage sludge

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1. Introduction

In Europe, the yearly production of sewage sludge is estimated at 10.13 million tons of dry matter; about the 40% is reused in agricultural soils (European Commission, 2010). The situation varies a lot among Member States: in some countries such as Denmark, France, Ireland, Spain and United Kingdom, over 50% of the sludge produced is spread on agricultural land, while in Belgium, Romania, the Netherlands and Greece this percentage equals zero. The incineration is the main alternative for sludge management in the EU15 States (Member State that joined the EU before 2004), while in the remaining countries the landfill is still the main destination for these wastes. The choice of recovery/disposal routes is influenced by the costs of different options; at European level the reuse in agriculture is around an average value of 44€/$t_{wet\ sludge}$ (transport included), while landfilling and incineration costs (always considering the transport) are 88 and 91€/$t_{wet\ sludge}$ respectively (Foladori et al., 2010).

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The issue of sludge management should be solved with several actions in different directions: the basic principles of European legislation on waste (EC Directive, 2008) transposed in Italy (Italian Decree, 2006, and subsequent modifications) provide, on priority scale, interventions aimed at waste prevention (e.g. reducing production at source), recovery (of matter and energy) and safe disposal.

As concerns the *sludge prevention*, several innovative technologies are available (Fytili and Zabaniotou, 2008): some processes are already present in the market and many treatments are being tested (Chu et al., 2009; Feng et al., 2009; Liu, 2003; Montusiewicz et al., 2010; Saby et al., 2003; Song and Hu, 2006; Tokumura et al., 2009; Wan et al., 2014; Zábranská et al., 2006). In particular, the minimization technologies applied on the sludge line of Wastewater Treatment Plants (WWTPs) are promising and could be used due to the high level of reliability with respect to technologies applied in the water line of WWTPs. Moreover, the biological treatments with very low sludge production (e.g. thermophilic aerobic membrane reactor, anaerobic biological processes etc.) seem to be very interesting (Bertanza et al., 2010; Collivignarelli et al., 2014).

Regarding *matter recovery*, the sludge can be reused in agricultural soils both with preventive hygienization treatment (with the use of alkaline reagents) and after a composting process (Zaha et al., 2011). There are many actions, mainly proposed by Control Bodies and Standardization Organizations, aimed at assessing the effects of this practice and at "renewing" the existing legislation, to ensure that the sludge recovery can be carried out with minimal risks for human beings and the environment (Piccinini and Centemero, 2007).

In terms of *energy recovery*, the innovative technologies (gasification, pyrolysis etc.) with important industrial applications (Dominguez et al., 2006; Nipattummakul et al., 2010; Sanin et al., 2008) are added to the conventional processes of incineration and the use of dried sludge as an alternative fuel in industrial kilns (e.g. for cement production).

Finally, as far as *landfill disposal* is concerned, it will be foreseen only for residues derived from the treatment for sludge recovery.

The *agricultural reuse* of sludge (directly or after composting) is an efficient solution to the problem of landfill disposal and becomes more interesting in terms of agronomic and economic effectiveness. The use of good-quality sludge has positive effects such as the supply of partially stabilized organic matter and the addition of macro-nutrients present mainly in organic form (and therefore with a slow release). However, the sludge contains heavy metals and poorly biodegradable trace organic compounds (Manea et al., 2013; Suciu et al., 2014) that can accumulate in the soils, even if some of them (such as copper and zinc), in small doses, could improve the biological cycle of the crops.

The spreading of sludge in agricultural soils has to be carried out in compliance with the legislation: (Directive 86/278/CEE at European level, transposed in Italy with Legislative Decree 99/92) in order to avoid any risk for the environment and the health of the population (EC Directive, 1986; Italian Decree, 1992). Many experiments carried out in Italy by Control Bodies have shown, after several years of sewage sludge application on agricultural soils with different crops (especially rice), an excellent nutrient effect (Gaskin et al., 2012; Najafi and Abbasi, 2013; Romani et al., 2013); nitrogen is also available throughout the crop cycle. The contribution of sewage sludge on agricultural land reduced the effect of organic matter loss in the soil (Mantovi et al., 2005), that, especially in southern Europe, is becoming a problem (Rusco et al., 2001), with the consequent increase in soil fertility.

In 2010, the sludge production in Italy was equal to 1.1 million tons of dry matter; the percentage of the sludge reused for agricultural applications has reached about 30% of total production (data reported in "Sewage sludge production and disposal from urban wastewater (in dry substance (d.s.))" Eurostat table – (Eurostat, 2015).

At regional level, the situation varies considerably: there are some regions, such as Liguria, Valle d'Aosta, Calabria and Marche, where the agricultural reuse of sludge is not implemented, while in other regions, such as Lombardy, Emilia Romagna, Puglia, Tuscany and Veneto where this practice is highly developed: these five regions spread in agricultural soils more than 90% of the total quantity reused in Italy for agricultural applications (ISPRA, 2013).

As concerns the Lombardy Region, the sludge produced was approximately equal to 800000 t/year "as it is". About 50% derives from WWTPs that treat municipal wastewater, 30% from WWTPs for industrial wastewater treatment and 20% from WWTPs of industry (especially food companies). Fig. 1 shows that over 50% of sewage sludge produced in Lombardy was reused in agricultural soils (R10): overall, the amount of sludge spread in agricultural land in Lombardy, between 2007 and 2010, is equal to an average value of 700000 t/year "as it is", corresponding to 116000 t/year of dry matter (about 330000 t/year "as it is" equal to 63000 t/year of dry matter in Pavia province). It is important to note that the plants on behalf of third parties (called Sludge Treatment Plants – STPs) located in Lombardy (that receive sludge from WWTPs for spreading in agricultural soils after suitable treatments), in addition to sewage sludge produced in the region, receive an additional quantity from other regions (mainly in the Po Valley); this value represents 50% of the total sludge for agricultural reuse in Lombardy.

As sludge is classified as a non-hazardous special waste, there is no legal ground to regulate such dynamics in the EU.

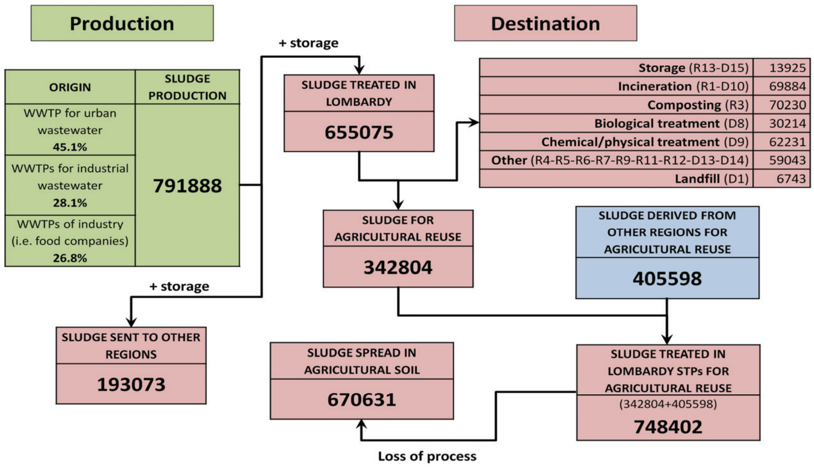

Fig. 1. Management of sewage sludge in Lombardy (2010) (all values are expressed in tons of raw sludge per year)

The Lombardy Regulation on the public utilities is the Regional Law 26/2003, that concerns the agricultural reuse of sewage sludge, has undergone two changes, through the Regional Laws 12/2007 and 7/2012. According to these regulations, the Regional Departments for the Environment, Territory and Agriculture began a process for the drafting of technical guidelines reported in DGR n. X/2031 (1 July 2014), replacing the previous DGR n. 7/15944/2003 (Lombardy Region, 2003; Lombardy Region, 2014).

The aim of the present work is to study the issues concerning agricultural reuse of sludge with the proposal of different intervention strategies. First, the qualitative and quantitative characteristics of sewage sludge reused in the Lombardy agricultural soils were analyzed (in particular, the concentrations of pollutants were compared with the limit values provided in DGR n. 7/15944/2003, in force before the publication of DGR X/2031/2014) (Lombardy Region, 2003; Lombardy Region, 2014). This phase was aimed to identify the issues regarding the recovery of sludge on agricultural land in Lombardy. Then, in order to identify the correct environmental strategies, six different regulatory scenarios were studied: the scenario effects on the qualitative characteristics of sludge reused in agricultural soils has been evaluated; particular attention has been paid to the odour emissions.

This work has highlighted some critical aspects related to reuse of sewage sludge, especially in Lombardy; moreover, it has been used as support for the drafting of DGR n. X/2031 (1 July 2014) (Lombardy Region, 2014).

2. Case study

2.1. Data collection

In order to analyze the characteristics of sewage sludge reused in agricultural land, a survey was performed; this investigation was carried out involving nine STPs (located in Lombardy) authorized for the treatment of sludge derived from WWTPs (public and/or private). In particular, we have elaborated over 2000 chemical analyses (ingoing and outgoing from STPs) obtained from Lombardian plants operating on behalf of third parties; these data regards the last five years. The considered STPs have treated an amount of sludge up to over 80% of the total sludge spread on agricultural land in Lombardy: so, the elaborations carried out are certainly representative of the regional situation.

2.2. Criteria for data elaboration

The data obtained during the survey regard heavy metals (arsenic, cadmium, hexavalent chromium, total chromium, mercury, nickel, lead, copper and zinc), microbiological parameters (fecal coliforms, Salmonella and viable helminth ova) and agronomic characteristics of the sludge (organic carbon – C_{org}, Total Phosphorus – TP and Total Nitrogen – TN). For each parameter, we calculated the percentiles (10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th}) and the mean; the standard deviation (σ) and the coefficient of variation (σ^*) were also calculated in order to evaluate the scattering of the results.

The results (concerning the sludge ingoing and outgoing from STPs) were compared with the regulatory limits reported in DGR n. 7/15944/2003 (in force, in Lombardy, before the publication of DGR X/2031/2014), in order to show any excesses (Lombardy Region, 2003; Lombardy Region, 2014).

3. Results and discussion

3.1. Survey results

3.1.1. Heavy metals, agronomic and microbiological parameters

In Table 1 the characteristics of sewage sludge ingoing and outgoing from STPs are shown. In particular, the content of heavy metals, the values of agronomic and microbiological parameters are reported; for each parameter minimum, mean, maximum and coefficient of variation (σ*) are shown.

Heavy metal concentrations that concern the sludge ingoing and outgoing from STPs are reported in the box plots shown in Figs. 2 and 3. In particular, for each parameter, the gray box represents the concentrations between the 10^{th} and 90^{th} percentiles; the spacing between the different parts of the box indicates the degree of dispersion (scattering); the lower and upper values outside the box represent minimum and maximum concentrations respectively. Furthermore, for each parameter, the regulatory limit (according to DGR n. 7/15944/2003) is reported (Lombardy Region, 2003).

The sludge ingoing to STPs showed average qualitative characteristics (in terms of heavy metals content) suitable for spreading in agricultural soils; nevertheless, some samples present remarkable excesses over threshold limit for arsenic, nickel, zinc and total chromium (as defined by Lombardy DGR n. 7/15944/2003). Furthermore, the STPs and their equipments do not allow the removal of heavy metals. The results of coefficients of variation (σ*) show that the variability of metal concentrations in the input sludge is very high; in the sludge reused in agricultural soils (outgoing from STPs) the scattering is generally reduced, in some cases significantly (Table 1).

The sludge derived from the WWTPs that treat municipal wastewater (classified with European Waste Code – EWC – 19 08 05) has concentrations of arsenic, nickel, mercury and cadmium significantly higher than other kinds of sludge (derived from biological treatment of industrial wastewater – EWC 19 08 12 – and from the treatment of textile industries, processing of paper and paperboard effluents).

As concerns the *agronomic parameters*, 5% of the samples ingoing to STPs do not meet the minimum content of organic carbon required by the regulation for reuse in agriculture. Moreover, the sludge outgoing from STPs shows concentrations of organic carbon and total nitrogen slightly lower than the sludge ingoing due to the effect of hygienization by means the use of alkaline reagents (Fig. 4). As regards the content of TP minor differences were observed between the ingoing and outgoing sludge treated by STPs.

As regards the *microbiological parameters* in the sludge ingoing to STPs the contents of Salmonella and especially of fecal coliforms usually exceed the regulatory limits; so the treatment of hygienization is needed.

The values obtained in the inactivation of microorganisms varied from 3 to 4 log for fecal coliforms and between 1.9 and 2.6 log for Salmonella.

Table 1. Characteristics of sludge ingoing and outgoing from STPs: results of survey (the bold values do not comply with DGR 7/15944/2003) (Lombardy Region, 2003)

	Parameter	*DGR* 7/15944/ 2003 limit values*	*Sludge ingoing to STPs*					*Sludge outgoing from STPs*				
			Minimum [mg kg_{SS}^{-1}]	*Mean [mg kg_{SS}^{-1}]*	*Maximum [mg kg_{SS}^{-1}]*	*σ**	*Number of exceeding/ number of analysis*	*Minimum [mg kg_{SS}^{-1}]*	*Mean [mg kg_{SS}^{-1}]*	*Maximum [mg kg_{SS}^{-1}]*	*σ**	*Number of exceeding/ number of analysis*
HEAVY METALS	As	10	0.01	5.9	**50**	2.7	166/1452	0.02	3.9	10	0.7	0/526
	Cd	20	0.01	1.2	17	1.4	0/1451	0.01	1.4	11	1	0/664
	Cr_{tot}	750	0.05	104	**1574**	1.3	7/1453	0.05	89	469	0.9	0/660
	Cr(VI)	10	0.01	0.3	5	1	0/612	0.01	0.5	5	1.2	0/564
	Hg	10	0.01	1.3	**14**	1.3	8/1096	0.01	1	10	1.3	0/663
	Ni	300	0.05	61	**1430**	1.5	33/1455	0.04	58	245	0.7	0/667
	Pb	750	0.05	78	**1163**	1.2	2/1454	0.10	62	432	0.9	0/668
	Cu	1000	2	317	**1350**	0.6	9/1456	1	282	908	0.7	0/668
	Zn	2500	5	757	**4718**	0.7	12/1459	19	675	2490	0.7	0/667
AGRONOMIC PARAMETERS	*Parameter*	*DGR* 7/15944/ 2003 limit values*	*Sludge ingoing to STPs*					*Sludge outgoing from STPs*				
			Minimum [$\%_{SS}$]	*Mean [$\%_{SS}$]*	*Maximum [$\%_{SS}$]*	*σ**	*Number of exceeding/ number of analysis*	*Minimum [$\%_{SS}$]*	*Mean [$\%_{SS}$]*	*Maximum [$\%_{SS}$]*	*σ**	*Number of exceeding/ number of analysis*
	C_{org}	20^	**2.2**	33	82	0.3	35/680	20	30	54	0.2	0/571
	TN	1.5^	**0.3**	5.2	45	0.5	6/684	**0.4**	4.4	30	0.6	3/571
	TP	0.4^	**0.01**	1.8	10	0.7	16/689	**0.3**	2.4	27	1.1	1/571
MICROBIOLOGICAL PARAMETERS	*Parameter*	*DGR* 7/15944/ 2003 limit values*	*Sludge ingoing to STPs*					*Sludge outgoing from STPs*				
			Minimum [MPN g_{SS}^{-1}]	*Mean [MPN g_{SS}^{-1}]*	*Maximum [MPN g_{SS}^{-1}]*	*σ**	*Number of exceeding/ number of analysis*	*Minimum [MPN g_{SS}^{-1}]*	*Mean [MPN g_{SS}^{-1}]*	*Maximum [MPN g_{SS}^{-1}]*	*σ**	*Number of exceeding/ number of analysis*
	Fecal coliforms	10000	0	**$4 \cdot 10^6$**	**$1500 \cdot 10^6$**	14.4	429/683	2	4200	**150000**	2	4/496
	Salmonella	100	0	**531**	**46000**	6.6	81/687	0	7	100	3.1	0/567

^ as lower limit; σ means "coefficient of variation"; "MPN" means "Most Probable Number"(DGR*: Lombardy Region, 2003)*

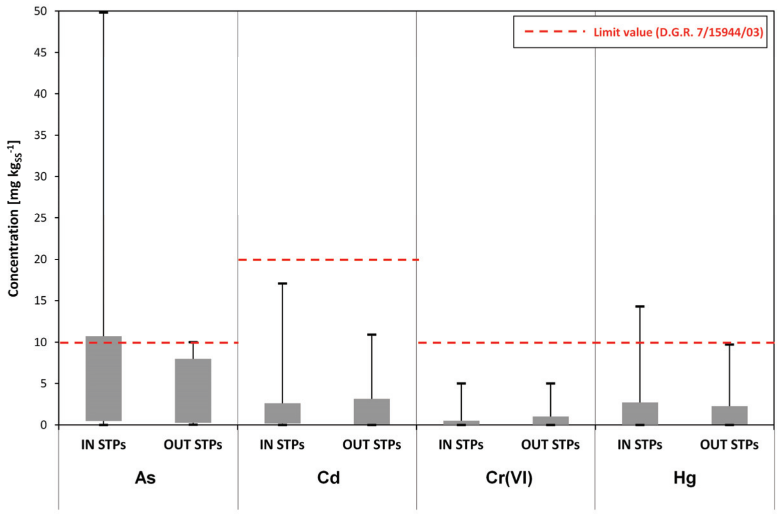

Fig. 2. Sludge ingoing (IN STPs) and outgoing (OUT STPs) from STPs: concentrations of As, Cd, Cr(VI), Hg

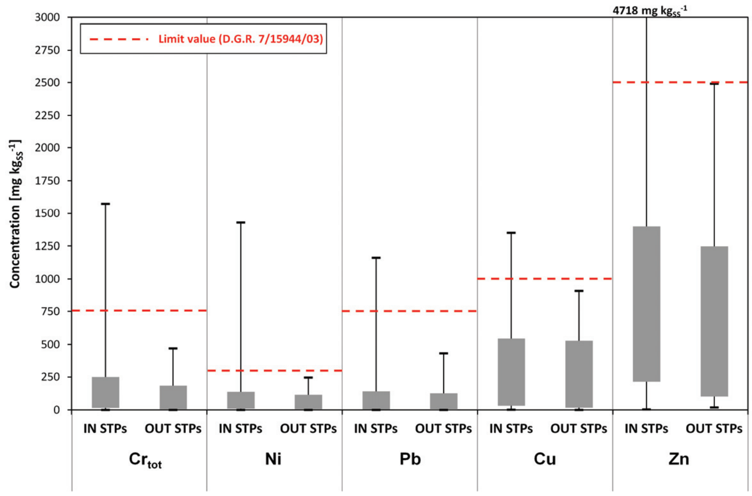

Fig. 3. Sludge ingoing (IN STPs) and outgoing (OUT STPs) from STPs: concentrations of Cr_{tot}, Ni, Pb, Cu, Zn

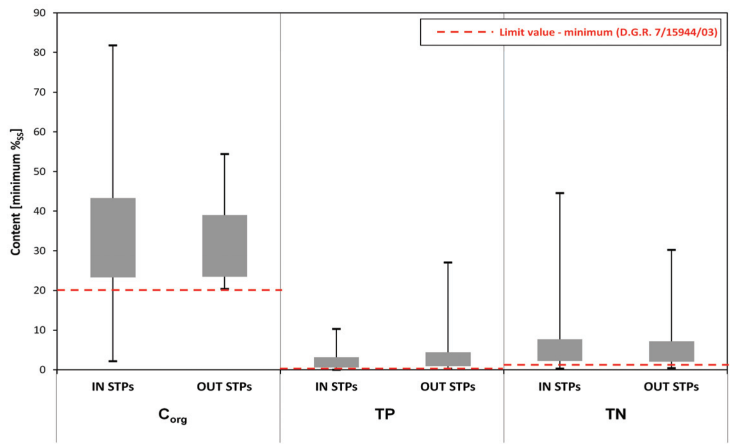

Fig. 4. Sludge ingoing (IN STPs) and outgoing (OUT STPs) from STPs: content of C_{org}, TP and TN

3.1.2. Sludge stabilization

In order to assess the *degree of sludge stabilization*, the percentage of volatile suspended solid (VSS) with respect to the total suspended solid (TSS) was calculated; this ratio (indicated by VSS/TSS) provides an evaluation of the sludge stabilization. The sludge is defined "stabilized" when it does not cause harmful effects on the environment due to biological transformation that occur in itself. The stabilization procedures commonly reduce putrescibility and odour, pathogenic microorganisms and VSS content.

In Fig. 5 the comparison between the VSS/TSS of sludge ingoing and outgoing from STPs is shown. It may be noted that the sludge ingoing to STPs is slightly stabilized (with a mean value of VSS/TSS equal to 68%); after the mixing/hygienization operation carried out into STPs, an average value of VSS/TSS equal to 58% is achieved. It is important to note that about 35% of sludge spread in agricultural soils has a ratio VSS/TSS higher than 60%.

As concerns the "weighted average" (calculated considering the amounts of sludge ingoing to STPs and their VSS/TSS values) a value of about 61% is obtained: in fact, the high quantities of sludge derived from medium-large size WWTPs are generally well-stabilized (low VSS/TSS), while the sludge with high values of VSS/TSS derives from small size WWTPs, that generally are equipped with sludge treatments (when present) poorly or not effective in terms of putrescibility reduction.

The control of this parameter is more important in order to reduce odour emissions: therefore, it is essential to provide stabilization treatments aimed at reducing the original characteristics of putrescibility and the odour issue. From technical point of view, several conventional and advanced treatments are available: they are based both on biological and chemical processes (Working Document on Sludge – 3rd Draft, 2000). In the biological stabilization processes, reduction of sludge putrescibility is achieved by means the removal of volatile solids; chemical stabilization, however, reduces the putrescibility through the inhibition of biological reactions by raising the pH up to 12 (for example with the use of lime). In this case, the effects of stabilization are temporary, because the carbonation of the lime by atmospheric CO_2 causes the progressive pH reduction, with a possible reactivation of the bacteria. In addition, the odours can be significantly reduced with appropriate management practices; for example, injection or incorporation of sewage sludge within 24 hours is recommended (Krogmann et al., 2001).

3.1.3. Critical issues obtained from survey

In summary, the results of the survey suggest the issues discussed below.

A. As concerns the sludge ingoing to STPs, acceptance criteria were not provided. Moreover, the equipments currently available in STPs are not able to remove heavy metals; in this case, the most critical pollutants are zinc and nickel.

B. The sludge ingoing to STPs has high variability in terms of qualitative characteristics. Moreover, an amount of high-quality sludge (especially in terms of low metal content) was sent to STPs. However, the mixing/hygienization operations carried out in STPs led to a "dilution" of high-quality sludge with the other sludge suitable for agricultural recovery, but with a worst quality.

C. The issue concerning the odour emissions is very relevant: more than one-third of sludge spread in agricultural land showed a VSS/TSS ratio higher than 60%. So, the reduction of VSS should be improved both for the WWTPs and for STPs.

D. As concerns the organic pollutants, no limit values were provided.

3.2. Analysis of different strategies and actions proposed

In order to contain the exceeding of regulatory limits for some heavy metals (issue A), it is appropriate to introduce *controls on sludge ingoing to STPs*. The acceptance criteria proposed (see Table 2) are based on thresholds for heavy metals in sludge provided by Legislative Decree 99/92 (Italian Decree, 1992), but taking into account tolerances of 10 or 20%, depending on pollutants. The tolerance values are related to: bioaccumulation, carcinogenicity of pollutants and quality of agricultural soils in Lombardy available for sludge application (Vitali et al., 2011).

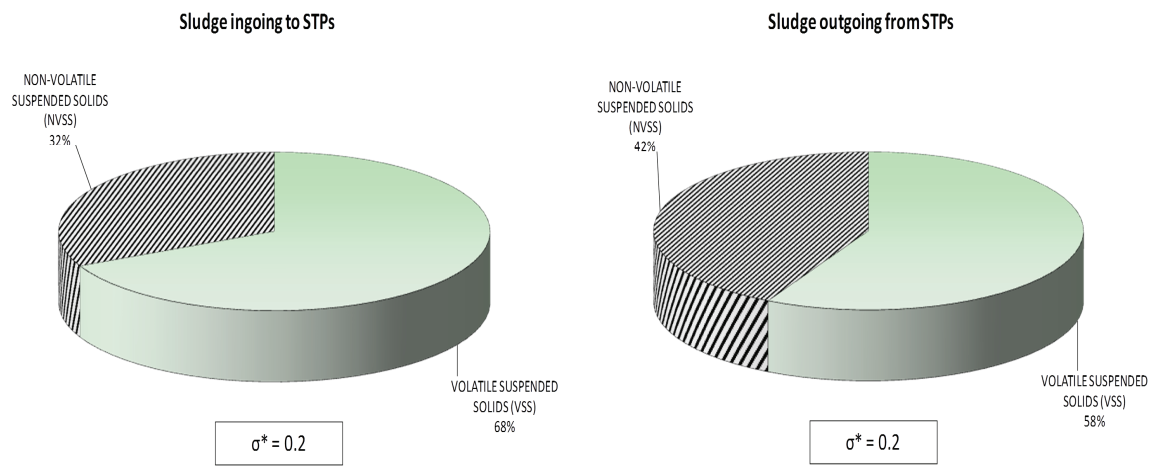

Fig. 5. Sludge ingoing and outgoing from STPs: VSS average content

The application of this criteria shows that almost all the sludge ingoing to STPs complies with the limit values proposed (Table 2).

As concerns the protection of high quality sludge ingoing to STPs (issue B), the different kinds of sludge should be diversified: this operation is provided in order to avoid the "dilution" of *high-quality sludge* with the *sludge with worst qualitative characteristics* but suitable for agricultural recovery. Thus, six policy strategies, based on different regulatory scenarios, were studied; their limits (regarding heavy metals and organic pollutants) are reported in Table 3.

Scenario 1 shows the limit values (for heavy metals only), equal to 1/5 of those considered in the Lombardy Region (2003): this option was provided by the legislation in case of sludge reuse (only for biological sludge derived from food industry) with a specific amount (per hectare of soil) three times higher than allowed. As concerns scenarios 2 and 3 two different options were evaluated (option 2 "moderate changes" and option 3 "more significant changes") provided by Working Document Sludge and Biowaste (European Commission, 2010); scenario 4 is based on Working Document on Sludge – 3rd Draft (European Commission, 2000).

Finally, two last scenarios are referred to the limit values of two regions near to Lombardy (Veneto and Emilia Romagna) in which the sludge recovery in agriculture is a common practice (ARPA Veneto, 2006). Based on the sludge quality survey carried out, the policy strategies were applied on the sludge outgoing from STPs. The results obtained are shown in Table 4; in particular, the percentages of sludge within the limit values provided by the different scenarios (only for heavy metals) are reported. The percentages values lower than 50% are highlighted.

In order to improve the quality of sludge in agricultural soils, "high-quality sludge" should be separate from "sludge suitable for spreading". This important aspect was adopted in DGR n. X/2031/2014 (Lombardy Region, 2014). As concerns the limit values of heavy metals, for high-quality sludge, scenario 3 (with the addition of arsenic reported in DGR n. 7/15944) was chosen (Lombardy Region, 2003). For other sludge suitable for reuse in agriculture, the limit values were provided in DGR n. 7/15944/2003 with the exception of As and Cr(VI) (that were deleted) (Lombardy Region, 2003).

Furthermore, in order to *contain the odour emissions* (issue C), limit values of VSS/TSS ratio were provided, both in high-quality sludge and in other sludge suitable for agricultural reuse; the limit thresholds are 60% and 65% respectively. According to the European disposition, the limit values of *organic pollutants* (issue D) were introduced. For all sludge spread in agricultural soil, scenario 2 was chosen; moreover, for PCDD/F, the limit value chosen is reported in DGR n. 2241/2005 of Veneto.

Summary, in Fig. 6 a flow diagram (*considering heavy metals only*) based on the evaluation carried out in the present work are shown. Heavy metals were considered because they represent the most critical parameters and cannot be controlled with the current equipments of STPs. According to DGR n. X/2031/2014, the acceptance criteria involve an amount of 1% of sludge that could not be sent to STPs for land application (Lombardy Region, 2014). Moreover, only considering heavy metals, the sludge reused in agricultural soils is divided into "high-quality sludge" and "sludge suitable for spreading": the partitioning is shown in Fig. 6. The critical parameters are nickel and zinc (Table 4).

4. Conclusions

In this study a methodological approach for regulatory planning concerning the use of sewage sludge for land application is reported. The case study is Lombardy, where sewage sludge reused in agriculture is very relevant. In fact, about 40% of sewage sludge (corresponding to 116000 t/year of dry matter) reused in Italy for land application is spread in the agricultural soils of Lombardy. The survey concerning the qualitative and quantitative characteristics of sludge reused in agriculture allowed the identification of several issues that were faced as follow:

Table 2. Acceptance criteria for sludge ingoing to STPs and percentages (by weight) of sludge within the limit values proposed

Parameter	***Measurement unit***	***Limit value for sludge ingoing to STPs***	***Sludge ingoing to STPs within the limit values [weight %]***
HEAVY METALS			
Cd	[mg kg_{SS}^{-1}]	≤22	100
Hg	[mg kg_{SS}^{-1}]	≤11	99.4
Cr_{tot}	[mg kg_{SS}^{-1}]	≤900	99.7
Ni	[mg kg_{SS}^{-1}]	≤330	98.9
Pb	[mg kg_{SS}^{-1}]	≤900	99.7
Cu	[mg kg_{SS}^{-1}]	≤1200	100
Zn	[mg kg_{SS}^{-1}]	≤3000	99.1
AGRONOMIC PARAMETERS			
C_{org}	[$\%_{SS}$]	>10	98.7
TN	[$\%_{SS}$]	>1	99.6

Table 3. Policy strategies evaluated in the present work

Parameter		Measurement unit	Limit values		SCENARIO1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5	SCENARIO 6
			Legislative Decree 99/92	*DGR 7/15944/ 2003*	*(1/5 of DGR 7/15944/2003 limit values)*	*(Option 2 Working Document Sludge and Biowaste)*	*(Option 3 Working Document Sludge and Biowaste)*	*(Working Document on Sludge 3rd Draft)*	*(DGR 285/2005 Emilia Romagna)*	*(DGR 2241/2005 Veneto)*
Heavy metals	As	$[mg\ kg_{SS}^{-1}]$	-	≤10	≤2	-	-	-	<10	-
	Cd	$[mg\ kg_{SS}^{-1}]$	≤20	≤20	≤4	≤10	≤5	≤5	<20	<20
	Cr(VI)	$[mg\ kg_{SS}^{-1}]$	-	≤10	≤2	-	-	-	-	-
	Hg	$[mg\ kg_{SS}^{-1}]$	≤10	≤10	≤2	≤10	≤5	≤5	<10	<10
	Cr_{tot}	$[mg\ kg_{SS}^{-1}]$	-	≤750	≤150	≤1000	≤150	≤800	<1000	<750
	Ni	$[mg\ kg_{SS}^{-1}]$	≤300	≤300	≤60	≤300	≤50	≤200	<300	<300
	Pb	$[mg\ kg_{SS}^{-1}]$	≤750	≤750	≤150	≤750	≤250	≤500	<750	<750
	Cu	$[mg\ kg_{SS}^{-1}]$	≤1000	≤1000	≤200	≤1000	≤400	≤800	<1000	<1000
	Zn	$[mg\ kg_{SS}^{-1}]$	≤2500	≤2500	≤500	≤2500	≤600	≤2000	<2500	<2500
	Se	$[mg\ kg_{SS}^{-1}]$	-	-	-	-	-	-	-	<5
Organic pollutants	AOX[1]	$[mg\ kg_{SS}^{-1}]$	-	-	-	-	-	≤500	≤1500	-
	LAS[2]	$[mg\ kg_{SS}^{-1}]$	-	-	-	-	<5000	<2600	-	-
	DEHP[3]	$[mg\ kg_{SS}^{-1}]$	-	-	-	-	-	<100	<100	-
	NPE[4]	$[mg\ kg_{SS}^{-1}]$	-	-	-	-	<450	<50	<50	-
	PAH[5]	$[mg\ kg_{SS}^{-1}]$	-	-	-	<6	<6	<6	<6	<6
	PCB[6]	$[mg\ kg_{SS}^{-1}]$	-	-	-	<0.8	<0.8	<0.8	<0.8	<0.8
	PCDD/F[7]	$[ngI\text{-}TE\ kg_{SS}^{-1}]$	-	-	-	-	<100	<100	<100	<50

[1] Sum of adsorbable organic halogen compounds; [2] Linear alkylbenzene sulfonate; [3] Di(2-ethylhexyl) phthalate; [4] Nonylphenol and nonylphenolethoxylates; [5] Polynuclear aromatic hydrocarbons; [6] Chlorinated biphenyle; [7] Polychlorinated dibenzo-p-dioxins and -furans

Table 4. Percentages (by weight) of sludge within the limit values of different scenarios

Parameter	SLUDGE OUTGOING FROM STPs WITHIN THE LIMIT VALUES [weight %]					
	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5	SCENARIO 6
	(1/5 of DGR 7/15944/2003 limit values)	*(Option 2 Working Document Sludge and Biowaste)*	*(Option 3 Working Document Sludge and Biowaste)*	*(Working Document on Sludge 3rd Draft)*	*(DGR 285/2005 Emilia Romagna)*	*(DGR 2241/2005 Veneto)*
As	**31**	-	-	-	100	-
Cd	95	100	98	98	100	100
Cr(VI)	100	-	-	-	-	-
Hg	86	100	98	98	100	100
Cr_{tot}	67	100	67	100	100	100
Ni	**48**	100	**39**	99	100	100
Pb	95	100	97	100	100	100
Cu	**23**	100	65	99	100	100
Zn	**31**	100	**38**	98	100	100

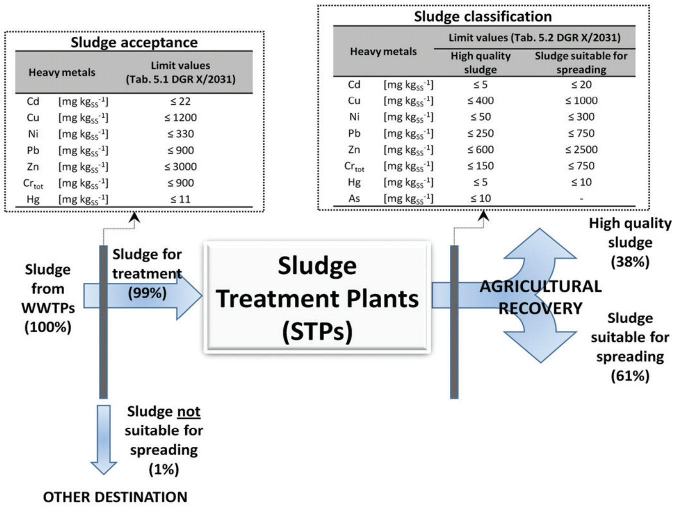

Fig. 6. Flow diagram of sludge ingoing and outgoing from STPs, according to DGR n. X/2031/2014 (considering heavy metals only) (Lombardy Region, 2014).

- introducing criteria for limiting the content of heavy metals in the sludge ingoing to STPs;
- defining two different sludge quality classes ("high-quality sludge" and "sludge suitable for spreading") in order to avoid the mixing of sludge with different quality in the STPs;
- controlling odour emissions due to poor sludge stabilization by means of restriction for VSS/TSS ratio;
- introducing limit values for organic pollutants, in compliance with European disposition.

The results of this study have been incorporated in regional guidelines.

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