

Production and characteristics of sewage sludge in Italy

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ABSTRACT

Results of an extended survey on the production and quality of sewage sludge produced in Italy are herewith reported and discussed. Data are relevant to 2015. They were provided by 84 Italian water utilities responsible for municipal wastewater treatment serving approximately 35 million persons. Total production was estimated at about 395,000 t dry solids/year, of which 9.9% is used in agriculture without further treatments, 26.4% is sent to external plants for compost production, 5.6% is sent to external plant for production of a soil conditioner called 'chalk of defecation', 17.2% is disposed to landfill, and 5.9% is sent to incineration or co-incineration plants. The rest (35%) is sent to external sludge centres for further treatments (mainly chemical and physical processes) before recovery/disposal. Regarding chemical characterization the following parameters were investigated: TOC, total nitrogen, total phosphorus, potassium, arsenic, cadmium, copper, nickel, lead, zinc, mercury, total chromium, chromium VI, selenium, hydrocarbons C10–C40, sum of polycyclic aromatic hydrocarbons, sum of polychlorinated biphenyls, sum of polychlorinated dibenzo-p-dioxins/dibenzo-p-furanes (toxic equivalent) salmonella, faecal coliforms, sulphur, sum of absorbable halogenated organic compounds, nonylphenol and nonylphenoethoxylates with one or two ethoxy groups, and di(2-ethylhexyl)phthalate. All the parameters showed that the quality of Italian sewage sludge is consistent with a typical sludge in Europe, Asia and America and the maximum concentrations of pollutants are well below the fixed standards of the European Directive 86/278 and the third draft of the European Commission's Working Document on Sludge.

Key words | micropollutants, production, quality, sewage sludge

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INTRODUCTION

Official statistics on production and characteristics of sewage sludge in Italy are lacking. Some data are available on the Eurostat web page in the section 'Environment and Energy', but only for the fiscal year 2010 (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_ww_spd&lang=en). Total sewage sludge production accounted for 1.103 Mt of dry solids, being 315,600 dry t utilized on agriculture (28.6%), 462,200 dry t disposed in landfill (41.9%), 36,700 dry t disposed by incineration (3.3%) and 94,700 dry t disposed by other methods (8.6%).

Other figures relevant to the fiscal year 2015 were presented by *Ispira* (2018), which accounted data on the basis of the official declarations due by the Italian companies according to the Decree of the President of Minister Council, 21 December 2015. Total production on wet

basis was estimated as 3,183,919 t, of which 2,924,089 t was managed, according to the managing options shown in *Figure 1*.

Data on sewage sludge characteristics are very abundant. *Andreoli et al.* (2007) presented figures on different Brazilian sewage sludge, including As (<0.006–202 mg/kg dry solids), Mo (0.02–12 mg/kg dry solids), and Se (<0.06–1.4 mg/kg dry solids). *Rizzardini & Goi* (2014) presented Italian data on quality of sewage sludge produced by small communities (4,000–6,000 inhabitants (inh.)). In these cases, quality does not seem to be affected by the possible intrusion of industrial wastewater into the sewerage. Concentration ranges (mg/kg dry solids) were the following: Cd (0.331–1.357), Cr (39.58–57.16), Cu (455.2–727.2), Ni (21.55–34.09), Pb (18.7–70.69), Zn (286.3–1260.8),

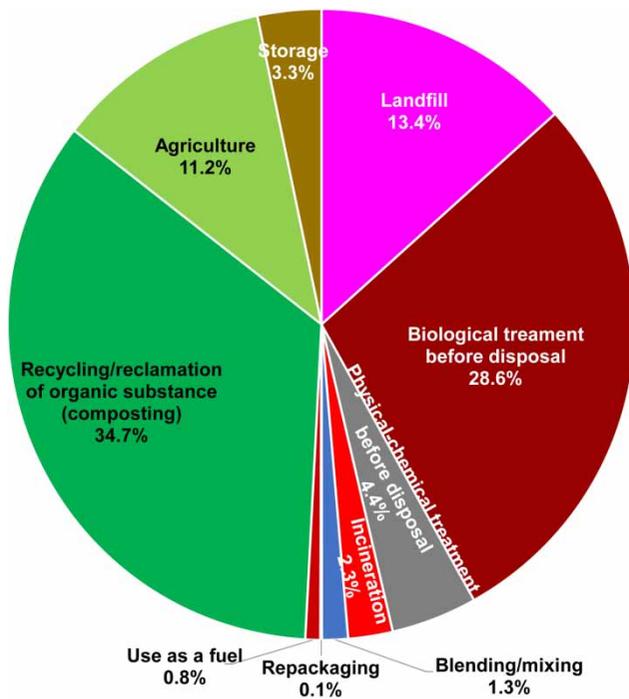


Figure 1 | Final outlet options of sewage sludge in Italy according to Ispra (2018).

Hg (0.58–1.73). They also investigated the presence of the organic micropollutants included in the third draft of the European Commission's *Working Document on Sludge* (European Commission, 2000), i.e. sum of absorbable halogenated organic compounds (AOX) (9.03–10.1); sum of linear alkylbenzene sulphonates (Σ LAS) (48.8–239.1); di(2-ethylhexyl)phthalate (DEHP) (6.2–13.04); sum of nonylphenol and nonylphenoxyethoxylates with one or two ethoxy groups (Σ NPE) (0.8–1.57); sum of polychlorinated biphenyls, generally congener numbers 28, 52, 118, 138, 153 and 180 (Σ PCB) (<0.0035); sum of polychlorinated dibenzo-p-dioxins/dibenzo-p-furanes (Σ PCDD/F) (40–49 ng/kg dry solids). Koch (1997) described sewage sludge management in Austria. On the basis of a long-term investigation of different sludges produced in the country, the author showed the following ranges and most frequent values of metal and organic micro-pollutant concentration (mg/kg dry solids): Cu (range 12–4,310, modal value concentration (i.e. most frequent concentration) 190), Zn (range 18–14,370, modal value 1,320), Pb (range 5–19,150, modal value 145), Cr (range 5–97,600, modal value 64), Ni (range 2–1,840, modal value 37), As (range 0.1–54, modal value 4), Hg (range 0.01–460, modal value 2), Cd (range 0.1–285, modal value 3), AOX (range 78–1,000, modal value 200), polycyclic aromatic hydrocarbons (PAH) (range 'not indicated'–7.7, modal value 0.26), PCB (range 0.06–1.84,

modal value 0.57), Σ PCDD (range 25–2,670 μ g/kg dry solids). Eljarrat *et al.* (2003) investigated concentrations of PCDD/F and PCB with similar properties, called dioxin-like (DL) PCB, in eight different sewage sludges produced in Catalonia with rural, urban and industrial origin. They found that PCDD/F toxic equivalent (TEQ) concentration range was 4.9–20.8 ng/kg dry solids and the DL PCB (congener nos. 81, 77, 105, 114, 118, 123, 126, 156, 157, 167, 169, 189) TEQ concentration range was 1.86–6.62 ng/kg dry solids while the concentration range of the Σ PCB indicators (congener nos. 28, 52, 101, 118, 138, 153, 180) was 22.7–72.5 μ g/kg dry solids.

Perez *et al.* (2001) found that the sum of concentrations of 16 PAH (including naphthalene) in sludge produced by two wastewater treatment plants (WWTPs) with secondary treatment ranged between 2.51 and 5.52 mg/kg dry solids and that it varied between 1.13 and 4.12 mg/kg dry solids in other sludges produced in four WWTPs with either primary or secondary treatment.

Interesting data on the evolution of sewage sludge quality from 2000 to 2015 by the Swedish official statistics (http://www.scb.se/contentassets/4d4d22ee07cf4baa9f47e5bab805c00c/mi0106_2016a01_sm_mi22sm1801.pdf) show (Figure 2) a remarkable increase of nitrogen concentration from 3.8% to 4.5% of dry solids and a substantial constant phosphorus concentration fluctuating in the range 2.6% to 2.8%. Concentrations of heavy metals and some organic pollutants (Figure 3) highlight that concentrations of Zn, Cu, Cr, Ni and Cd are practically constant, while those of Pb, Hg, nonylphenol, PAH and PCB decrease in the period from 2000 to 2014–2016.

Similar figures were presented by Umweltbundesamt (2013). According to the German Federal Office for the Environment the typical concentration range of the sewage sludge characteristics are the following:

- Elemental composition range (% of dry solids): C 33–50%, O 10–20%, H 3–4%, N 2–6%, S 0.5–1.5%, F < 0.01%, Cl 0.05–0.5%, P 0.2–5.5%.
- Metal concentration range (mg/kg dry solids): Sb 5–30, As 4–30, Pb 70–100, Cd 1.5–4.5, Cr 50–80, Cu 300–350, Mn 600–1,500, Ni 30–35, Se 1.0–1.5, Tl 0.2–0.5, V 10–100, Hg 0.3–2.5, Zn 100–300, Sn 30–80.
- Typical composition of organic micropollutants: AOX 350 mg/kg dry solids, PCDD/F (TEQ) 35 ng/kg dry solids.

Remarkable reduction of metal concentration, with specific regard to Pb, Cd, Cr, Ni, Hg and Zn, was observed from 1977 to 2006 (>67% reduction).

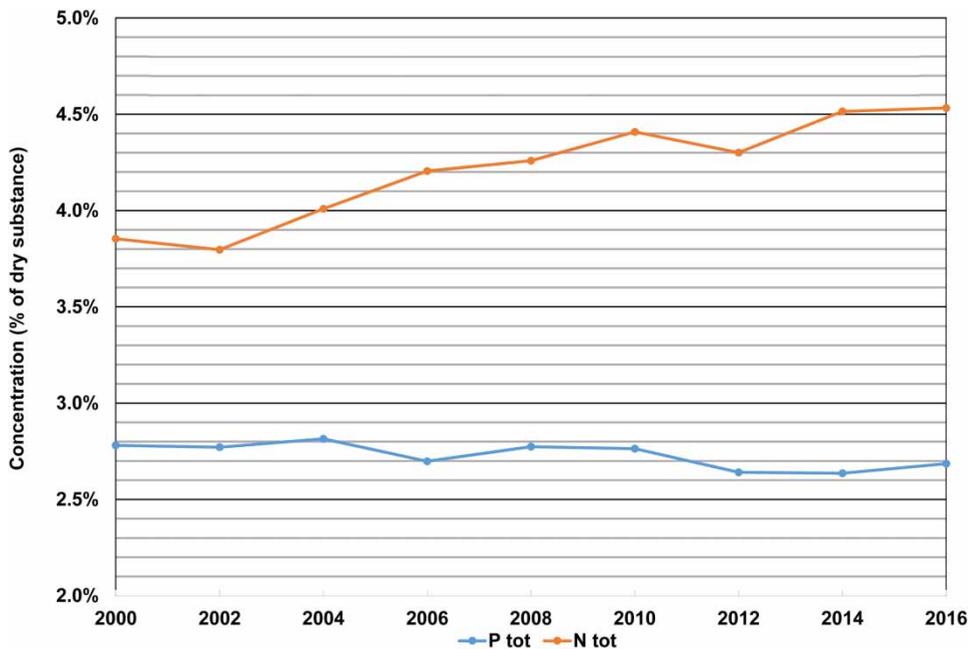


Figure 2 | Nutrient concentration in Swedish sewage sludge from 2000 to 2016.

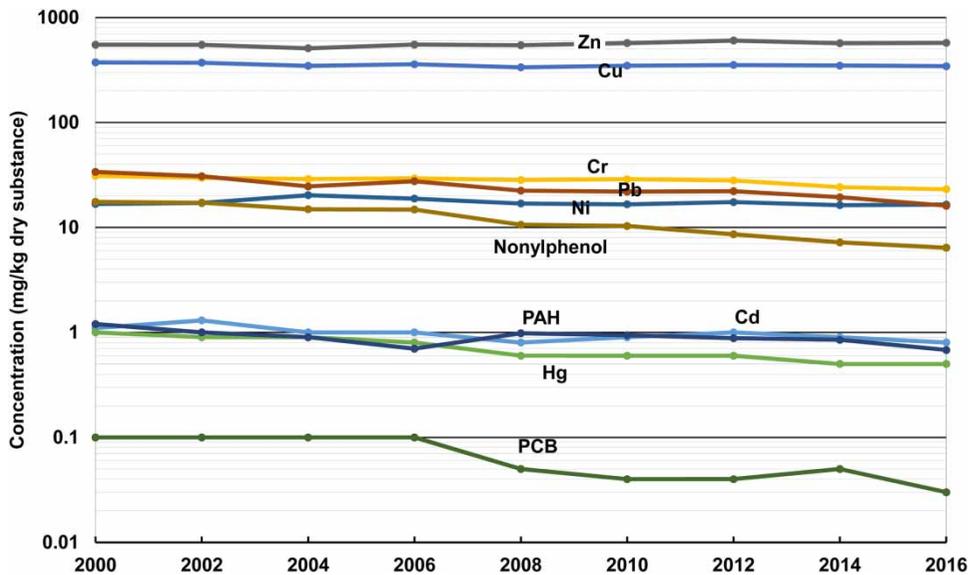


Figure 3 | Metals and organic pollutants concentration in Swedish sewage sludge from 2000 to 2016.

Evolution of sludge quality during the last 30 years is also well documented by the [New Jersey Department of Environment Protection – Division of Water Quality \(2017\)](#), which reported data on concentrations of 11 metals from 1983 to 2016 (Figure 4). A sharp decrease of concentrations may be observed for Be, Cd, Cr, Pb, Hg and Ni. In contrast, As and Se show an unexpected increase, at least up to 2008 and 2009, respectively.

UTILITALIA, i.e. the federation representing the Italian water companies, carried out in 2017 a survey among its associates to assess sludge production and quality, with the aim to estimate the current sewage sludge production in Italy and to build a data bank with sewage sludge characteristics to be compared with international data. Relevant figures are presented in this paper.

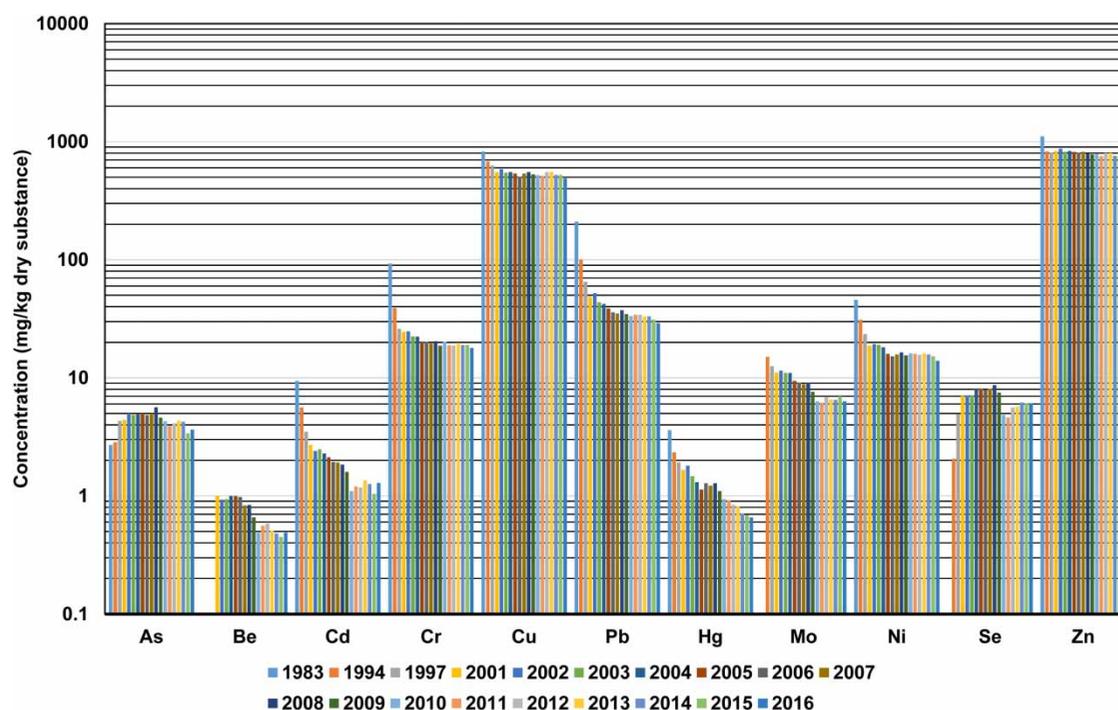


Figure 4 | Metal content of sewage sludge in New Jersey from 1983 to 2016.

SURVEY CRITERIA

Data on production and quality of sewage sludge (only for installation of capacity higher than 20,000 inh.) produced in 2015 by 84 Italian water utilities were collected. Each water company provided records of total sludge tonnage and mean cake concentration according to the different fates, i.e. direct use in agriculture, landfilling, incineration or co-incineration, composting plants, production of a soil conditioner called ‘defecation chalks’, external sludge centres for additional treatments beyond those carried out inside the WWTP. Defecation chalks are produced by a first alkaline conditioning and a second neutralization phase carried out either by sulphuric acid and ferric chloride or by carbon dioxide and ferric chloride. After conventional dewatering, the stable and inodorous sludge is in Italy a product (soil corrective) according to the fertilizing legislation (ministerial decree 28 June 2016).

According to the Italian legislative decree 99/1992, which is the Italian transposition of the European Directive 86/278, sewage sludge must be characterized every 3 months for the WWTPs of capacity >100,000 inh., every 6 months for WWTPs with capacity in the range 5,000–100,000 inh, and once a year for little WWTPs. Therefore, for each WWTP the water companies provided two or four official test reports including all the parameters

included in the Annex IB of the decree 99/1992 (metals, organic carbon, P, N and salmonella). In some cases, official records were also given on the hydrocarbon (C10–C40), PAH, PCB, PCDD/F concentrations as they in some cases are additionally required by regional authorization decrees.

SEWAGE SLUDGE PRODUCTION AND DESTINATION IN ITALY

Sludge production of WWTPs treating wastewater produced by about 35 million residents accounted for 395,132 t of dry solids. Considering a total treated population of about 75.2 million equivalent inhabitants (Istat 2017), including industrial loads conveyed into the public sewers, the total estimated production can be extrapolated to about 850,000 t of dry solids.

The above data overestimate the official reporting data by *Ispra* (2018) which for 2016 amounted to a total sludge production of 3,183,919 t of wet sludge. Considering a mean concentration of dry solids of 22.5% the above production corresponds to 716,382 t dry solids/year. The specific sludge production [g dry solids/(inh. × d)] of the Italian regions is extremely variable between the minimum of Sicily [5.2 g dry solids/(inh. × d)] and the maximum of Trentino Alto Adige [74.6 g/(inh. × d)]. This is clear evidence that wastewaters are

not collected and treated uniformly and that, especially in some southern areas, the wastewater treatment service is deficient.

The survey highlights that water utilities deliver 65% of sewage sludge either to a final destination, i.e. agriculture (9.9%), incineration (3%), co-incineration plant (2.9%), land-fill sites (17.2%), or to final recovery plants which transform sewage sludge into products, i.e. compost (26.4%) or defecation chinks (5.6%). The remaining part of sewage sludge (35%) is delivered to sludge centres which are generally not managed by the water companies but rather by private waste companies. As different types of sludges, wastes and biomass are accepted in these centres, sewage sludge traceability is lost and therefore it is not possible to ascertain which will be final destinations, but preferentially they are recovered in agriculture.

SEWAGE SLUDGE QUALITY IN ITALY

Some results are shown in Figure 5. All the 95th percentiles are well below the established limits or the accepted standards, thus highlighting the good quality of the Italian sewage sludge.

It may be seen that for some principal toxic elements (Cd, Ni, Hg) the plots show a sudden increase at 85th–90th percentile which probably depends on some industrial contribution, but still the values remain well below the current Italian limits. For arsenic concentration (typical values 2–9.2 mg/kg dry solids) it was found that some unexpected high values (up to 41.6 mg/kg dry solids) were detected in the surroundings of Rome and Viterbo, and in sites of Tuscany and Veneto. This might be due either to some underground intrusion into the sewerage or to the As concentration in the drinking waters being close to the current limit of 10 µg/L. In fact, underground waters of volcanic areas of Lazio are naturally rich in As, like in other similar areas in Argentina, Chile, Mexico, China, Hungary, and West Bengal (Smedley & Kinniburgh 2002). Release of As in underground waters also occurs in reducing conditions, for example in the presence of peaty-clay soil rich in organic material. Degradation of peat, with the associated high levels of ammonium, is accompanied by the progressive reduction of O₂, NO₃⁻, Mn(IV), Fe(III), SO₄²⁻, and CO₂. This phenomenon leads to the release of arsenic adsorbed on the surface of the iron and manganese oxides (Casentini & Pettine 2010; Casentini *et al.* 2010; Arpav 2016).

Typical selenium concentrations in Italy (2.6–4.3 mg/kg dry solids) are in agreement with data of Umweltbundesamt (2013) but not with those of New Jersey (Figure 4). This

conclusion based on a not abundant set of data needs to be confirmed. Selenium has been regulated only recently (the Law 16 November 2018, n. 130 fixed the limit of 10 mg/kg dry solids), and therefore before this law was issued only some Italian water companies took care of its monitoring due to local prescriptions.

Nitrogen concentrations higher than 6% dry solids might be due either to the absence of primary sludge or to the insufficient sludge stabilization with consequent low release during anaerobic digestion. It is worth noting that in Italy primary sedimentation is generally not used in medium and small WWTPs. Sometimes it is also not used in some large plants located in sensitive areas where nitrogen has to be removed according to the directive on urban wastewater treatment (European Communities 1991). Phosphorus concentration, typically in the range 1.5–2.0%, appears instead lower than in Swedish sludge. It is not possible to assess why, and if it depends on the different P content in the commercialized detergents used for dish washing and laundry machines.

Regarding organic micropollutants, attention is paid in Italy to hydrocarbons C₁₀–C₄₀, total PAH and total PCB. PAH and PCB concentrations are typically lower than 0.6 and 0.1 mg/kg dry solids, respectively. Already for many years, hydrocarbons present in Italian sewage sludge has focused the attention of public institutions, authorities (including the magistracy) and stakeholders. This often resulted in the prohibition of the use of sewage sludge in agriculture at least in some areas. The Supreme Court (sentence 6 June 2017, n. 27958) has recently established the principle that sewage sludge can be used in agriculture only when, in addition to all the conditions and prescriptions of the Legislative Decree 99/92, hydrocarbons concentration does not exceed 50 mg/kg dry solids. This decree stopped the use of sewage sludge in Tuscany and Lombardy. The new Italian law 130/2018 fixed the limit for hydrocarbons at 1,000 mg/kg wet sludge, which typically corresponds to 5,000 mg/kg dry solids. The high hydrocarbons concentration in sewage sludge, up to 1% of dry solids, can be explained by the polar compounds like fat, oil and grease of animal and vegetable origin and by the humic and fulvic acids produced by biodegradation of organic matter during stabilization, which interfere with the determination of mineral oils using the standardized analytical method (CEN 2004).

CONCLUSIONS

Due to the lack of official data, UTILITALIA carried out a survey in 2017 among Italian water utilities to assess

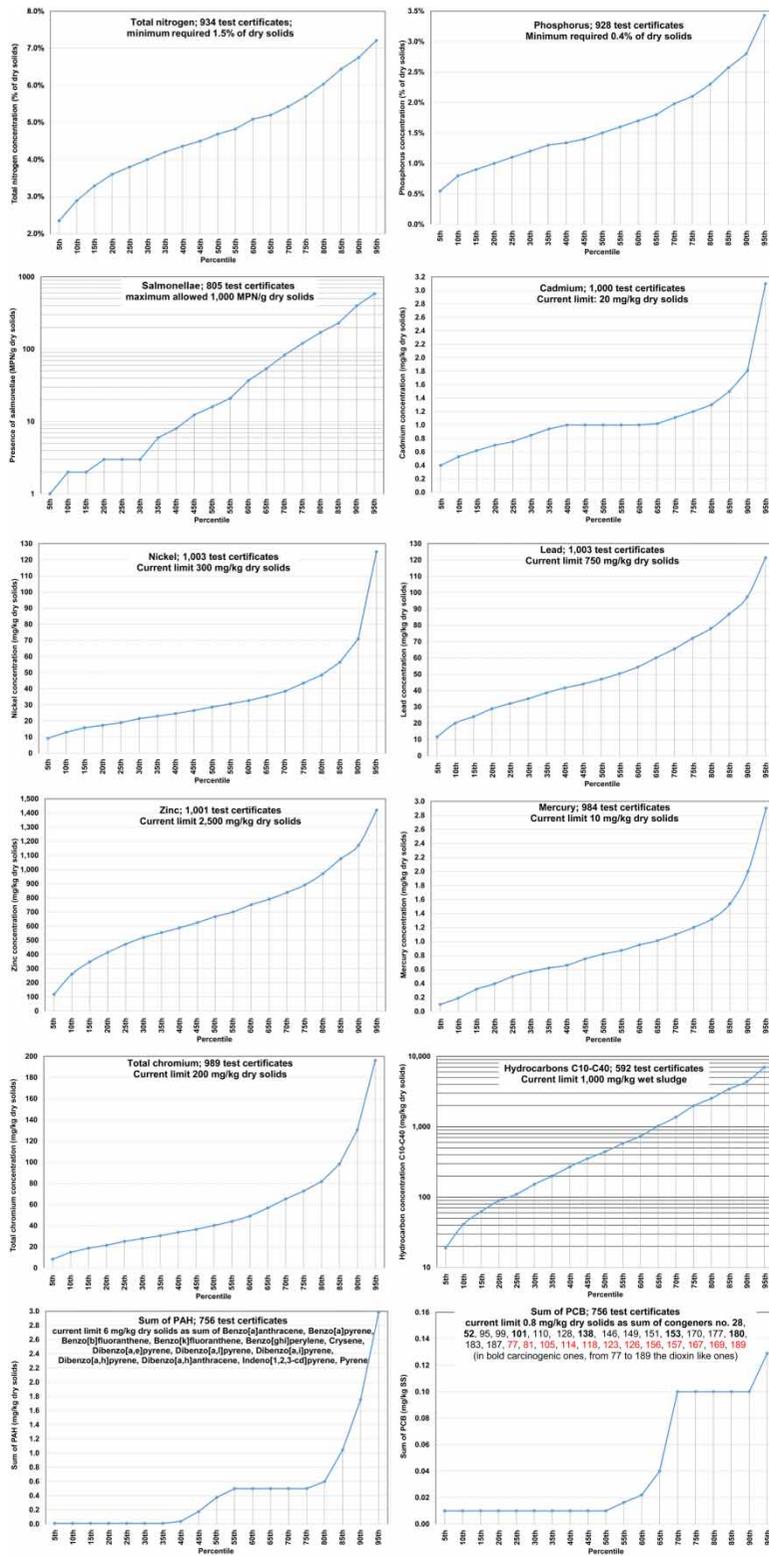


Figure 5 | Concentration (mg/kg dry solids) except for total N, total P and K which are in % of dry solids and for salmonellae which is in MPN/g dry solids) vs percentiles for 12 parameters (total N, total P, salmonellae, Cd, Ni, Pb, Zn, Hg, total Cr, hydrocarbons C10–C40, ΣPAH, ΣPCB) in Italian sewage sludge. Limits and minimum required concentrations apply for sludge use in agriculture.

sewage sludge production and quality. According to the previous available statistics by Eurostat for the year 2010, production was 1.103 Mt dry solids, of which 28.6% was sent to agriculture, 41.9% to landfill, 3.3% to incineration and 8.6% to 82.4% other not-specified destinations. Data collected by this survey through 84 Italian water companies cover the whole of 2015 for a total served population of about 35 million inhabitants, i.e. about 46.5% of the current equivalent population served by the public WWTPs (75.2 million inhabitants). Total sludge production accounted for 395,000 dry t, which can be extrapolated to 850,000 dry t/year for the total equivalent population, i.e. 23% lower than Eurostat statistics. According to the Italian Superior Institute for Environmental Protection and Research (Ispra 2018) the current sewage sludge production (2016) is even lower, i.e. about 3.2 Mt of wet sludge (<800,000 dry t, probably about 640,000 dry t). The same source has put in evidence that in some Italian regions sewage sludge production is quite scarce, thus evidencing that the wastewater treatment service is not uniform for the whole country. Data extrapolation can therefore tend to overestimate sewage sludge production.

Water companies of the public service deliver 65% of the produced sludge to final destinations. Of this part, 15% is sent to agriculture (9.9% of total production), 41% to composting plants (26.4% of total production), 9% to plants for the production of a soil corrective called defecation chalks (5.6% of total production), 9% to incineration or coincineration plants (5.9% of total production) and 26% to landfill sites (17.2% of total production). The remaining 35% is sent to external sludge centres for further treatment (generally chemical treatments are carried out but also physical,

biological and thermal treatments are possible), where the traceability is lost as other sludges, including some with different codes of the European Waste Catalogue, organic waste and biomass are mixed, thus making it impossible to ascertain final destinations.

Sewage sludge quality in Italy is homogeneous with that of other countries (see Table 1). Some small deviations can be observed for phosphorus concentration, which appears relatively lower than the corresponding Swedish data (Figure 2) and for selenium (typical range 2.6–4.3 mg/kg dry solids) at least with regard to New Jersey data (Figure 4) which in the recent years are close to 6 mg/kg dry matter.

The presence of arsenic in sewage sludge (typical Italian concentration 2.0–9.2 mg/kg dry solids) could depend either on infiltration into sewerage from underground waters (containing arsenic of natural origin) or on drinking water with a relatively high arsenic content up to the limit of 10 µg/L set by the European Directive 98/83. It is worth noting that in some Italian areas the presence of arsenic in sewage sludge can reach values up to 40 mg/kg dry solids.

A long ‘soap opera’ afflicts the sewage sludge management in Italy regarding the presence of hydrocarbons, which in other European, Asian and American countries are not so strictly monitored. Their presence in sewage sludge in typical concentrations of 90–2,500 mg/kg dry solids are considered by the Italian jurisdictions as prohibitive for sludge use in agriculture. The new law 130/2018 was recently issued which fixed the hydrocarbons C10–C40 limit at 1,000 mg/kg wet sludge. It is likely that hydrocarbons in sewage sludges derive from the high presence of vegetable/animals oils, fats and grease in urban wastewater destined to be partially transferred to primary and secondary

Table 1 | Comparison of the range concentrations of metals according to the different sources

	Andreoli et al. (2007)	Rizzardini & Goi (2014)	Koch (1997)	Sweden ^a	Umweltbundesamt ^b	New Jersey (2017)	Italy 20th–80th percentile (present study)
Arsenic	<0.006–202		0.1–5.4		4–30	2.7–5.6	2–9.2
Cadmium	0.06–20	0.331–1,357	0.1–285	0.8–1.3	1.5–4.5	1.04–9.4	0.7–1.3
Chromium		39.58–57.16	5–97,700	23.1–31	50–80	17.9–93	21.5–81.6
Copper	6–841	455.2–727.2	12–4,310	335–373	300–350	489–825	181–385
Mercury	0–15	0.58–1.73	0.01–460	0.5–1	0.3–2.5	0.66–3.6	0.4–1.3
Nickel	0.38–411	21.55–34.09	2–1,840	16.3–20.3	30–35	13.9–45.8	17.3–48.5
Lead	3–273	18.7–70.69	5–19,150	16.1–33.8	70–100	29–210	28.8–78
Selenium	0–1.4						2.6–4.3
Zinc	4.4–2,846	286.3–1,260.8	18–14,370	508–602	100–300	733–1,110	414–971

^ahttp://www.scb.se/contentassets/4d4d22ee07cf4baa9f47e5bab805c00c/mi0106_2016a01_sm_mi22sm1801.pdf.

^bhttps://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/sewage_sludge_management_in_germany.pdf.

sludge especially by sorption processes. Their presence in primary sludge was assessed to be more abundant than in secondary sludge (Gianico et al. 2013; Braguglia et al. 2015). Other reasons for the hydrocarbon presence in sewage sludge might be the presence of humic and fulvic acids (Réveillé et al. 2003) formed during organic matter biodegradation during stabilization, which might be detected as hydrocarbons.

Regarding the other organic micropollutants, AOX concentration was detected up to 1,000 mg/kg dry solids (Koch 1997) while a single value of 350 mg/kg dry matter was reported by Umweltbundesamt (2013). The origin of single composts included in AOX is still not deeply investigated, nor their relevance to environment and human health. PAH and PCB concentrations in sewage sludge, when present over the quantification limit, are generally lower than 6–7 and 2 mg/kg dry matter, respectively, although PCB concentration in most cases is lower than 0.1 mg/kg dry solids. In Italian sludges 95th percentiles of PAH and PCB were 3 and 0.13 mg/kg dry solids, respectively. Dioxin and furans, as ubiquitous pollutants, are also present in sewage sludge at concentration up to 50 ng/kg dry solids. The 95th percentile of PCDD/F TEQ concentration of the Italian sludge was 15.2 ng/kg dry solids.

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