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Abundance and characteristics of microplastic in sewage sludge: A case study of Yangling, Shaanxi province, China

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ABSTRACT

Microplastics (MPs), as a new type of pollution, could result in serious environmental pollution due to its special properties. Meanwhile, the damage of MPs to environment could be reflected by the MPs characteristics in sewage sludge, one of dominant sinks of MPs. Therefore, this study investigated the abundance and characteristics of MPs of sewage sludge derived from Yangling, Shaanxi province. Results showed that among of all detected MPs, the particle size ranged from 8 μm–1 mm, especially 8–400.00 μm, accounting for 97.27%. Moreover, the microplastics were dominantly in the shape of fragment in white. Additionally, 41.18% of the microplastics were identified as PVC, which led to higher risk index in Yangling. Furthermore, human density, human activities, environmental factors, and industrial types were responsible for the different details of microplastics in sewage sludge. Concluded from these results, more attention is supposed to pay on MPs pollution in Yangling zone.

1. Introduction

Plastics are extensively used in daily life (clothes, construction, agriculture, packaging and so on) attributed to their excellent durability, strength, cheap price and handiness [1]. According to the statistics, the plastics production rise to 3.59×10^8 tonnes in 2018 all over the world [2]. The plastics waste released into environment, could be broken into smaller materials under the influence of physical, chemical and biological conditions [3,4]. Generally, plastics featured with diameter less than 5 mm are regarded as microplastics (MPs) [5]. Up to date, sewage disposal plant was regarded as dominant sources of MPs in the environment, especially in sewage sludge (SS), which accounted for ~90% [6–10]. It was confirmed that the contents of MPs were 1000–34,000 particles/kg (dry basis) in SS in developed countries like America, German, Finland and Sweden. While there were 22,700 particles/kg (dry basis) in SS collected from coastal regions in China [11]. However, applying SS into farmlands was one of practical ways to recycle SS in the worldwide, which could introduce more MPs into soil system [10]. It was estimated that 6.3×10^4–43×10^4 tonnes MPs were imported into soil through sewage sludge in North America, while 4.4×10^4–30×10^4 in Europe [12]. Meanwhile, 1.56×10^{14} particles/kg/year MPs were released into the environment through the recycle of SS in China [13].

Once MPs are introduced into soil system through the land utilization of SS, it takes a longer period to be decomposed by microbes attributed to its polymer composition [14,15]. During this process, MPs could absorb more hydrophobic organic contaminant and heavy metals, which was facilitated by its own characteristics like smaller particle size, strong hydrophobicity and huge specific surface area [15]. Additionally, some toxic compounds like bisphenol A, butyl phthalate, poly brominated diphenyl ethers and heavy metals used for coloring MPs, could enter into soil environment with land utilization of SS, which is a threaten the soil ecosystem and microbial activities [16,17]. Furthermore, the MPs alone or in combination with toxic chemicals can be transferred along the food chain through bioaccumulation and biomagnification processes, which in turn lead to embolization of small vessels in human following long-term oral administration, and thus caused risk to human safely [14,18]. Therefore, it is essential to investigate the characteristics of MPs in SS so as to comprehensively evaluate the risks of MPs.

To date, many researchers had studied the MPs abundance in SS all over the world [7,8,10,19–21]. However, due to the difference existed in

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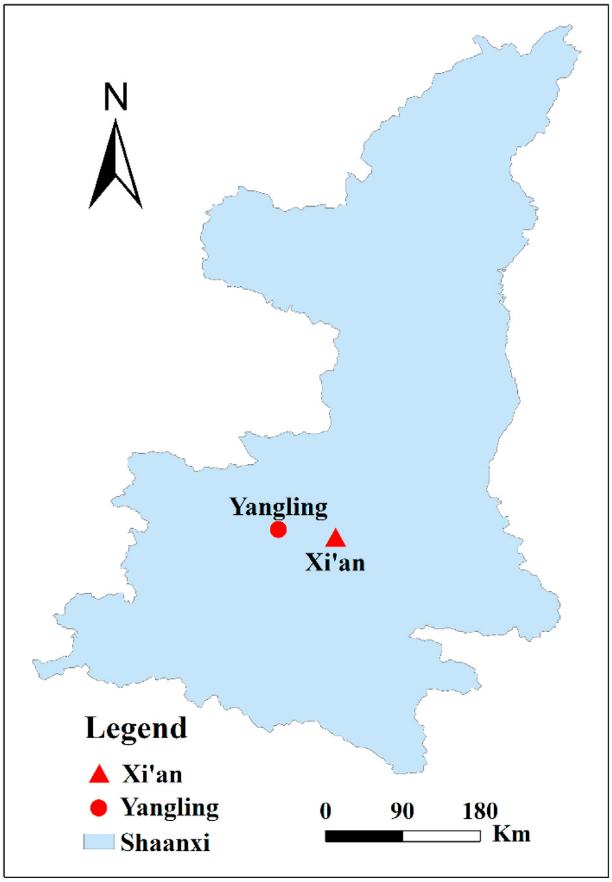

Fig. 1. Maps showing the locations of microplastic sampling situation.

different regions including dietary habit, agricultural industry, industrial manufacture, human activities and wastewater treatment process, it is important to investigate the MPs pollution around our living environment [3]. Yangling, a small city not far from Xi'an, captain city of Shaanxi province, China, is the seminary of the Chinese agriculture and plays an important role in driving the development of modern agricultural industry in arid area. There is limited research to explore the abundance and properties of MPs in this region.

Therefore, the objectives of this study are that: 1) to study the abundance of MPs in dewatered SS; 2) to know the characterization of MPs of dewatered SS; 3) to evaluate the risks of MPs to environment in Yangling.

2. Materials and methods

2.1. Samples collection and extraction

The dewatered SS used in this study was collected from the sewage disposal plant located in Yangling, Shaanxi province on the July 24th' 2019 (Fig. 1). Before extracting MPs, SS samples were normalized as methods described by Besley et al. [22]. The solution used to extract MPs was prepared by adding NaCl to saturation (1.2 g/L) as reported by Li et al. [13] and Li et al. [10]. After stirring at 60 °C for 8 h with the speed of 600 rpm, this solution was then filtered through 0.45 μm filter paper to make sure the accuracy of extraction process.

The SS and fully-saturated NaCl solution were mixed at 1: 15 (g/mL), and then stirred for 5 min to obtain suspension [13]. This supernatant settled down overnight and top water layer was filtered using a sieve with pore size of 37 μm through a vacuum pump. The obtained extract in the sieve was placed in a clean glass braker and then was treated with 100 mL hydrogen peroxide (H_2O_2, 30%) to remove the soft and easily disintegrating organic materials [13]. Subsequently, this mixture was poured into 200 mL of distilled water, vacuum-filtrated through glass fiber filter featured with pore size of 0.8 μm (GF/F, 50 mm Ø, Whatman). Then the obtained filter paper was dried at 50 °C for three days and placed in Petri dish for further analysis [13,23]. In order to make assurance of MPs characteristics, extraction process was repeated triplicate.

2.2. Visual analysis and FTIR spectroscopy

These filter papers were detected by stereomicroscope (Nikon SMZ25, Japan), which could quantify the MPs ranged from 0.05 to 5 mm. Meanwhile, types and color of the MPs were also recorded during visual examination. Furthermore, some criteria reported by Bosker et al. [24] was followed to avoid misidentification of MPs.

For the MPs bigger than 1 mm, Fourier Transform Infrared (FTIR) (Vetex 70, Bruker, Germany) was applied to distinguish chemical composition under the mode of attenuated total reflection (ATR); while the chemical compounds of MPs ranged from 0.05 to 1 mm were identified by Fourier microscopic infrared, with 16 scans at a resolution of 2 cm^{-1} in the range of 650–4000 cm^{-1} [13,25]. The identification of MPs was on account of the absorption value of specific chemicals and by comparing each spectrum with standards of polymer spectra [14,26].

2.3. Statistical analysis

The 1/8 area of filter obtained above was used to detect the abundance of the MPs by Nano Measurer software. While the damage of MPs to environment could be reflected by risk index, which was calculated as following equation [3]:

$$\textit{Risk index} = \sum P_n \times S_n$$

where P_n is the percentage of each MPs polymer type; S_n is the hazard score of the MPs polymer, which was reported by Lithner et al. [27].

3. Results and discussions

3.1. The abundance of the MPs

As performed in Fig. 2, the abundance of MPs was ~220 × 10^3 particles/kg dry weight SS in Yangling, which was one or two orders higher concentrations MPs than sludge collected from Germany, Ireland and Swedish. This was probably ascribed to different population densities and different waste management systems between developed countries (Germany, Ireland and Swedish) and developing countries (China) [28,29]. Moreover, previous studies reported that MPs abundance in dewatered SS in 2014–2015 was 1.60–56.4 × 10^3 particles/kg dry sludge, with an average of 22.7 ± 12.1 × 10^3 particles/kg of dry sludge in China, which was lower than that in this study [13]. This higher concentration of MPs may be because that with the development of economy, plastics plays a more important role in daily life due to its convenience and cheap price in recent years (clothes, packing and agriculture) [13,30].

In this study, the dominant particle size of MPs was 8.00–400.00 μm, accounting for 97.27%. The result demonstrated that smaller MPs were observed in SS obtained from Yangling, and compared with larger one, the smaller MPs were more resistant to environmental degradation and remained for a longer time along with damage to ecological and biological systems [27,31]. Therefore, smaller MPs should be paid more attention in Yangling.

3.2. The abundance of the MPs based on color

Dyeing plastics could make plastics have specific properties including malleability, tolerance, electroconductivity and other functions in agriculture. Besides, the color of MPs is useful to identify potential sources of

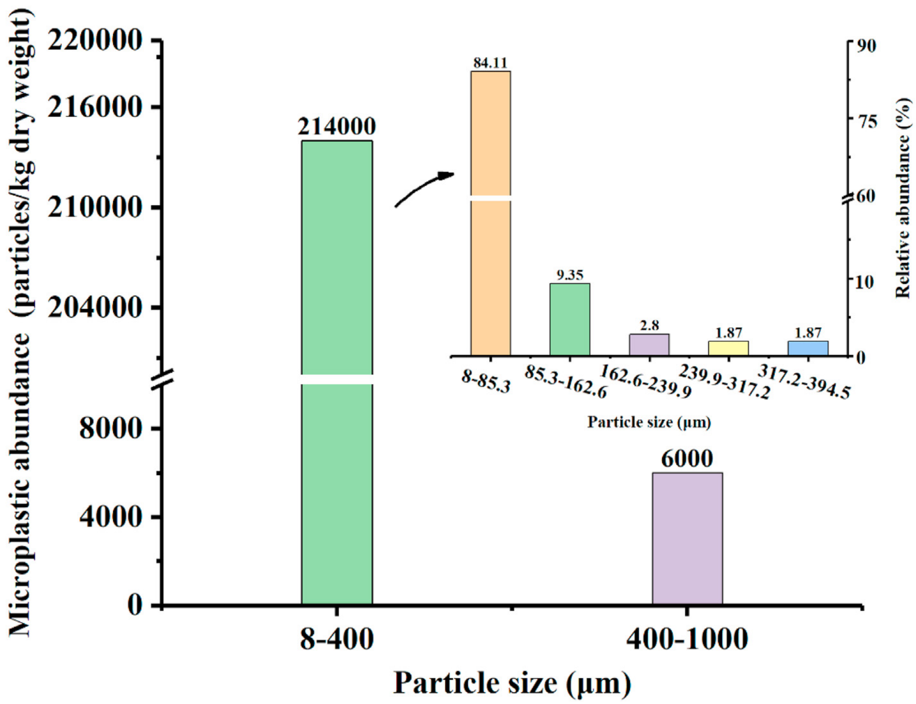

Fig. 2. The particle size abundance of microplastics.

plastics as well as potential contamination [32]. As performed in Fig. 3, the MPs extracted from dewatered SS could be distinguished by blue, yellow, black, red/orange and white. The abundances of MPs in color were white (58.18%), yellow (21.82%), black (10.00%), red/orange (9.09%) and blue (0.91%) in order. The light MPs (yellow and white) occupying for a higher proportion could be caused by weathered and faded function of light and hydraulic effect [33]. While the consumption of black plastics for agriculture was responsible for relatively higher proportion of MPs featured with color, which was similar with the investigation results reported by Li et al. [13].

3.3. The abundance of MPs referred to shape

Based on shapes, the detected MPs of dewatered SS in Yangling could be grouped into four types including fiber, sphere, film and fragment (Fig. 4). The fragment compromised a predominant portion of MPs in dewatered SS collected from Yangling, followed by film, fiber and spere in order [34]. The abundances of MPs based on the shape were not similar with the findings reported by Li et al. [13] and Zhou et al. [3], who pointed out that dominant MPs shape were fiber, fragment, film, foam, flake and sphere. The lower proportion of fiber of dewater SS in Yangling may be caused by followed reasons: 1) The human densities was lower compared with Sichuan, Chengdu and Guangdong city; 2) More attention was focused on agricultural planning and livestock breeding in Yangling, which led to that fewer industrial by-products were imported into sewage [35]. Besides, 90% of residues were student and farmer in Yangling district, which resulted in the wide use of packing bags, plastic containers and mulching film, and the utilization of these plastic materials led to the generation of fragment and film [36]. As for film, it accounted the lower proportion of all MPs types, which was possibly caused by the decomposition of film into smaller particle size (Nano microplastics), which could not be detected by this extraction method.

3.4. The chemical composition identification of MPs

Fourier microscopic infrared (Bruker VERTEX70) is used to identify the type of polymer ascribed to its better reliability in detecting the chemical composition [3,13,32]. As preformed in Fig. 5, the Poly Vinyl

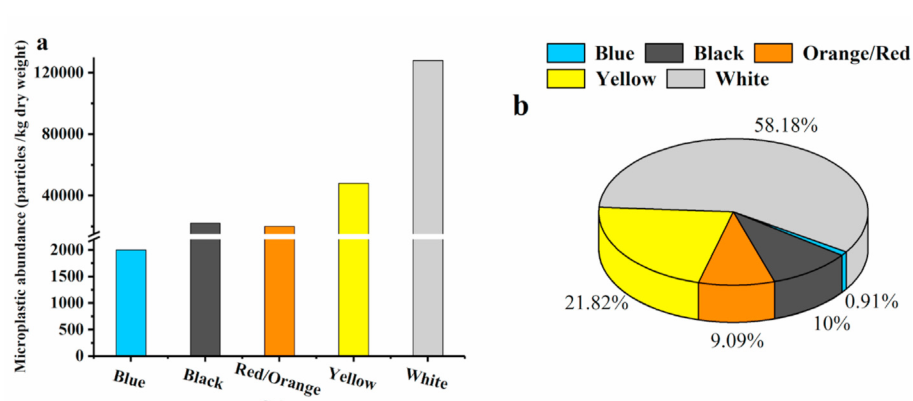

Fig. 3. The color distribution of microplastics. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

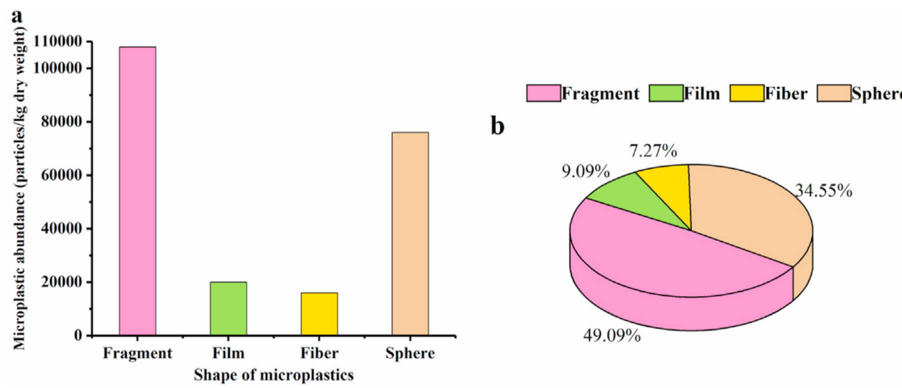

Fig. 4. Typical shape of microplastics.

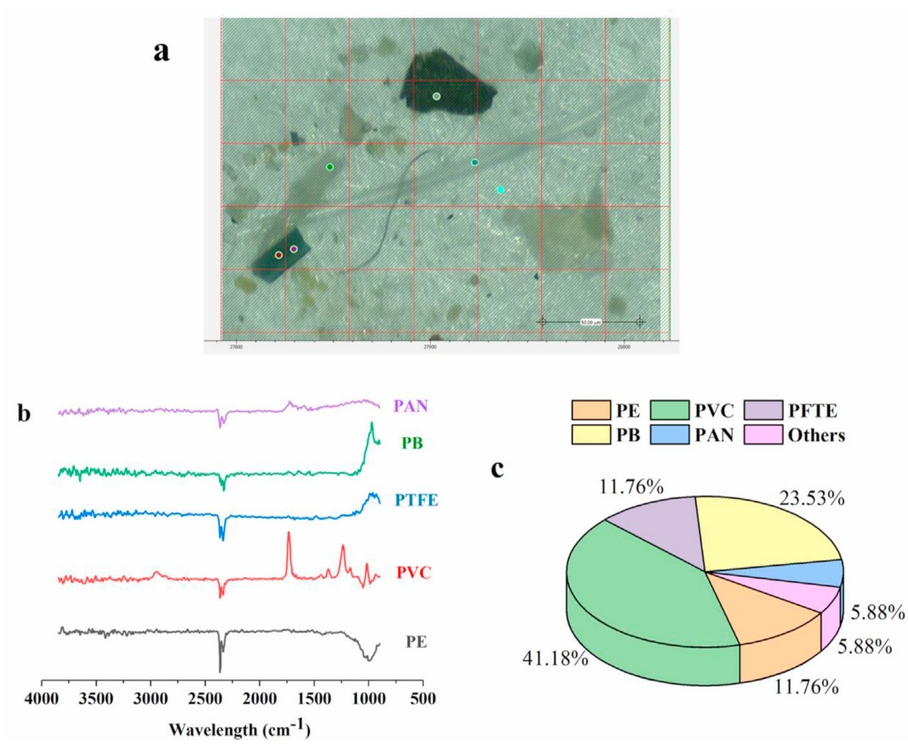

Fig. 5. The chemical identification of microplastics.

Chloride (PVC, 41.18%), Poly (1-butene) (PB, 23.53%), Polytetrafluoroethylene (PTFE, 11.76%), Polyethylene (PE, 11.76%), Polyacrylonitrile (PAN, 5.88%) and Others (5.88%) were dominant polymers types. While Zhou et al. [3] reported out that dominant MPs were polypropylene (PP, 34%), followed by PE (29%), polystyrene (PS, 23%), PVC (3%) and others (11%) in the Tuojiang river basin, which was different with the findings reported in this study. This difference was probably attributed to the different human density and activities in different regions [32].

PVC is widely used in pipe, toys and electric wire due to its high strength, nonflammability, insulativity, resistance of the temperature and low manufacturing cost. The higher proportion of PVC in this study was consistent with their high availability and wide application in daily life. Besides, the resistance to temperature of PVC limited the breakdown of PVC in natural environment. Similarly, PB has excellent high temperature resistance, corrosion resistance, chemical stability and non-toxicity, which lead to the wide application in transporting hot water. Therefore, we suspected that the residential buildings located in Yangling were potential source of these PB items. Though PE has a wide range of ability and it is known to originate from packaging, the proportion is lower in this study [37]. Possible reasons were that the degradation of PE was facilitated by temperature, pH, attached biomass, current, radiation and other environmental factors as well as machinal abrasion [32,38]. Meanwhile, the cloth was dominant potential source for PAN. To sum up, the chemical composition of MPs was affected by the mutual action of intrinsic properties of MPs, human activity and external environment [39].

3.5. Risk to environment posed by MPs

Quantities of researches have assessed the toxic impacts of MPs on organisms [40], but limited research was about the systematic assessment of the MPs risks for certain region. Hence, the method described by Zhou et al. [3] was applied to evaluate the MPs risk index (H) values of specific regions. Meanwhile, the risk is divided into I ($H < 10$), II ($10 \leq H < 100$), III ($100 \leq H < 1000$), IV ($1000 \leq H < 10,000$) and V ($\geq$10,000), respectively [27]. As shown in Table 1, the risk categories of Yangling was IV, and higher PVC content was responsible for this phenomenon.

Table 1
The risk index of microplastics of dewatered sewage sludge in Yangling.

Microplastics type	Percentage of microplastics types (%)	Hazard score of the microplastics polymer	Risk index
PE	11.76	11	2738.47
PVC	41.18	5001	
PTFE	11.76	NC	
PB	23.53	1	
PAN	5.88	11,521	
Others	5.88		

PE: Polyethylene, PVC: Poly Vinyl Chloride, PTFE: Polytetrafluoroethylene. PB: Poly(1-butene); PAN: Polyacrylonitrile; NC: Not classified.

Similar results were also pointed out by Zhou et al. [3] that a certain amount of PVC lead to the higher H value in Ziyang and Fushun. Therefore, the results obtained from this study revealed that MPs pollution in Yangling is urgent to handle and control, and more attention should be paid on the treatment of PVC in the future. Besides, environmental factors and human activities play important roles in fate of MPs, so this model should be refined by more data.

4. Conclusion

Quantities of MPs were accumulated in sewage sludge. Moreover, among of all detected MPs, the particle size of them range from 8 μm–1000 μm, especially 8 μm–400 μm accounting for 97.27%. Furthermore, 41.18% MPs are identified as PVC, which lead to higher risk index in Yangling. Human density, human activity, environmental factors and other items could be responsible for the different investigation in Yangling. Therefore, it is urgent to control MPs for recycling sewage sludge safely. To further, the model for risk index could be refined step by step.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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