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Review

Vulnerability of drinking water supplies to engineered nanoparticles

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ABSTRACT

The production and use of engineered nanoparticles (ENPs) inevitably leads to their release into aquatic environments, with the quantities involved expected to increase significantly in the future. Concerns therefore arise over the possibility that ENPs might pose a threat to drinking water supplies. Investigations into the vulnerability of drinking water supplies to ENPs are hampered by the absence of suitable analytical methods that are capable of detecting and quantifiying ENPs in complex aqueous matrices. Analytical data concerning the presence of ENPs in drinking water supplies is therefore scarce. The eventual fate of ENPs in the natural environment and in processes that are important for drinking water production are currently being investigated through laboratory based-experiments and modelling.

Although the information obtained from these studies may not, as yet, be sufficient to allow comprehensive assessment of the complete life-cycle of ENPs, it does provide a valuable starting point for predicting the significance of ENPs to drinking water supplies.

This review therefore addresses the vulnerability of drinking water supplies to ENPs. The risk of ENPs entering drinking water is discussed and predicted for drinking water produced from groundwater and from surface water. Our evaluation is based on reviewing published data concerning ENP production amounts and release patterns, the occurrence and behavior of ENPs in aquatic systems relevant for drinking water supply and ENP removability in drinking water purification processes. Quantitative predictions are made based on realistic high-input case scenarios. The results of our synthesis of current knowledge suggest that the risk probability of ENPs being present in surface water resources is generally limited, but that particular local conditions may increase the probability of raw water contamination by ENPs. Drinking water extracted from porous media aquifers are not generally considered to be prone to ENP contamination. In karstic aquifers, however, there is an increased probability that if any ENPs enter the groundwater system they will reach the extraction point of a drinking water treatment plant (DWTP).

The ability to remove ENPs during water treatment depends on the specific design of the treatment process. In conventional DWTPs with no flocculation step a proportion of ENPs, if present in the raw water, may reach the final drinking water. The use of ultrafiltration techniques improves drinking water safety with respect to ENP contamination.

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Abbreviations

CCC	Critical coagulation concentration
CFT	Colloid filtration theory
CNT	Carbon nanotube
DWTP	Drinking water treatment plant
ENP	Engineered nanoparticle
GAC	Granular activated carbon
HA	Humic acid
IEP	Isoelectric point
IS	Ionic strength
MF	Microfiltration
MWCNT	Multi-walled carbon nanotube
NOM	Natural organic matter
NP	Nanoparticle
PAC	Powdered activated carbon
SWCNT	Single-walled carbon nanotube
TOC	Total organic carbon
UF	Ultrafiltration
WWTP	Wastewater treatment plant

1. Introduction

The use of engineered nanoparticles (ENPs) has now become widespread in a variety of consumer products and also in industrial applications. Examples include the use of TiO_2 nanoparticles (NPs) in sunscreens (Popov et al., 2005; Samontha et al., 2011) or in photovoltaics (Chen and Mao, 2007), Ag NPs in a range of consumer products including, for example, socks (Geranio et al., 2009; Lorenz et al., 2012) due to their antimicrobial properties, CeO_2 NPs as fuel additives (Cassee et al., 2011; US EPA, 2009), and C_{60}-fullerenes in cosmetics (Benn et al., 2011).

With increasing production volumes and applications (Khan and Asmatulu, 2013), together with anticipated further development in the stabilization and functionalization of ENPs (Khan and Asmatulu, 2013), it is clear that ENPs will enter into natural environments, including aquatic environments.

A number of investigations have shown that ENPs can be toxic to organisms and pose ecotoxicological risks in aquatic environments, as summarized by Bhatt and Tripathi (2011) and Baun et al. (2008).

Consequently, possible risks posed to humans and the risk of ENPs being present in drinking water have come into focus, attracting the attention not only of the scientific community and regulatory authorities, but also of the general public.

Once released, the occurrence, distribution and persistence of ENPs in aquatic systems depend on their colloidal stabilities. ENPs can, for example, dissolve, or they can aggregate/agglomerate and sediment, or they can remain stable within an aqueous phase (Fig. 1).

The results of laboratory investigations proved that the stability of ENPs is controlled by both their physico-chemical properties (or those of the particle populations) and the hydrochemical conditions, as has already been established for natural particles (Buffle and Leppard, 1995). However, little data is available regarding their actual occurrence in aquatic environments. This absence of data is mainly due to the lack of sensitive and selective analytical methods suitable for detecting and characterizing ENPs in complex natural matrices (von der Kammer et al., 2012). Only first approaches exist to selectively detect and characterize ENPs in complex matrices with a high background of natural NPs (Gondikas et al., 2014).

The possible presence of ENPs in raw waters raises the question of the extent to which they can be removed in drinking water treatment plants (DWTPs), in order to ensure the safety of drinking water supplies in the case of ENPs being present in the raw waters.

Particle removal is one of the main objectives of drinking water treatment. Processes such as coagulation, flocculation and sedimentation, and granular media filtration or membrane filtration are specifically designed to remove particulate matter. The mechanisms, influencing parameters, and removal efficiencies of the technologies have been well investigated and are generally well understood for particles in the micrometer size range or larger (Lawler, 1986; Crittenden et al., 2012).

However, much less is known about the ability of different treatment processes to remove particles smaller than 1 μm, and the mechanisms and influencing parameters affecting the behavior and eventual fate of such particles within water treatment systems are much less well understood. This is particularly true for ENPs.

ENP production amounts, release patterns and the fate in the aquatic environment and in water treatment processes have been addressed in a variety of experimental and theoretical investigations. Even though the potential risks to aquatic environments associated with the increasing proliferation of ENPs in many aspects of society is widely acknowledged, the significance of ENP contamination in drinking water supplies has not yet been sufficiently addressed through any comprehensive evaluation of relevant scientific publications and the current state of knowledge.

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