Science of the Total Environment 636 (2018) 299–313

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Review

Sources, behaviour, and environmental and human health risks of high-technology rare earth elements as emerging contaminants

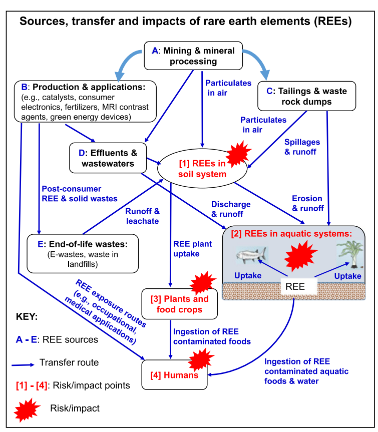
Willis Gwenzi [a,*], Lynda Mangori [b], Concilia Danha [b], Nhamo Chaukura [c], Nothando Dunjana [d], Edmond Sanganyado [e]

[a] Biosystems and Environmental Engineering Research Group, Department of Soil Science and Agricultural Engineering, University of Zimbabwe, P.O. Box MP167, Mt. Pleasant, Harare, Zimbabwe
[b] Department of Environmental Sciences and Technology, School of Agricultural Sciences, Chinhoyi University of Technology, Private Bag 7724, Chinhoyi, Zimbabwe
[c] Nanotechnology and Water Sustainability Research Unit, College of Science, Engineering and Technology, University of South Africa, Johannesburg, South Africa
[d] Department of Soil Science, Marondera University of Agricultural Sciences and Technology, P. Bag 35, Marondera, Zimbabwe
[e] Marine Biology Institute, Shantou University, Shantou, Guangdong Province, China 515063

HIGHLIGHTS

- Various routes transfer rare earth elements (REEs) from sources into the environment.
- Multiple intake routes and risk factors predispose human health to REEs.
- Several human and ecological health effects of REEs are well-documented.
- A conceptual framework and interventions to reduce the health risks are highlighted.
- Source partitioning, behaviour, ecotoxicology and epidemiology remain under-studied.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 January 2018
Received in revised form 15 April 2018
Accepted 17 April 2018
Available online 27 April 2018

Editor: Mae Mae Sexauer Gustin

Keywords:
Cerium
Ecotoxicology
Europium
Gadolinium
Lanthanides

ABSTRACT

Recent studies show that high-technology rare earth elements (REEs) of anthropogenic origin occur in the environment including in aquatic systems, suggesting REEs are contaminants of emerging concern. However, compared to organic contaminants, there is a lack of comprehensive reviews on the anthropogenic sources, environmental behaviour, and public and ecological health risks of REEs. The current review aims to: (1) identify anthropogenic sources, transfer mechanisms, and environmental behaviour of REEs; (2) highlight the human and ecological health risks of REEs and propose mitigation measures; and (3) identify knowledge gaps and future research directions. Out of the 17 REEs, La, Gd, Ce and Eu are the most studied. The main sources of anthropogenic REE include; medical facilities, petroleum refining, mining and technology industries, fertilizers, livestock feeds, and electronic wastes and recycling plants. REEs are mobilized and transported in the environment by hydrological and wind-driven processes. Ecotoxicological effects include reduced plant growth, function and nutritional quality, genotoxicity and neurotoxicity in animals, trophic bioaccumulation, chronic and acute toxicities in soil organisms. Human exposure to REEs occurs via ingestion of contaminated water and food, inhalation, and direct intake during medical administration. REEs have been detected in human hair, nails, and biofluids. In humans, REEs cause nephrogenic systemic fibrosis and severe damage to nephrological systems associated with Gd-

* Corresponding author.
E-mail addresses: wgwenzi@agric.uz.ac.zw, wgwenzi@yahoo.co.uk. (W. Gwenzi).

https://doi.org/10.1016/j.scitotenv.2018.04.235

based contrast agents, dysfunctional neurological disorder, fibrotic tissue injury, oxidative stress, pneumoconiosis, cytotoxicity, anti-testicular effects, and male sterility. Barring REEs in medical devices, epidemiological evidence directly linking REEs in the environment to human health conditions remains weak. To minimize health risks, a conceptual framework and possible mitigation measures are highlighted. Future research is needed to better understand sources, environmental behaviour, ecotoxicology, and human epidemiology. Moreover, research on REEs in developing regions, including Africa, is needed given prevailing conditions predisposing humans to health risks (e.g., untreated drinking water).

Contents

1. Introduction

In recent years, emerging contaminants (ECs) attracted great public and research attention due to their potential human and ecological risks. However, ECs are currently unregulated partly, because their ecotoxicological effects are often poorly understood or sensitive and reliable quantitative analytical methods were unavailable until recently (Petrović et al., 2003). Existing research, including reviews, on ECs has been limited to biological agents such as antimicrobial resistant bacteria and their resistance genes, industrial chemicals such as solvents, food additives/colourants, fire retardants, pharmaceuticals, and personal care products (Jurado et al., 2012; Petrie et al., 2015). Although often overlooked, rare earth elements (REEs), also known as the lanthanide group elements, are an example of ECs. Like most ECs; (1) they are currently unregulated in humans and the environment (Kulaksız and Bau, 2013), (2) they are not routinely monitored in environmental and public health programs, (3) they are micropollutants detectable with analytical equipment with very low detection limits; and (4) their mechanisms of environmental and human toxicity are poorly understood.

Until recently, REEs have received limited attention from environmental and public health researchers probably due to their limited industrial use. High-technology REEs such as lanthanides lanthanum (La) to lutetium (Lu) and scandium and yttrium, are used in the production of electronic devices and advanced engineered systems. For example, REEs are employed in the following: (1) in the production of electronic devices e.g., mobile phones, (2) in the development of advanced weapon systems, (3) as components of super-capacitors and conductors, and (4) as contrast agents in medical imaging such as magnetic resonance imaging (MRI) (e.g., Bau et al., 2006; Kulaksız and Bau, 2011a, 2011b; CR Li et al., 2013, X Li et al., 2013). Recent technological advances in medicine, mobile communication, energy, and ammunitions have resulted in an increase in the extraction and subsequent use of REEs. The increase in industrial applications could be accompanied by their increase in the environment, posing public and ecological health risks. In the context of contaminants of emerging concern, the current study is limited to the lanthanides (La-Lu), yttrium, and scandium.

Recently, there has been an increase in data on the environmental occurrence, behaviour, and health risks of anthropogenic REEs (e.g., Tepe et al., 2014; Hatje et al., 2016; Ayedun et al., 2017; Dan et al., 2017). Earlier reviews focused on the industrial applications, environmental behaviour and human toxicity of REEs, yet none considered them as ECs (e.g., Fraum et al., 2017; Rogowska et al., 2018). Fraum et al. (2017) presented a review on Gd risk assessments with emphasis on nephrogenic systemic fibrosis, including; immediate adverse