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A bibliometric analysis of research on the risk of engineering nanomaterials during 1999–2012

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HIGHLIGHTS

- Research on the risk of engineering nanomaterials was characterized based on SCI-Expanded during 1999–2012.
- Research emphases were obtained through synthesized analysis by co-citation and words from author keywords.
- Health effect and nanotoxicology of engineering nanomaterials were common research issues.
- Environmental behavior and ecological risk of engineering nanomaterials are getting popular.

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ABSTRACT

A bibliometric analysis based on the Science Citation Index Expanded (SCI-Expanded) from the Web of Science was carried out to provide insights into research activities and tendencies of the global risk of engineering nanomaterials (ENMs) from 1999 to 2012. The number of publications per year has increased steadily since approximately 2006. The USA produced 41.9% of all pertinent articles followed by China with 14.8% and UK with 9.1%. *Environmental Science & Technology*, *Toxicology*, and *Journal of Nanoparticle Research* were the three most common journals in this field. A synthesized analysis by co-citation and words from author keywords provided the clues to discover the current research emphases. The mainstream research related to risk of ENMs was toxicological effects and ecological risk. Toxicity effect strongly promoted the development of related research in the past 14 years. Research on environmental behavior and ecological risk of ENMs is the fast growing field.

1. Introduction

Nanotechnology as a driving force for a new economy, is revolutionizing the chemical, telecom, biotech, pharmaceutical, health care, aerospace, and computer industries, and many exciting new nanotech applications are envisioned for the near future (Maynard et al., 2006). According to the report of the U.S. National Science Foundation (NSF), the nanotechnology-related product market was predicted to be over one trillion dollars by 2015 (Hullmann, 2007). Nanotechnology has become a top priority in governments, the private sector and the public all over the world (Roco, 2003).

Engineered nanomaterials (ENMs) are manufactured materials having at least one dimension in the nanoscale (ca. 1–100 nm) dimension. The nanotechnology field continues to grow rapidly and the increasing use of ENMs in commercial products translates into an increasing presence in the biosphere (Lowry et al., 2012; Wiesner et al., 2006; Mueller and Nowack, 2008). While the nanoscale dimensions give ENMs new characteristics, the potential for their release in the environment and subsequent effects on ecosystem health is becoming an increasing concern (Yang et al., 2009; Gottschalk and Nowack, 2011). Studies have suggested that the released nanomaterials can affect biological behaviors at the cellular, subcellular and protein levels (Nel et al., 2006; Colvin, 2003; Donaldson et al., 2006; Owen and Handy, 2007). Moreover, some nanoparticles readily travel throughout the body, deposit in target organs, penetrate cell membranes, lodge in mitochondria, and may trigger injurious responses (Oberdoster et al., 2005; Kreyling et al., 2002; Semmler et al., 2004; Åkerman et al., 2002; Rejman et al., 2004). Therefore, their risk assessment should be evaluated to make proper prevention and control countermeasures. As research in the field of risk from ENMs is attracting increasing attention, it is urgent to portray the global trend of the research fields that sustain human life.

Bibliometrics is a useful tool to map the literature around a research field. It refers to research methodology employed in library and information sciences, which utilizes statistics and quantitative analysis methods to describe distribution patterns of articles with a given topic, field, institute or country. These methods have recently been employed to investigate research trends of specific fields (Braun et al.,

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1995; Ho, 2008; Li et al., 2009a, 2009b). An assumption was made in these studies that the research publications of a country in a certain scientific subfield reflect its commitment to the state of science and is a reasonable indicator for research and development efforts in that field. However, there are some universal deficiencies in traditional bibliometrics analysis in scientific research fields. Many studies only select several journals or categories to represent global research trends related to a certain topic (Mela and Cimmino, 1998; Klein and Hage, 2006). The change in citations or publication counts of countries and organizations cannot completely indicate the development trend or future orientation of research field (Chiu and Ho, 2007). More information like source title (Li et al., 2009a, 2009b), author keyword (Ugolini et al., 2001), keyword plus (Qin, 2000), abstracts (Zhang et al., 2010) and funding agencies (Wang et al., 2012) should be introduced into the research trend study.

Research related with risk of ENMs during the past 14 years was analyzed to provide a basis for a better understanding of the global research situation, establishing long term strategies for this field. The analyzed aspects covered not only the quantitative description of publications, including annual outputs, mainstream journals, Web of Science categories, leading countries and institutions, funding agencies, but also the research tendencies and hotspots obtained from the synthesized analysis by co-citation and words in author keywords.

2. Methodology

The methodology used in this research was similar to other bibliometric studies (Chiu et al., 2004; Hirsch, 2005). Data were obtained from the online version of SCI-Expanded databases of the Web of Science from Thomson Reuters on 13th July 2013. According to the Journal Citation Reports (JCR), it indexes 8471 major journals with citation references across 176 scientific disciplines in 2012.

For bibliometric analysis, the online version of SCI-Expanded was searched with keywords (nanomaterial* or "nano-metal oxide*" or "nano metal*" or nanotube*or "quantum dot*" or C_{60} or C_{70} or fullerene* or SWCNTs or MWCNTs or nano-Ag or nano-Au or nano-Cu or nano-Al or nano-Fe or nano-Ti or nano-Zn or nano-CdSe or nano-ZnS or nano-CdTe or nano-TiO_2 or nano-Al_2O_3 or nano-Fe_2O_3 or nano-Fe_3O_4 or nano-ZnO or nano-CuO or nano-silver or "nano $ZnFe_2O_4$") and (risk or "environmental exposure" or "health effect" or "environmental behavior" or "toxicity assess*" or nanotoxicology or nanotoxicity or ecotoxicity) to compile a bibliography of all articles related to the research in the field of risk from ENMs. As journal articles represented the majority of document types that also included whole research ideas and results (Ho et al., 2010), only journal articles were searched for bibliometric analysis as the relevant citable items. Altogether 901 original articles were used for further analysis.

Downloaded information included names of authors, contact address, title, year of publication, author keywords, keywords plus, abstract, funding agencies, Web of science categories of the article, and names of journals publishing the articles. The records were downloaded into spreadsheet software. Articles originating from England, Scotland, Northern Ireland, and Wales were reclassified as from the United Kingdom (UK). Contributions of different institutions and countries were estimated by the affiliation of at least one author to the publications, where the term "single country article" was assigned if the researchers' addresses were from the same country. The term "internationally collaborative article" was designated to those articles that were coauthored by researchers from multiple countries. The term "single institution article" was assigned if the researchers' addresses were from the same institution. The term "inter-institutionally collaborative article" was assigned if authors were from different institutions (Fu et al., 2013). Citespace 3.5 was applied in the co-citation analysis (Chen, 2004, 2006). It can help to identify the most popular words used in articles over a particular period of time. Relevant parameters in citespace program for co-citation analysis were set as follows: the thresholds were (3, 2, 15), (4, 3, 19) and (4, 3, 20); Reference was chosen as the node; Title, abstract, descriptor and identifiers were chosen as sources; None was chosen as term. Minimum Spanning Tree (MST) was employed in network pruning. The slice length was 2-year. 683 nodes and 1011 links were obtained to compose the co-citation map after running the program.

3. Results and discussion

3.1. Performance of publication

3.1.1. Publication outputs

To obtain an overview of ENMs' risk research, the annual number of articles during 1999–2012 was displayed in Table 1. The number of ENMs risk publications increased from 1 in 1999 to 256 in 2012, with the total publications reaching 901. The number of publications per year has increased steadily since approximately 2006. And the average article lengths fluctuated slightly, with an overall average of 8.2 pages. 10.0 references were cited per article in 1999, comparing to 45.8 references per article in 2012, with slight increases through-out the 14 years. An increasing number of authors carrying out research on risk of ENMs from 3 in 1999 to 1473 in 2012, the average number of authors of a single article was 4.3.

3.1.2. Publication distribution of countries, institutions and funding agencies

The analysis of author's countries/territories was based on journal articles in which the address and affiliation of at least one author were provided. It was noted that the SCI had a policy of omitting certain addresses (e.g. those preceded by the phrase "on leave from"). There were 10 articles without any author address information on ISI Web of Science and the total article number for distribution analysis of country and institute publications was 891. Of all the articles with author address, 695 (78.0%) were single country articles and 196 (22.0%) were internationally collaborative articles. Table 2 shows the top 20 countries/territories ranked by the number of total publications with other information: the number and percentage of single country articles and internationally collaborated articles, as well as first author and corresponding author articles.

The contribution of different institutions was estimated by the institution of the affiliation of at least one author of the published papers. The top 10 institutions in the past 14 year period are displayed in Table 3. Among the top 10 institutions, 6 were in the United States, 2 were in China and one each in Switzerland and Denmark. Leading was the Chinese Academy of Sciences with 43 articles, followed by the National Institute for Occupational Safety and Health of United States (NIOSH, USA; 31) and the Swiss Federal Laboratories for Materials (EMPA; 22) from Switzerland. The Chinese Academy of Sciences also

Table 1
Characteristics by year of publication outputs from 1999 to 2012.

PY	TP	AU	AU/TP	PG	PG/TP	NR	NR/TP
1999	1	3	3.0	5	5.0	10	10.0
2001	1	2	2.0	4	4.0	16	16.0
2004	3	5	1.7	27	9.0	64	21.3
2005	8	40	5.0	64	8.0	258	32.3
2006	30	111	3.7	268	8.9	1116	37.2
2007	51	284	5.6	483	9.5	1858	36.4
2008	90	429	4.8	792	8.8	3298	36.6
2009	90	440	4.9	773	8.6	3627	40.3
2010	148	749	5.1	1428	9.6	6780	45.8
2011	223	1246	5.6	1992	8.9	9908	44.4
2012	256	1473	5.8	2583	10.1	11716	45.8
Average			4.3		8.2		33.3

PY: published year; TP: total articles; AU: author number; AU/TP: author number per article; PG: page count; PG/TP: page count per article; NR: cited reference count; NR/TP: cited reference count per article.