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## Review

# Pharmaceuticals and the Environment (PiE): Evolution and impact of the published literature revealed by bibliometric analysis



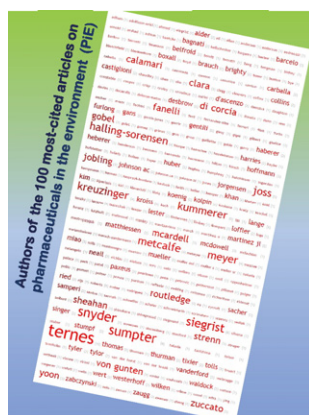
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## HIGHLIGHTS

- Pharmaceuticals in the environment (PiE) as a field of research has displayed exponential growth since the late 1990s.
- As a highly transdisciplinary field of research, PiE crosscuts many topics, concerns, and disciplines.
- The historical emergence of some of the many facets of PiE's was examined using bibliometric analysis.
- Some facets span over 70 years of publishing, raising questions regarding research priorities and resource allocation.
- A definitive, core list of PiE's most highly cited papers was compiled (385), together with a wide range of other metrics.

## GRAPHICAL ABSTRACT



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## ABSTRACT

The evolution and impact of the published literature surrounding the transdisciplinary, multifaceted topic of pharmaceuticals as contaminants in the environment is examined for the first time in an historical context. The preponderance of literature cited in this examination represents the earlier works. As an historical chronology, the focus is on the emergence of key, specific aspects of the overall topic (often termed PiE) in the published literature and on the most highly cited works. This examination is not a conventional, technical review of the literature; as such, little attention was devoted to the more recent literature.

The many dimensions involved with PiE span over 70 years of published literature. Some articles began to appear in published works in the 1940s and earlier, while others only began to receive attention in the 1990s and later. Decades of early research on what at the time seemed to be disconnected topics eventually coalesced in the mid-to-late 1990s around a number of interconnected concerns and issues that now comprise PiE. Major objectives are to provide a new perspective to the topic, to facilitate more efficient and effective review of the literature by others, and to recognize the more significant, seminal contributions to the advancement of PiE as a field of research. Some of the most highly cited articles in all of environmental science now involve PiE. As of April 2015, a

**Abbreviations:** API, active pharmaceutical ingredient; CECs, contaminants of emerging concern; EDC, endocrine disrupting chemical; EPA, U.S. Environmental Protection Agency; EPR, extended producer responsibility; FDA, U.S. Food and Drug Administration; GS, Google Scholar; MDR, multidrug resistance; MXR, multixenobiotic resistance; PiE, pharmaceuticals in the environment; PhACs, pharmaceutically active compounds; PPCPs, pharmaceuticals and personal care products; TPs, transformation products; TrOC (TOrC), trace organic chemical.

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core group of 385 PiE articles had each received at least 200 citations; one had received 5424 citations. But hundreds of additional articles also played important roles in the evolution and advancement of the field.

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## 1. Introduction

A perspective is presented on the early history surrounding the evolution of the topic of pharmaceuticals as contaminants in the environment. This perspective is derived from examining key words and the metadata associated with a comprehensive database of articles relevant to this multi-faceted topic. The articles in this database were published in an array of resources, but primarily journals, books, reports, and dissertations:

Daughton and Scuderi, 2016b “Pharmaceuticals and Personal Care Products (PPCPs): Relevant Literature”.

[Note: the non-standard format used in this paper to cite references is discussed at the end of Section 3 (Approach).]

The wide spectrum of issues surrounding this complex, multi-faceted topic span over 70 years of published literature. Some articles began to appear in published works in the 1940s and earlier. Other aspects did not begin to receive attention until the 1990s and continuing to this day. With decades of research on what at the time seemed to be disconnected topics, a discrete field of research eventually coalesced in the mid-1990s around a number of interconnected concerns and issues related to the environmental occurrence of the active ingredients in drugs (known as active pharmaceutical ingredients, APIs). Among a number of terms used over the years, this field of research is frequently referred to as Pharmaceuticals in the Environment — often abbreviated PiE.

This examination is not a review of the literature. It is not an examination of the technical content of the PiE published literature or an attempt to distill new knowledge regarding the PiE topic. Rather, it began simply as an attempt to see whether new insights might emerge when trying to examine from some new perspectives a very large body of published literature surrounding a complex and expansive facet of environmental science. While this examination of PiE tries to show the historical trajectory of PiE and to place some events in an historical context, it does not attempt to summarize or critique what has been learned or to proffer where its future should aim; as such, it is important to keep in mind that the focus is on the older, pioneering literature rather than newer literature. To my knowledge, such an assessment has not been attempted before — nor has one been specifically called for. This effort was partly motivated by the fact that PiE comprises an extremely large body of disparate published literature, contributed from many different and usually disconnected technical disciplines. At the least, this examination tried to document some of the history behind the evolution or emergence of PiE as a field of study. As such, errors and omissions are inevitable — sometimes casualties of the subjective nature of defining the actual scope of PiE as a dedicated field of research.

This article could be partly viewed as an historical bibliometric examination of PiE. Surprisingly, very few bibliometric examinations

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