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Perspective

Closing Blank Spots and Illuminating Blind Spots in Research on Emerging Contaminants: The Source–Pathway–Receptor–Impact–Mitigation (SPRIM) Continuum as an Organizing Framework

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Abstract: Emerging contaminants (ECs) include: (1) high-technology rare earth elements, (2) nanomaterials, (3) antibiotic/antimicrobial resistance, (4) microplastics, and (5) synthetic organic chemicals, which are currently unregulated. ECs continue to attract considerable research and public attention due to their potential human and ecological health risks. However, an organizing conceptual framework for framing research on ECs is currently missing. Lacking a conceptual framework, only a few aspects are frequently well-studied (i.e., bandwagon/Matthew effect), while other equally important topics receive only cursory attention. In this Editorial perspective, the Source–Pathway–Receptor–Impact–Mitigation (SPRIM) continuum is proposed as an organizing framework to guide research on ECs. First, a description of the SPRIM continuum and its components is presented. Compared to the prevailing and seemingly ad hoc approach predominant in research on emerging contaminants, the potential novelty of applying the proposed SPRIM continuum framework is that it addresses the bandwagon, or Matthew, effect. As a decision-support tool, the SPRIM continuum framework serves a dual function as (1) a checklist to identify key knowledge gaps and frame future research, and (2) a primer for promoting the collaborative research and application of emerging big data analytics in research on emerging contaminants. Collectively, it is envisaged that the SPRIM continuum framework will provide a comprehensive and balanced understanding of various aspects of emerging contaminants relative to the current approach. The challenges of the SPRIM continuum framework as a framing and decision-support tool are also discussed. Future research directions on ECs are discussed in light of the SPRIM continuum concept. This Editorial closes with concluding remarks and a look ahead. The issues discussed are cross-cutting or generic, and thus relate to several groups of ECs, including emerging organic contaminants (EOCs), which are the focus of the current Special Issue. This Special Issue, entitled 'Emerging Organic Contaminants in Aquatic Systems: A Focus on the Source–Pathway–Receptor–Impact–Mitigation Continuum', calls for high-quality contributions addressing several aspects of EOCs in aquatic systems. As a Guest Editor, I welcome and look forward to several high-quality contributions addressing at least one component or the entire spectrum of the SPRIM continuum.

Keywords: decision-support tool; dissemination pathways; emerging organic contaminants; exposure pathways; health risks; hotspot sources; receptors; research framing; risk mitigation; source–pathway–receptor model

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Citation: Gwenzi, W. Closing Blank Spots and Illuminating Blind Spots in Research on Emerging Contaminants: The Source–Pathway–Receptor–Impact–Mitigation (SPRIM) Continuum as an Organizing Framework. *Water* **2023**, *15*, 526. https://doi.org/10.3390/w15030526

Academic Editors: Daniel D. Snow and Shengrui Wang

Received: 15 December 2022
Revised: 17 January 2023
Accepted: 26 January 2023
Published: 28 January 2023

1. Introduction

Emerging contaminants, also referred to as contaminants of emerging concern, are widely used in industry, healthcare and household products [1,2]. Broadly, emerging contaminants include the following five groups: (1) high-technology rare earth elements, which are technology-critical elements [1]; (2) microplastics and nanoplastics [3]; (3) antimicrobial/antibiotic resistance [4]; and (4) synthetic organic chemicals classified as emerging organic contaminants (EOCs), such as pharmaceuticals and perfluoroalkyl and polyfluoroalkyl substances (PFASs) [5], which are the focus of the current Special Issue. In recent years, the term 'emerging contaminants' has also been extended to include novel entities. Novel entities include: (1) cellular agriculture, (2) gene editing/CRISPR (clustered or clusters of regularly inter-spaced short palindromic repeats), (3) blockchain technology, (4) engineered biomaterials, (5) technology-critical elements, and (6) nanomaterials [6,7]. Note that the first three groups are beyond the scope of the current discussion, which focuses on the remaining groups (high-technology rare earth elements, antibiotic/antimicrobial resistance, microplastics, EOCs) sharing a number of generic characteristics summarized below.

Despite the diversity among and even within the various groups, emerging contaminants share at least one of the following generic characteristics: (1) are currently unregulated due to lack of maximum guideline limits, (2) their human and ecological health risks are not yet well-understood, (3) are excluded in routine environmental monitoring or surveillance programs, and (4) require highly advanced and sensitive analytical equipment for their detection because they tend to occur in minute or low concentrations (e.g., ng/kg or ng/L) [5,6,8]. Due to their potential human and ecological health risks, emerging contaminants have attracted considerable global research attention in high- and middle-income countries, and to a lesser extent in low-income countries.

Globally, a large and growing body of literature exists on various emerging contaminants in the environment, including aquatic systems [9]. For example, several studies, including reviews, have investigated emerging contaminants in the following aquatic matrices: (1) surface water, (2) wastewaters, (3) groundwater, (4) drinking water systems, and (5) biota (including aquatic and marine foods). A number of books focusing on emerging contaminants also exist [9,10]. However, a qualitative analysis of the literature, including reviews, show that studies on the occurrence, behaviour, and fate of these contaminants in aquatic systems tend to dominate research compared to those investigating other aspects such as health risks. For example, research on quantitative health risk assessment in various environmental matrices, including aquatic ecology and humans, has relatively lagged behind that on the occurrence, behaviour, and fate of emerging contaminants. This lack of quantitative data is even more dire in the case of the human health risks of various emerging contaminants. The bandwagon (or Matthew) effect may partly explain this trend. The bandwagon effect occurs when a phenomenon or topic widely studied and reported in the literature continues to attract more research attention than those which are less studied [11,12]. The adverse impacts of the bandwagon/Matthew effect have been discussed in a number of earlier papers on emerging contaminants. These adverse effects include (1) the exclusion of equally important research topics in the research agenda and (2) unwarranted bias in the allocation of scarce research resources including funding, research time, and expertise [11,13].

An even more profound knowledge gap in the literature is represented by the lack of an organizing conceptual framework to guide the framing of research on emerging contaminants, including EOCs. The lack of an organizing conceptual framework has been pointed out in a few recent papers by the current author [6]. An organizing framework is critical to ensure that all key aspects of emerging contaminants are addressed in research in order to gain a comprehensive understanding of a field. In the literature, some of the commonly mentioned conceptual frameworks include the source–pathway–receptor model [14–18]. To date, only a few recent studies have applied the source–pathway–receptor model, and this has been limited to microplastics, nanomaterials, and legacy contaminants [14–18]. By comparison, application of the source–pathway–receptor model to emerging contaminant groups such as high-technology rare earth elements, antibiotic resistance, engineered biomaterials, and EOCs is still lacking. Moreover, the traditional source–pathway–receptor model is silent regarding behaviour and fate pathways, impacts or health risks on the receptors, as well as risk mitigation through preventive and control methods. This calls for an over-arching organizing conceptual framework to guide research on emerging contaminants. To address this key knowledge gap, the current Editorial perspective presents the Source–Pathway–Receptor–Impact–Mitigation (SPRIM) continuum framework as an organizing or decision-support tool for framing research on emerging contaminants (Figure 1). Here, a description of the SPRIM continuum framework and its key components are presented.

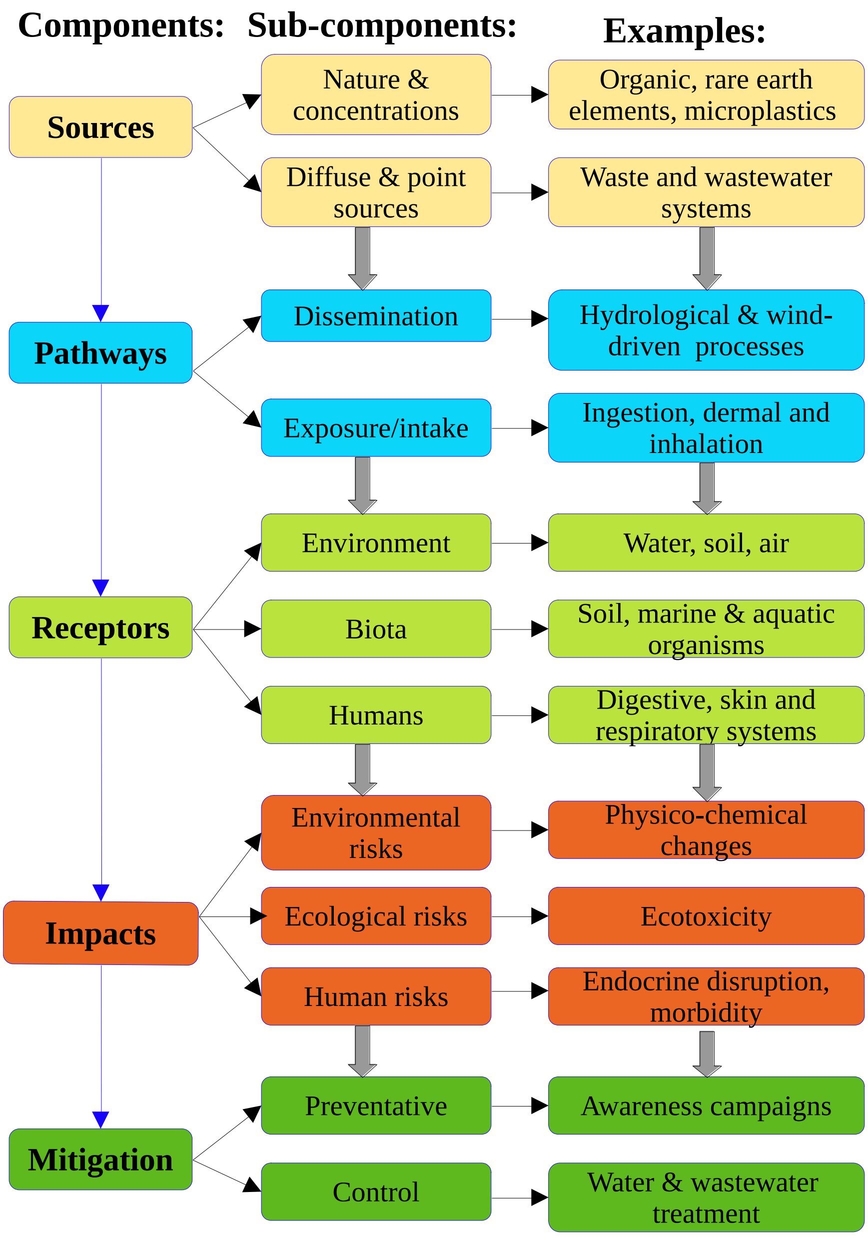

Figure 1. A summary depiction of the Source–Pathway–Receptor–Impact–Mitigation (SPRIM) continuum framework.

In summary, the present paper posits that, compared to the prevailing and seemingly ad hoc approach predominant in research on emerging contaminants, the potential novelty of applying the proposed SPRIM continuum framework is that it addresses the bandwagon or Matthew effect. As decision-support tool, the SPRIM continuum framework serves a dual function as a: (1) checklist to identify key knowledge gaps and frame future research, and (2) primer for promoting collaborative research and application of emerging big data analytics in research on emerging contaminants. Collectively, it is envisaged that the SPRIM continuum framework will provide a comprehensive and balanced understanding of various aspects on emerging contaminants relative to the current approach. Future research directions are discussed in light of the SPRIM continuum framework. The Editorial perspective closes with concluding remarks and a look ahead on the Special Issue entitled 'Emerging Organic Contaminants in Aquatic Systems: A Focus on the Source–Pathway–Receptor–Impact–Mitigation Continuum'. Note that although the present Special Issue focuses on EOCs, the SPRIM continuum as an organizing framework and decision-support tool is cross-cutting and generic, and thus is also relevant to other groups of emerging contaminants summarized earlier.

2. SPRIM Continuum Framework

The SPRIM continuum framework comprises of five (5) key components: (1) sources, (2) pathways, (3) receptors, (4) impacts/risks/consequences, and (5) mitigation (Figure 1). Here, a brief description of each component is presented. A further description of the SPRIM continuum is presented in a number of earlier papers by the current author [6,9], while related concepts such as the source–pathway–receptor model are discussed elsewhere [16–18].

2.1. Sources

In the SPRIM continuum framework, the sources include the following: (1) the nature and concentrations of the emerging contaminants, (2) anthropogenic emission sources of the emerging contaminants, including both point and diffuse sources, and (3) hotspot reservoirs that receive, harbour, then further transmit emerging contaminants. Examples of sources include industrial and domestic waste and wastewater systems [1,18,19].

2.2. Pathways for Dissemination, Exposure, Behaviour, and Fate

In the literature, the term 'pathways' collectively refers to (1) the routes or mechanisms by which emerging contaminants undergo dissemination/migration from the source to other environmental compartments and (2) the exposure routes or mechanisms, including the exposure media, and single as well as multiple exposure or intake routes [16,17]. However, this notion excludes pathways controlling the behaviour and fate of emerging contaminants (e.g., degradation pathways), which are not currently addressed in any other aspect of the SPRIM continuum. Thus, the present paper addresses pathways including the physico-chemical and biochemical conversion, degradation and excretion routes or mechanisms that control the behaviour and fate of emerging contaminants in the SPRIM continuum. Note that, in this context, the behaviour and fate of emerging contaminants are not limited to one compartment in the SPRIM continuum. Rather, these processes occur along the entire SPRIM continuum, including in sources, along dissemination or exposure pathways, in receptors, during the course of exerting human and ecological health impacts, and ultimately in the mitigation phase (e.g., removal and fate in water and wastewater treatment systems).

2.3. Receptors

In the SPRIM continuum framework, the term 'receptors' can be applied at different levels, including: (1) environmental matrices or compartments impacted by emerging contaminants, such as water, air, soil, biota, and humans; (2) specific organisms, populations or communities in an aquatic ecosystem; (3) at the organismal level, receptors refer to organs, systems (e.g., respiratory, endocrine, enzyme), and biomolecules and biochemical processes (oxidative stress); and (4) specific target cell receptors in organisms. Thus, the receptors can be identified at various levels of biological organization, including at molecular, cellular, system, organism, individual, population, and community levels. At higher levels of biological organization, receptors may also be identified at the level of ecosystem functions, biodiversity, goods, services, and benefits.

2.4. Impacts/Risks

The impacts, also known as consequences, are the human and ecological risks of the emerging contaminants at various levels of biological organization following exposure of receptors via multiple pathways. These levels of biological organization are as described earlier for receptors. Specifically, this includes impacts or risks at scales from molecular to higher levels, including ecosystem functions, goods, services, and benefits. Related to impacts or consequences are end-points used as indicators of impacts or risks. These end-points include biometric (e.g., growth), biochemical (e.g., enzyme inhibition), and histopathological morbidity and mortality indicators.

2.5. Mitigation

The term 'mitigation' has a broad meaning in the SPRIM continuum framework, including: (1) exposure and health risk assessment to identify hotspots or high-risk areas, as well as those at high risk of exposure; (2) preventative methods and barriers aimed at avoiding exposure to emerging contaminants and their health risks; and (3) control methods meant to remove, inactivate, and/or detoxify emerging contaminants in order to reduce exposure and/or health risks. Several health risk assessment tools exist, including both qualitative and quantitative tools. Mitigation approaches for safeguarding environmental, ecological, and human health include: (1) engineering approaches relying on removal or detoxification methods or technologies including those used for waste, water and wastewater treatment; (2) non-engineering or soft engineering approaches including awareness and educational campaigns to cause behavioural changes. A detailed discussion of the mitigation of emerging contaminants, including the application of integrated approaches, is presented in a previous paper [19–21].

3. SPRIM as a Framing and Decision-Support Tool for Research

3.1. Merits and Opportunities

Figure 2 depicts how the SPRIM continuum concept can be used to develop a checklist of questions for use as a decision-support tool for framing research on emerging contaminants. For example, given an emerging contaminant of interest, the SPRIM continuum framework can be used to evaluate the evidence to determine the most-studied and poorly understood aspects. Then, the under-studied aspects are used as a basis to develop and frame future research, thus avoiding duplicating previous research efforts. Using the SPRIM continuum to determine what aspects of emerging contaminants are well-studied versus those that are poorly understood constitutes the decision-support application of the framework. If all aspects of the SPRIM continuum for a given emerging contaminant are well-known, this then justifies the need to identify other emerging contaminants. Once another emerging contaminant of potential investigation has been identified, the process is repeated, starting with the evaluation of evidence with respect to the sources of the emerging contaminant (Figure 2). Relative to the current ad hoc approach to research on emerging contaminants, the SPRIM continuum framework has the merits summarized below.

3.1.1. Providing a Comprehensive Understanding of Emerging Contaminants

The application of the SPRIM continuum framework avoids the current seemingly narrow focus on a few aspects pertaining to emerging contaminants. In this regard, regular reflection and reference to the SPRIM framework can be used to assess the extent to which research at any given point in time covers the key aspects of the SPRIM continuum. Thus, given scientific evidence based on a group of or individual emerging contaminants, a checklist or matrix can be developed using the SPRIM components to evaluate the extent to which the studies address aspects relating to sources, pathways, receptors, impacts/risks, and mitigation. Then, a simple tally of the data can show aspects that are well-studied versus those that are under-represented in the literature, and thus in need of further research.

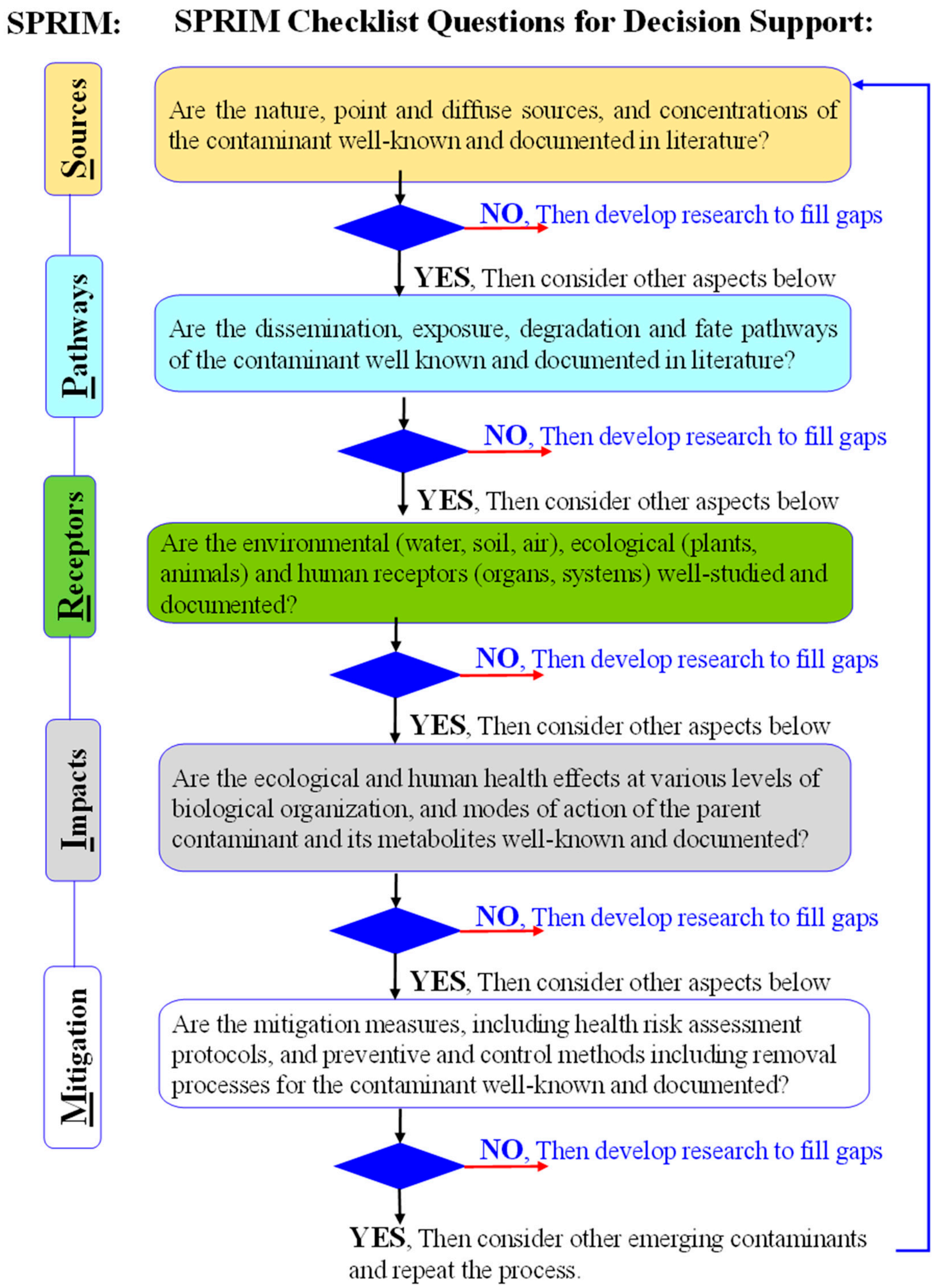

Figure 2. A flow-chart depicting the Source–Pathway–Receptor–Impact–Mitigation (SPRIM) continuum framework as a decision-support tool to frame research on emerging contaminants.

3.1.2. SPRIM Continuum Framework as a Complementary Tool to Quantitative Reviews

Although often time-consuming and requiring expert skills compared to qualitative or narrative reviews, quantitative reviews are critical in understanding various aspects of a research field. Quantitative reviews include those based on bibliometrics or scientometrics, meta-analysis, and big data analytics. Quantitative reviews, including those based on bibliometric, meta-analytic, and big data analytic approaches, can be used to identity temporal and spatial patterns in research, classic articles (highly cited), sleeping beauties (pioneering papers whose scientific importance is not recognized for several years after publication), and under-studied aspects. For example, the SPRIM continuum framework combined with word cloud analysis based on articles in scholarly databases such as Scopus, Web of Science, and Google Scholar can provide an overview or summary of research on a field via textual data visualization. Thus, combining textual data visualization and the SPRIM continuum framework provides a more nuanced overview of a research field than textual data visualization or SPRIM alone.

3.1.3. Overcoming the Bandwagon Effect and its Impacts on Research

A regular analysis of research on a particular group of or specific emerging contaminants using the SPRIM continuum framework may assist researchers, decision-makers and policy-makers, including funding agencies, to identify prominent focal research areas in a field. These prominent focal research areas tend to be over-subscribed by researchers in terms of grant proposals, research effort and time, and even publications (i.e., bandwagon/Matthew effect). Identifying where the bandwagon/Matthew effect occurs in a research field using the SPRIM continuum framework provides insights into under-represented but relevant topics. In turn, this can guide the prioritization and allocation of scarce resources, including funding. Thus, the SPRIM continuum concept can be used as a framing tool to avoid the bandwagon/Matthew effect and its impact on research, including bias in the allocation of scarce research resources.

In summary, in view of the foregoing, the SPRIM continuum framework, especially when combined with data visualization tools, may provide the most relevant information to decision- and policy-makers, including funding agencies. In this regard, the SPRIM framework can be used to channel resources to research by addressing the following questions related to decision- or policy-making: (1) What are the most prominent and funded research topics on emerging contaminants? (2) What are the research trends and key knowledge gaps? (3) Are there adequate original articles on a topic for a commissioned synthesis review to formulate decisions and policies? (4) What are the critical knowledge gaps to be addressed prior to decision- and policy-making?

3.1.4. The SPRIM Framework: A Primer for Collaborative Research and Application of Big Data Analytics

Evidently, the SPRIM continuum transcends various disciplines, including environmental sciences, microbiology/ecology, (eco)toxicology, human toxicology, epidemiology, and civil/environmental engineering. Thus, addressing the various aspects of the SPRIM continuum calls for systematic collaboration among diverse team members, each with their own academic and research background, experience, and methodologies. In this regard, the SPRIM continuum framework may serve as a primer or tool to promote collaborative research on emerging contaminants. Yet, collaborative research projects could pose potential challenges with respect to data collection protocols, and how the resulting data are archived, labelled, organized, analysed, and visualized. One option to avoid such potential conflicts is to include the core team members during each stage of the project, from research conceptualization, design, implementation, analysis and interpretation of data, to subsequent communication to the various stakeholders. This approach will ensure a collective understanding of the research protocols and the entire project.

Admittedly, a collaborative project involving a diverse research team and addressing the entire SPRIM continuum will generate a putative large dataset. Such large or massive datasets could be collected at different spatial and temporal scales, have varied and complex structures, and are often expressed in various units, depending on the discipline. Large datasets with complex and varied structures, which are difficult to store, retrieve, analyse, and visualize for further processing and application in decision- and policy-making are regarded as big data [22,23]. In turn, big data analytics has the potential to handle such large and complex data.

Big data analytics refers to a suite of related analytical processes or techniques of analysing and researching large datasets to reveal hidden or salient spatial and temporal patterns, trends, and relationships, which may not be apparent using conventional statistical tools [22,23]. Big data analytics is a collective term referring to analytical tools such as data mining, network analysis, artificial neural networks, and machine learning or artificial intelligence. Although big data and big data analytics are attractive research tools in emerging contaminants, their application is still limited. In fact, the present call reiterates earlier ones highlighting the need to harness big data techniques to better understand the occurrence, behaviour, fate, and health risks of emerging contaminants [13,24–26]. Thus, the need to analyse big data generated from research based on the SPRIM continuum framework could act as a precursor for the application of such big data analytical tools in research on emerging contaminants.

3.2. Overview of Current Applications of the SPRIM Continuum

The merits and opportunities offered by the SPRIM continuum framework make it an attractive tool for framing research on emerging contaminants, including EOCs. However, to date, its application remains limited, even for research on legacy or traditional contaminants. For example, a rapid qualitative review of scholarly databases such as Google Scholar and Scopus shows that the source–pathway–receptor model, which is a variant of the SPRIM framework often excluding the impacts/risks and mitigation, has only been applied to the following legacy or traditional contaminants:

(i) Toxic trace metals [14,28];
(ii) Solutes such as nutrients (N, P) and sediments [15];
(iii) Pathogenic and indicator organisms such as *E. coli* [29].

The application of the SPRIM continuum framework to emerging contaminants is still in its infancy. The few exceptions applying the source–pathway–receptor model are limited to the following emerging contaminants:

(i) Nanomaterials [16,17];
(ii) Microplastics [18,30].

However, a series of recent reviews by the current author pointed out the need to apply the SPRIM continuum as an organizing framework for research on emerging contaminants [6,9,13,30]. The reasons for the low application of the SPRIM continuum framework even for legacy contaminants are unclear, but could point to potential challenges as summarized below.

3.3. Challenges and Potential Solutions

As a relatively new field of research, the application of the SPRIM continuum framework to emerging contaminants could be indicative of potential challenges. These potential challenges are summarized here.

3.3.1. SPRIM Continuum Data Acquisition Is Cumbersome and Costly

Data acquisition using conventional monitoring and laboratory analytical tools covering the whole spectrum of the entire SPRIM continuum is putatively cumbersome, time-consuming, and costly. Therefore, given that most research projects have a timeline of about 3 years, this may limit the application of the SPRIM continuum framework. For this reason, studies often focus on a few aspects rather than the entire SPRIM continuum. This calls for long-term studies and the use of novel tools for rapid data acquisition, including the development, validation, and application of automated sensors for the monitoring and detection of emerging contaminants. Other tools to be explored include the use of emerging monitoring tools such as remote sensing, GPS, and GIS for the rapid acquisition of data at various temporal and spatial scales. Given that data on the SPRIM continuum can be large and in various formats, such data may qualify as big data [30]. Thus, the acquisition and analysis of such big data harness emerging advanced tools for the better synthesis, storage, retrieval, analysis and visualization of results. Such tools include network analysis, genomics, data mining, and models. A detailed discussion of the novel and emerging tools, as well as their applications in research on emerging contaminants, are given in previous papers [13,31].

3.3.2. Application of SPRIM Continuum Framework Falls in 'No Man's Land'

The SPRIM continuum covers a wide range of disparate aspects often researched by various experts. For example, on the one hand, the occurrence, behaviour, and fate and environmental dissemination of emerging contaminants are often research domains covered by environmental and earth scientists. On the other hand, exposure pathways, receptors, and ecological health risks are niche research areas for biological scientists, including environmental microbiologists and terrestrial, marine, and aquatic ecologists. Furthermore, aspects pertaining to humans, including exposure pathways, receptors, and health risks, as well as the pharmacology and epidemiology of emerging contaminants, are the domains of medical and public health experts. Health risks assessment and mitigation, including preventive and control methods, may be the concern of environmental engineers, chemists, water/wastewater engineers, and materials scientists, who develop and evaluate novel materials for the remediation of emerging contaminants to safeguard human and ecological health. Thus, SPRIM continuum components are split among several, often disparate, research disciplines. Currently, however, only a few of these disciplines (environmental scientists, biologists, chemists) tend to dominate research on emerging contaminants. In contrast, experts in other fields such as medicine tend to play a lesser role in research on emerging contaminants. It is well-known that when a topic falls among or is split among two or more major disciplines, it tends to be overlooked by the different disciplines [13,27]. In other words, the subject falls into 'no man's land', and tends to be under-studied compared to those falling within specific disciplines. Such topics constitute blank and blind spots in research on emerging contaminants. Thus, addressing the SPRIM continuum calls for more collaboration among traditionally disparate fields such as environmental science, chemistry, biology, epidemiology and biostatistics.

3.3.3. Potential Caveats in Publishing SPRIM Continuum Research

The SPRIM continuum framework covers various components (Figure 1). Therefore, field-based papers or even reviews attempting to apply the SPRIM continuum framework may be considered by journal reviewers and editors as overly broad and lacking focus. This may make the publication of papers investigating the whole spectrum of the SPRIM continuum problematic and less attractive. Options to overcome this limitation include publishing papers as sequels of several related papers, for example, as papers I, II, III, IV and V, each focusing on a specific aspect of the SPRIM continuum. This could then be followed by an integrative or synthesis paper using novel tools such as modelling to gain further insights which may not be apparent in the individual papers. Such effort should not be misconstrued as salami publishing, an unethical publishing practice aiming to obtain two or more publications from a single study at the expense of one comprehensive study. Alternatively, the series of papers could be published as a Special Issue targeting only papers addressing the whole SPRIM continuum. Lastly, there is also scope to compile synthesis papers that rely on multiple studies addressing various aspects of the SPRIM continuum. Such studies may include synthetic reviews and those based on big data analytics as well as in silico or computational modelling. To achieve this, it is critical for researchers to make raw data investigating various components of the SPRIM continuum readily available for further analysis and synthesis.

3.3.4. Lack of Modelling Tools for SPRIM Continuum

As an emerging field of research, emerging contaminants, unlike legacy contaminants, still lack appropriate tools such as Source–Pathway–Receptor–Impact–Mitigation models to track emerging contaminants in the SPRIM continuum. This observation has been pointed out in earlier papers on emerging contaminants [28,29]. Earlier efforts to address these gaps include a conceptual framework proposed for emerging contaminants based on the source–fate–transport concept [28,29]. However, these frameworks still lack comprehensive information on aspects such as human exposure and health risks, as well as mitigation using various preventative barriers or control methods. However, these recent advances provide scope for the further development, validation, and application of such process-based models for tracking emerging contaminants in the SPRIM continuum.

4. Closing the Blank and Blind Spots in SPRIM Continuum

A qualitative analysis of the evidence on emerging contaminants using the SPRIM continuum framework shows that several knowledge gaps still exist. These key knowledge gaps which constitute the blank and blind spots in research on emerging contaminants are highlighted under each component. Note that the list is not comprehensive or exhaustive, and thus the reader is referred to comprehensive reviews including a dedicated book by the current author on various emerging contaminants, including high-technology rare earth elements, antibiotics, microplastics, and synthetic organic chemicals [9]. Note that in the case perfluoroalkyl and polyfluoroalkyl substances (PFASs), also known as 'forever' chemicals, various aspects of the SPRIM continuum remain relatively under-studied compared to other groups of emerging organic contaminants. Here, an overview of the state-of-the-art research on each component is presented, followed by a summary of some of the knowledge gaps and future research needs.

4.1. Sources

There is currently a significant body of literature on the sources of emerging contaminants, with the bulk of studies focusing on waste and wastewater systems. Several reviews also exist on the occurrence of emerging contaminants in various sources, including wastewaters [1,19]. Among emerging organic contaminants, the group of pharmaceuticals and personal care products tends to dominate research compared to other groups such as flame retardants, gasoline additives, artificial sweeteners, and musks and fragrances. However, the following aspects warrant further research attention:

(i) Novel sources of emerging contaminants such as the funeral industry [13,31] and beauty parlours such as spas and hair salons, where various emerging contaminants are potentially in use;
(ii) Putative hotspot sources such as on-site sanitation systems (e.g., pit latrines and septic tanks) commonly used in low-income settings;
(iii) Deposition of airborne emerging contaminants as a diffuse source of pollution;
(iv) The partitioning or apportionment of emerging contaminants among the various sources.
(v) In addition to pharmaceuticals and personal care products, more research is needed on currently less-studied groups such as musks and fragrances, gasoline additives, flame retardants, and artificial sweeteners.

Hence, further research is required to address these gaps.

4.2. Pathways for Dissemination, Exposure, Behaviour, and Fate

A number of studies have investigated the dissemination, behaviour, and fate of emerging contaminants in aquatic environments such as wastewaters and drinking water systems [30]. However, the bulk of these studies are short-term in nature, while studies on dissemination pathways tend to be narrative, qualitative, or inferential. Thus, a closer examination of the evidence revealed the following gaps:

(i) The relative contributions of the various dissemination and exposure pathways are still poorly understood;
(ii) Long-term data on the behaviour and fate of emerging contaminants are still lacking; hence, the long-term degradation kinetics and the controlling factors are poorly studied, especially in the predominantly tropical environments in low-income regions such as Africa;

(iii) Data on the behaviour and fate of emerging contaminants are limited to static media, while those investigating these processes during the course of dissemination and exposure are still limited.

4.3. Receptors

A number of studies, including reviews, have investigated receptors in terms of impacted environmental compartments and organisms in specific ecosystems (e.g., aquatic environments) [31]. However, data are still limited on the following:

(i) Specific receptors of emerging contaminants within an organism at cellular, process, and system levels;
(ii) Receptors in the human body following exposure via multiple routes;
(iii) Receptors at higher levels of biological organization, specifically ecosystem functions, goods, services, and benefits;
(iv) How the emerging contaminants cascade through receptors at various levels of biological organization.

4.4. Impacts/Risks

A number of studies have investigated the impacts of emerging contaminants on aquatic organisms at individual and process levels, and a few at the level of trophic interactions [32]. However, limited studies have investigated the following:

(i) Ecological impacts at higher levels of biological organization, including ecosystem function, goods, services, and benefits;
(ii) Biodiversity loss due to emerging contaminants relative to other environmental and anthropogenic stressors;
(iii) Quantitative epidemiological human exposure and health risks of emerging contaminants associated with ingestion, dermal intake, and inhalation—in fact, the lack of direct evidence linking emerging contaminants in the environment to specific adverse human health outcomes in terms of morbidity and mortality is one of the key knowledge gaps.

4.5. Mitigation

The mitigation of emerging contaminants, particularly their removal in aquatic environments including water and wastewater systems via treatment methods, is one of the most researched aspects [20,21,32,33]. For example, several studies have investigated the removal of various emerging contaminants using conventional and advanced removal methods, and several reviews exist on the subject [20,33]. The bulk of these studies used artificial or synthetic solutions or mixtures of emerging contaminants. Other studies have also developed health risk assessment tools, including qualitative and quantitative ones [5,34]. However, analysis of the evidence revealed the following gaps:

(i) Limited evidence exists on the removal of emerging contaminants in real wastewaters or drinking water contaminated with emerging contaminants; unlike synthetic or artificial solutions of emerging contaminants, real water or wastewaters are more complex, and in such matrices, co-occurring legacy and emerging contaminants may interfere with the removal of emerging contaminants;
(ii) The removal of emerging contaminants by low-cost treatment methods such as biosand filtration, boiling, ceramic filters, and solar disinfection (SODIS) has received cursory attention; to date, studies on the removal of emerging contaminants have focussed on methods commonly used for conventional or advanced water and wastewater treatment systems.

Collectively, these knowledge gaps, which motivated the present Special issue, constitute some of the key blank and blind spots which should form the next research frontier on emerging contaminants.

5. Concluding Remarks and a Look Ahead

Until now, the need for an organizing conceptual framework as a decision-support tool for framing research on emerging contaminants, including synthetic organic chemicals, has received cursory attention. To address this gap, the current Editorial perspective for a Special Issue proposes the Source–Pathway–Receptor–Impact–Mitigation (SPRIM) continuum concept as an organizing framework and decision-support tool to guide the framing of research on emerging contaminants. The summary contributions of this Editorial perspective are as follows:

(i) A description of the SPRIM continuum framework and its components was presented;
(ii) The potential applications and merits of the SPRIM continuum framework relative to the current ad hoc approach were discussed;
(iii) The challenges associated with the application of the SPRIM continuum framework were discussed, and proposed solutions were presented;
(iv) Current research focal areas and future directions on emerging contaminants were highlighted in light of the SPRIM continuum framework.

The SPRIM continuum framework is a generic decision-support tool to guide the framing of research on emerging contaminants, including EOCs. In summary, compared to the prevailing and seemingly ad hoc approach predominant in research on emerging contaminants, the potential novelty of applying the proposed SPRIM continuum framework is that it addresses the bandwagon/Matthew effect. As a decision-support tool, the SPRIM continuum framework serves a dual function: (1) as a checklist to identify key knowledge gaps and frame future research, and (2) as a primer for promoting collaborative research and application of emerging big data analytics in research on emerging contaminants. Collectively, it is envisaged that the SPRIM continuum framework will provide a comprehensive and balanced understanding of various aspects of emerging contaminants relative to the current approach.

The present Special Issue entitled 'Emerging Organic Contaminants in Aquatic Systems: A Focus on the Source–Pathway–Receptor–Impact–Mitigation Continuum' calls for high-quality contributions addressing EOCs in aquatic systems in the context of the SPRIM continuum. As a Guest Editor, I therefore welcome and look forward to several high-quality contributions addressing EOCs in at least one component or the entire spectrum of the SPRIM continuum. In the short and long term, one hopes to witness an increase in the number of papers paying attention to, and applying, the SPRIM continuum as an organizing framework and decision-support tool to guide research on EOCs.

Funding: This research received no external funding.

Data Availability Statement: No data were generated in this study.

Acknowledgments: I am grateful to Chicgoua Noubactep, who edited the manuscript to improve the clarity of presentation. I am also grateful to the reviewers' comments that greatly improved the manuscript and motivated the following specific revisions: (1) further detailed description of framework; (2) Figure 2, a checklist illustrating how to use the concept as a tool to frame future research; and (3) The SPRIM framework: A primer for collaborative research and use of big data analytics. However, I am entirely responsible for any views and opinions expressed in the manuscript.

Conflicts of Interest: The author declares no conflict of interest.

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