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ABSTRACT

Pollutant Release and Transfer Registers (PRTRs) collect and provide information on chemicals released to the environment or otherwise managed as waste. They support the public's right–to-know and provide useful information in gauging performance of facilities, sectors and governments. The extent to which these data have been used in research, particularly in relation to human health, has not been documented. In this scoping review our objective was to learn from scholarly literature the extent and nature of the use of PRTR data in human health research. **We performed** literature searches (1994-2011) using various search engines/key words. Articles selected for review were chosen following predefined criteria, to extract and analyse data. One hundred and eighty four papers were identified. Forty investigated possible relations with health outcomes: Thirty-three of them identified positive associations. The rest explored other uses of PRTR data. Papers identified challenges, some imputable to the PRTR.

We conclude that PRTR data are useful for research, including health-related studies and have significant potential for prioritizing research needs that can influence policy, management and ultimately human health. In spite of their inherent limitations, PRTRs represent a perfectible, unique useful source, whose application to human health research appears to be underutilized. Developing strategies to overcome these limitations could improve data quality and increase its utility in future environmental health research and policy applications.

Keywords:

Pollutant Release and Transfer Registries; PRTR; human health; industrial emissions; toxic chemical releases

INTRODUCTION

Pollutant Release and Transfer Register (PRTR) is the generic term used to describe a type of publically available database that contains information on the quantities of toxic chemicals or other pollutants released from industrial facilities or other businesses to air, water and land, or otherwise managed as waste (e.g. recycled, burned for energy recovery) within a given country. A PRTR is established and maintained by a country's national environmental authority. The pollutant amounts reported to a PRTR are not always based on direct measurements, but are usually based on estimates. Estimated emission quantities are often derived from different methods including mass balance or engineering calculations, and emission factors relating a pollutant amount to production/activity levels. The accuracy of these depends on the available estimation methodology, and therefore may differ in the level of accuracy. These data are typically submitted to the authority maintaining the PRTR on a regular basis (usually annually) by facilities that are required to report such information. Some PRTRs also include estimates of releases from diffuse sources, such as agriculture, transportation and the end use of products (PRTR.net 2012).

The purpose of PRTRs is primarily to increase the public's knowledge of, and access to, information on the releases and other waste management practices of toxic chemicals and other pollutants in their communities. This information: provides the public with knowledge on the dispositions of pollutants in their communities; help enable citizens to make informed decisions regarding the consequences of such dispositions; and enable citizens to take action. Federal, regional, state, and local governments also use PRTR data for prioritization purposes. The development and implementation of a PRTR adapted to national needs assists governments in tracking the generation, release, and fate of emissions of toxic chemical substances and other pollutants over time, examining progress in reducing emissions, and setting pollution prevention and sustainability priorities.

Publically available PRTRs began to be established after the 1984 industrial disaster in Bhopal, India, which sparked interest in community right-to-know programs (Harjula 2006). The United States' Toxics Release Inventory (TRI) was the first public PRTR. EPA published its first annual TRI dataset in June of 1989, which pertained to toxic chemicals discharged from facilities in 1987 (EPA 2012b) (Environmental Protection Agency 1989).

Encouraged by the Organization for Economic Co-operation and Development (OECD) 1996 recommendation on implementing PRTRs (Harjula 2006), many other countries in most parts of the world have since established and /or modified their own PRTRs. Currently, more than 50 countries have implemented a fully operational PRTR or pilot PRTR. Examples of other PRTRs are: Canada's National Pollutant Release and Transfer Inventory (NPRI), European Union's European Pollutant Emissions Register (EPER), Australia's National Pollutant Inventory (NPI), Mexico's Registro de Emisiones y Transferencia de Contaminantes (RETC). More countries will join the PRTR initiative in the coming years. International efforts to reduce health impacts from toxic environmental chemicals have prompted the United Nations Institute for Training and Research (UNITAR) to promote implementation of PRTRs in more countries (UNitar 2013).

Though PRTRs are defined internationally (PRTR.net 2012), and many are modeled after the U.S.' TRI, many of the existing PRTR systems vary widely from country to country, particularly in the chemicals tracked, coverage of industrial sectors and activities, and in how emission and other reportable quantities are determined. These differences can be ascribed to the fact that a given country will engineer its PRTR within the boundaries of existing statutory authority and its country-specific goals and objectives as the drivers behind the PRTR structure. As countries' goals and objectives and environmental statutory differ, therefore so do countries' resulting PRTRs. The differences among PRTRs from different countries lead to comparability issues when trying to compare or integrate data from the PRTR of one country with data contained in the PRTR of another country (Kerret and Gray 2007).

As PRTR data are intended for a wide variety of users, including government agencies, industry managers, scientists, community groups, and the general public, making this information available to, and useable by these separate user groups is an ongoing priority of any PRTR system (PRTR.net 2012). PRTR information is frequently made available through internet-based tools that enable users to conduct analyses online, or in downloadable form for subsequent analysis. As part of their periodic (e.g., annual) update with newly reported information, many environmental authorities supplement the information with an official report that identifies trends or other noteworthy observations and provides analyses of specific chemicals, sectors, and geocoded locations of interest. Some governments publish interactive maps of the complete database and some publish tools to create maps from the data, such as the U.S Environmental Protection Agency's TRI Explorer, TRI.net, and MyRTK tools (EPA 2012b). However, given the ever-advancing field of information technology, and evolving needs of PRTR data users, making the information available in its most useable forms is an ongoing priority.

Worldwide, the disclosure of routine emissions and transfer quantities of toxic chemicals to PRTRs has been a major factor in the reduction of pollutant emissions generally observed in countries that have PRTRs (Bui and Mayer 2003; Thorning 2007). Community groups have used PRTRs to directly influence management of facilities in which concerns were identified (Jackson

2000). Thus the PRTRs contribute to the public's access to information and influence reductions in pollutant releases (Harrison 2003).

Policy makers, decision makers, and communities are concerned about negative health outcomes resulting from toxic chemical releases. PRTR data, in conjunction with additional information (e.g. pollutant characteristics), can provide starting points in the determination of potential impacts of these releases on human health. Identification and characterization of any causal associations between pollutants and health impacts require exposure assessments, ideally at the personal level and through the use of monitored data (Zou, Wilson et al. 2009). Nevertheless, this is not achievable at times when examining possible impacts of hundreds of chemicals, making PRTR emission data a source of surrogate chemical exposures for a comprehensive amount of chemicals in large population studies (**Table 1**), as part of a continuum in exposure assessment.

Beyond that, the potential economic impact associated with health risks can also be estimated. For example, in the Canadian province of Ontario total toxic pollution was positively related to per capita health expenditures. Future public health investment, therefore, should include environmental protection since this may potentially reduce health expenditures (Jerrett, Eyles et al. 2003). Using PRTRs as a tool, research may be able to identify potential causal relationships between pollution emissions and negative health outcomes within given localities. This provides decision makers with more evidence upon which to develop relevant policies intended to reduce negative health outcomes and their associated economic costs.

***Utilizing PRTR data*:** In order to promote the proper use and applicability of PRTR data, most PRTR Programs, as well as organizations that embrace the usefulness of PRTRs (e.g., the OECD), have developed guidance documents, tools, and methods for utilization of the data. In addition, several groups have also developed user-friendly tools for individual and community use. Examples of such tools include:

- THE RIGHT-TO-KNOW NETWORK (RTKNET.ORG 2009);
- *Scorecard*: the pollution guide: GoodGuide (Scorecard 2011);
- CAREX CANADA Surveillance of environmental & occupational exposures for cancer prevention (CAREX 2012);
- *Taking Stock Online*, a North American integrated PRTR database developed by the Commission for Environmental Cooperation (CEC 2011);
- *Centre for PRTR Data*, a tool developed by the OECD through the United Nations Economic Commission for Europe (OECD)

However, the available tools for accessing data are generally insufficient for users who want to access non-aggregated data and to identify individual or community health risks (Hammond, Conlon et al. 2011). At a public meeting of the 'North American meeting of the Commission for Environmental Cooperation' North American PRTR project held in 2010 (CEC), concerns were raised about the lack of broad use of these data and the need for increased applicability and wider use of PRTR data.

While awareness of PRTRs may be high among environmental groups (Thorning 2007), it is very low among the general public with studies citing from 2% to 11% awareness level (Aoyagi 2007; Atlas 2007; Thorning 2009). These findings may relate to peoples' indifference or to the complexity of the data and the clarity of their relationships with health outcomes. In spite of the development of various tools, communities still need expert assistance to interpret and to translate the data into a usable form (Hammond, Conlon et al. 2011).

Interested in the use of PRTR data to investigate associations between pollution and human health outcomes, we performed preliminary searches identifying a limited number of peer-reviewed articles. Therefore, we decided to expand the search to encompass all uses of PRTR aiming to mine the scholarly literature in order to characterize the extent and nature of the use of PRTR data in human health-related research, and evaluate its usefulness in such research. Specifically, the objective of this paper is to identify and examine the range and nature of the scholarly literature in which the scientific community has used PRTR data (particularly in association with human health outcomes), summarize and disseminate our research findings, and identify research and knowledge gaps.

Our findings may also guide improvements to PRTR data reporting. Improved data could be used to promote advancements in environmental management leading to reductions in emissions of harmful substances and support decision-making related to human health and the environment.

THE SCOPING REVIEW PROCESS

We chose to undertake a scoping review given the relatively undeveloped state of this field of research and limited comparability among publications that used PRTR data, following Arksey and O'Malley's framework (Arksey 2005).

Data selection process:

Papers were included if they used PRTR data. Only English language, peer reviewed works (including conference proceedings, books and theses, but not reports) were included, and only those for which full text was available. Date limits were established by the dates of the initial release of the first PRTR in 1988 (i.e. US TRI). We selected documents published before July 2011.

1. As a first step, we used a broad research theme that assisted in identifying relevant literature from a variety of resources and included both qualitative and quantitative studies in our results. Various search techniques and terms were used to maximize potential findings. Keywords were used individually or in combination and included:

(PRTR, “pollution release and transfer”, “release and transfer reg*”, “toxics release inventory”)

(medic*, health*, pediatric, illness, wellness, cancer, carcinoma, paediatrics*, asthma, copd).

These searches were later broadened and refined to include: (toxics release, npri, national pollut*, pollut* release) (simulate, dispers*, model, analys*, develop*, design*, understand*, evaluat* , indicat*, appl* , validat* , verif*, research, systematic) NOT (National Pollutant Discharge Elimination System). Where appropriate controlled vocabulary terms, such as those in the Medical Subject Headings (MESH) were also searched.

Databases included: Compendex, EMBASE, Environment Abstracts, GEOBASE, Global Health, MEDLINE, Pascal, Pollution Abstracts, and Scopus. Proquest Dissertations and Theses Databases were searched for works containing TRI or PRTR and related terms. As many studies did not document the US’s TRI as a PRTR, searches for TRI and health terms in MEDLINE and Scopus were performed. To capture further applications of PRTR data, Environment Abstracts, Pollution Abstracts, TOXLINE/toxicology, and Water Resources Abstracts were searched, using terms related to pollutant and toxic releases.

2. In order to ensure the search was comprehensive, we undertook a second step, searching for additional publications in the citations of the papers identified in stage one as using PRTR data to

examine the relationship with health outcomes. We added any new articles that fit the inclusion criteria to this study. All identified references were stored in the RefWorks citation management system.

RESULTS OF THE SCOPING REVIEW

Stage I: We identified 1318 records through database searches and hand searching. Cited reference searching identified 28 additional publications (Citations were checked for health outcomes only, due to the limited numbers of identified publications).

Stage II: After removing duplicates, 867 publications were screened. One reviewer screened the publications, using the inclusion/exclusion criteria defined above.

Stage III: In the second screening, one reviewer read 342 articles in full and those that met inclusion/exclusion criteria were selected. In cases of uncertainty whether or not a publication met the criteria, a second reviewer evaluated them. Searches and data handling were recorded.

Stage IV: 184 references fit the inclusion criteria and were included for synthesis.

Paper selection was documented according to the PRISMA flowchart (**Figure 1)**. This figure describes the overall flow of the scoping review literature search and publication selection process. Data extracted from the studies included: the study year, type of work, origin country of the PRTR data used, year of PRTR, chemicals, the study's objective, methods, outcomes studied, results, and identified limitations of PRTRs. Data were recorded in Excel spreadsheets and later formatted into evidence tables to manage the data and to chart key patterns and themes.

Two readers sorted these publications to the following two groups then:

1. Peer-reviewed studies that investigated PRTR data and actual human health outcomes data.

2. Peer-reviewed studies that investigated PRTR data and any other outcomes, or described other uses of the data.

Publications from both groups were then researched for challenges and limitations.

Only 184 of 1346 found documents met all selection criteria. Of the 184 documents, only 40 examined for associations between PRTR emissions with human health outcomes, and an additional 144 used PRTR data in other research undertakings. The identified publications included primary research articles, dissertations and theses and conference proceedings. These publications had diverse objectives and used a wide variety of methodologies. The earliest identified studies were published in 1993. Publication output followed an erratic upward pattern in time until 2009, when a downward tendency started to occur (**Figure 2**).

The extent, range, methods, and challenges identified are presented below, grouped by:

a) Human health outcomes
b) Other uses
c) Challenges and limitations

a) Human Health Outcomes

Our search identified 40 publications that described research aimed at identifying relationships between industrial emissions of toxic chemicals and other pollutants (as quantified in the form of PRTR data) and adverse effects on human health.

PRTR by country: of these studies, 34 (85%) used the TRI as the PRTR data source. The PRTR systems of other nations accounted for the remainder: five from the Spanish portion of the

European Pollutant Emission Register (EPER) and one from the UK's National Atmospheric Emissions Inventory (**Table 1**).

Years of publications: ranged between 1997-2011 (**Figure 2).** Publications started to appear in 1993, several years after the first PRTR was established. Although increasing numbers of publications were found, the distribution is erratic. It was not until 1997 that health related studies started to be published. Health studies were sparse before 2004, and their rate of publication increased in the following years.

Health outcomes studied: Of the identified studies, 24 (60%) investigated whether relationships exist between PRTR-related emissions and cancer incidence. Other health outcomes investigated include: negative birth outcomes, population mortality rates, neuro-developmental disorders, and other specific conditions (e.g. multiple sclerosis, asthma, and mental illness) (**Table 1**). Fourteen papers focused on child or maternal exposure (**Figure 3).**

Chemicals: The chemicals studied in the identified research varied (**Table 1**). Some used all reported emissions, while others used: chemical releases from specific industry sectors (such as manufacturing, paper and pulp, combustion facilities, metal production, petroleum refiners, or all industries) (**Table 1**). Some studies used chemicals that are known to cause a specific toxic effect (such as cancer or developmental toxicity), single chemicals (such as benzene, lead, or mercury), or a group of chemicals (e.g. metals, volatile organic compounds). Three further publications considered the location of PRTR reporting facilities to investigate health risk areas.

Methods and Results: More than half (22) of the papers described the use of one or more of a variety of statistical analyses and Geographic Information System (GIS) methods. The statistical methods used include: linear regression, Poisson regression, and Bayesian approaches. It was not possible to discern a specific pattern in the choices of statistical methods used. Most of the studies (33 out of 40, 82%) reported associations of varying strength between health outcomes and emission and seven papers reported no health associations.

b) Other Uses

In this category 144 publications were identified (**Table 2**).

PRTR by country: 93 publications used the TRI as the PRTR data source, 19 used Japan's PRTR, 11 used Canada's National Release and Transfer Inventory (NPRI), 6 used the European PRTR data, 6 used Australia's NPI, and 1 used Mexico's RETC. Eight studies compared data from more than one PRTR (US, Japan, Canada, Australia, Mexico, United Kingdom, Korea, and Europe).

Years of publication: studies were published between 1993 and 2011 (**Figure 1**). Increased numbers of publications started after 1995 with variations over time.

Chemicals studied: 79 studies looked at general emissions while 65 others looked at a specific chemical or groups of specific chemicals.

Other uses of PRTR data: publications have used PRTR data for diverse objectives (**Table 2**). Many of the publications used one or more of the objectives listed in **Table 2** (when studies fit into more than one category, they were classified by the main theme). This indicates the complexity of this field of research. In general, studies evaluated potential risk for human health (e.g. cancer) based on chemical characteristics only and not health outcomes, or assessed the impact of the potential health risk on housing market, corporate values, etc. Other studies assessed trends in chemical releases, evaluated emissions, and the environmental performance in response to different policies, public pressure, or changes in management. Still, other studies investigated the accuracy of the data presented, and chemicals' measurements and characteristics (i.e. flow, exposures, risk impact). The data were also used to describe demographics around facilities, including socio-economic variables, to examine possible relationships between emissions and other social variables. Lastly, some of the papers investigated awareness among members of the public about PRTRs and possible uses by communities.

Methods and presentation of results: The publications identified used a variety of analytic methods, such as: advanced statistic analysis, simple analysis using trends, comparisons, measurements, GIS (36 papers), and various modelling systems. There were at least 25 studies that focused on describing research tools, research models, or different methods to analyse PRTR data.

The studies used different tools and venues to present their research. These included the use of GIS or maps, human health index/toxicity index, websites, books/papers, public and government meetings and discussions, online tools, chemical rankings and formation of management frameworks.

c) Challenges and Limitations

This field of research is challenged by the data itself, as detailed in **Table 3 and Table 4**. The majority of publications (172 out of 184) identified limitations attributed either to research design, lack of supporting data, or to limitations imputable to the PRTR data. These limitations mainly included difficulties with data accuracy, quality, and completeness. Authors identified data quality/completeness issues that could affect the results of the data analysis such as: lack of non-threshold emissions reporting, under-reporting, change in reporting requirements over time, and lack of tracking for all chemicals in use (**Table 3**).

Other identified limitations could be imputed to study design or the lack of supporting data **(Table 4)**, including: the lack of use of confounding variables, such as demographic and socio-economic variables (major confounding) or other sources of exposures (i.e. occupational exposures, traffic, smoking - in the case of health studies). Other limitations relate to the lack of information of potential risk to human health from emissions tracked in PRTR; the lack of chemical dispersion estimations; and problems related to the frequent modifications of geographic unit areas that rely on the number of individuals living in those areas. In the health outcomes studies a specific limitation was identified relating to the lag time between exposure and health effects.

DISCUSSION

The objectives of this scoping review were to assess the use of PRTR data with specific focus on health related studies and to identify objectives and challenges of this type of research. In order to have a complete picture of research publications that used PRTR data, the different methods and challenges found in all publications using PRTR data were included in the analysis of results.

The impact of emissions of toxic chemicals on health is well documented. Even low-level chronic exposures to some chemical pollutants have been implicated as contributors to the increase and prevalence of diseases or illnesses such as cancer; negative developmental and birth outcomes; asthma; and neuro-development delay (Boeglin, Wessels et al. 2006; Whitworth, Symanski et al. 2008; Bose-O'Reilly, McCarty et al. 2010; Mattison 2010; Rusconi, Catelan et al. 2010). The economic cost of ill health due to pollution is estimated to be substantial (Jerrett, Eyles et al. 2003; Agarwal, Banternghansa et al. 2010). The identification of the impact of environmental pollution on human health and sustainable development has created the need to monitor and account for emissions and transfers of pollutants.

A total of 184 publications were identified in our research, and these publications had various applications and objectives. We divided these into two general categories: human health outcomes studies (40 publications) and other uses studies (144 publications).

Time range and extent of publications:

We identified papers starting at 1993, six years after the initiation of the first PRTR, the US TRI. Research publications that examined health outcomes began to appear four years later. This could be attributed primarily to the inherent lag time between receipt of the data by the agency, processing and release of the data by the agency to the public, time needed to conduct research, and publication of the research results. Another contributing factor could be the general lack of awareness of PRTR datasets among researchers. The interest in and use of data increased through subsequent years and continues as such. For example, our findings identified 24 published theses, which reflect the incorporation of PRTR data into training of new researchers. There was an overall small increase in the number of publications per year, more evident in the health outcomes category. This may indicate that health research using PRTR data is a growing field.

Origin of publications:

Many countries were represented in the identified publications, though most of these studies used the US TRI dataset and where published by researchers from U.S.-based organizations. In the health outcomes category there is a notable absence of publications from research groups based in countries such as Canada, Australia, and Japan, which were found to be more active in publication of other uses of PRTR data. The exclusion of non-English language studies may have affected our study's findings. Another possible cause may relate to the fact that the US TRI was the earliest PRTR and users of TRI data have had more time to develop research methodologies and optimize the data for analysis. In addition, the US TRI has been actively developing tools to assist users with data analysis and incorporating tools to easily cross–reference with other environmental databases or registries (National Emissions Inventory, Envirofacts, Facility Registry System, etc.) (EPA 2012c). The lack of publications could also be due to lack of awareness in the public and the scientific communities of the availability of the data. It may also reflect the relative sizes of the environmental health research communities in each country, or the availability of support and funding of this kind of research.

Compared to other PRTR datasets, the relatively wide use of the US' TRI to identify possible associations between industrial emissions of toxic chemicals with human health impacts demonstrates that the same kind of study could be done with other PRTR datasets, recognizing that the specific characteristics of a given PRTR would need to be addressed.

Data uses, methods and methodologies:

We identified a wide range of uses of the PRTR data indicating that the data may be useful in answering various types of research questions. Nevertheless, further research will need to assess the impact of PRTR-based research on local policy and practice, much like the recent study undertaken by the US Environmental Protection Agency's (EPA) TRI Program. The study identified EPA-funded research from 1995-2010 that involved the use of TRI data and all corresponding publications, analyzing the use of TRI data and the outcome(s) of the research. (EPA 2012a).

Some of the papers identified in the present study also offered methods or methodologies that may be useful when using PRTR data in research and assessing impacts.

In the health outcomes category, a large number of the studies found a statistically significant positive correlation between pollutant releases and negative health outcomes. It is not clear if a particular analytical methodology is more likely to find significant relationships. Conley (Conley 2011) claims that the use of different methods of analysis can give different results about the impact of pollution on health outcomes and that the most reliable estimates did not always result from using complex methods.

Additionally, models of exposure need to consider factors such as chemical properties and behaviour in the environment, meteorological conditions, and local topography. Therefore, assessment of actual or potential health impacts from routine industrial emissions or other transfers of chemicals into the environment requires a combination of different research methodologies as part of a continuum in exposure assessment and as indicated in several of the reviewed papers.

Health outcomes and age:

Many studies focused on cancer incidence. This may be because there are known relationships between industrial emissions of carcinogenic chemicals and incidences of cancers in humans. It may also relate to the fact that health data are easier to retrieve from cancer registries. Some studies investigated other health outcomes, demonstrating the future usefulness of PRTR data in various kinds of health research (**Table 1**). We also analysed age groups that were studied and found that 14 out 40 papers focused on children. There is an increased interest in children's health research since children are often more susceptible to exposure to chemicals and, with some chemicals, are also more sensitive to the toxic effects they cause. However, funding directed towards prevention and health outcomes research in children has been declining (Hay, Gitterman et al. 2010). Our findings show some increase in the total number of studies looking at health outcomes in general but not a specific increase in research focused on health outcomes in children.

Limitations identified by authors of the reviewed publications:

The majority of publications acknowledged some limitations in their research, which were divided into two categories: 1) limitations that were imputable to the PRTR data and, 2) limitations imputable to study design.

1) Many of the limitations referred to the type, quality, and accuracy of the data. Lack of "non-threshold" emissions of toxic chemicals (i.e. emissions that are not reported because a reporting threshold was not triggered) and the inclusion of a limited number of chemicals are some examples identified as limitations affecting the research. Some studies have addressed this by estimating non-threshold emissions using different techniques, based on productivity ratios or labour use ratios, or assuming average emissions of a percentage of the threshold. Most PRTRs track the more toxic chemicals used in commerce, but the respective chemicals regulated by at least some PRTRs have changed through the years. Not infrequently, a given environmental authority will expand or decrease the number of chemicals regulated by its PRTR program, as societal priorities change or additional information on such chemicals becomes available. Such changes can confound research aimed at using the information collected by the PRTR as a data

source, unless normalization is made for such changes in chemical coverage. Other limitations referred to accuracy and inclusion criteria for reporting of the data. Even errors in the location of the emitting facilities (e.g. address provided corresponds to headquarters and not to the emitting facility, inaccurate geocoding) were identified as an obstacle in obtaining accurate results (Garcia-Perez, Boldo et al. 2008). While infrequent, threshold levels for reporting emissions or other waste management quantities on one or more chemicals change, or industry exemptions are added or removed. For example, in 1994 the US EPA finalized a regulatory action that greatly increased the number of chemicals regulated under its PRTR (the TRI). . In 1997, the US EPA finalized a regulatory action that expanded the types of facilities required to report emissions and other waste management quantities of toxic chemicals to the TRI. In the year 2000, the thresholds that triggered reporting of toxic chemicals that also persist in the environment and bioaccumulate in the food-web were greatly lowered. (Currie and Schmieder 2009). These actions, while they greatly expanded the information collected by the TRI, can confound research investigations unless these changes are taken into account during the investigations. For example, researchers can normalize for changes to the chemicals regulated by a given PRTR by using core chemicals (chemicals which have been regulated by the PRTR throughout the years), or by only using data from years after reporting has stabilized. In some instances, such changes have driven some municipalities to develop their own requirements (e.g. the province of Ontario, Canada after deeming the NPRI requirements to be insufficient (MOEE 2010)). The factors described above and those imputable to study design further emphasize the need for scholarly research, as was noted by many studies.

2) Many of the studies included the need to incorporate confounding variables e.g. socio-economic and demographic. Another commonly cited limitation was lack of toxicity equivalents that can provide an indication of potential risk. Lack of toxicity equivalents, instead of absolute amounts emitted, remains a limitation in many papers, although, some offer data converted to a human health index. For chemicals that are structurally similar and cause the same toxic effect, but vary in their potency (i.e. dose needed) to cause the effect, toxicity equivalents are useful for facilitating the estimation of the cumulative risk posed by emissions of multiple congeners of the chemical class. Toxicity equivalents are generally based on the assumption that congeners in the series cause the toxic effect through the same biochemical mechanism, and the toxic potency is normalized through the equivalency.

Some authors (Coyle, Hynan et al. 2005; Boeglin, Wessels et al. 2006; Luo, Hendryx et al. 2011) identified that lack of data for describing the time lag between exposure and onset of harmful health effects is an inherent difficulty in PRTR health outcome research. Other authors considered that this factor is addressed when studying child health outcomes. Agarwal et al. chose to focus on health effects in infants under one year and over 20 weeks in utero. By doing so, they avoided the proxy estimates for life time exposure levels (Agarwal, Banternghansa et al. 2010). However, the effect of an exposure lag in studies that included children up to age 18 may be very different from the effect of a lag in studies that included only children up to age 5. Limitations referred also to aggregation of population data, exposure data and the Modified Areal Unit Problem (MAUP) (Openshaw 1984) (Table 4). Privacy concerns often require the use of aggregated data, at the level of relatively large government administrative defined areas, such as the census tract, states/provinces or country. The differences of the resolutions of the data derived from PRTRs (point location: longitude/ latitude) and government sources may make comparison impossible. This creates the problem of changing results and correlations when different spatial units are used (MAUP). For example, using data at the county level versus the state level yields different results. MAUP may be addressed in study design by using a variety of different areal units if the data allows.

Though there are limitations to the PRTR data there are researchers who use the geocoded data for various research objectives and for examining health outcomes in particular.

Limitations of this literature review:

A limited number (forty) of health outcome-related publications were identified in the present study. While half of the references to these publications were found by an extensive search in databases using various key words and search engines, the other half were identified by a manual search. International PRTRs are often referred to by its national name and not by PRTR, and though some searches were done for the US's TRI, searches were not done for all name-variants in all languages and thus the keyword search may not have captured all studies, inevitably missing some publications. Indexing services are also slow to create controlled thesaurus terms in new areas, so articles may be only indexed to broader terms. Another limitation of this literature review was the inclusion of English literature only, though PRTR data is national and many nations publish in different languages. Foreign language databases were not searched. Future research may benefit from the application of a systematic review to examine health outcomes using PRTR data.

Potential uses of PRTR data in the future:

New research methods such as data mining, land use regression models and interdisciplinary methods could be used to minimize limitations imputable to study design. Through the inclusion of a larger number of variables and particularly socio-economic variables (which was identified as one of the major missing confounders) limitations can be further minimized. Interdisciplinary research could identify chemicals and mixtures of chemicals, which may potentially affect human health and may need to be mandated for scrutiny. Interdisciplinary research can also support the identification of associations with emerging health conditions (e.g. obesity, neurodevelopmental, etc.). While researchers have begun to use PRTR data in investigation of health outcomes there is definitely room for expanding the use of these valuable data in future research and support future local planning and decision-making.

Other improvements that could increase the use of the PRTR information include raising awareness of the existence of such databases and improving translation of the data to usable forms. Effective translation of the synthesized data should be an essential part of the PRTR agenda. It would require experts' knowledge to translate the collected data for environmental regulators; the medical research community, health care providers and public health officials to develop an action plan for an area of concern (Maantay 2002; Bae, Wilcoxen et al. 2010). Worldwide, many resources have been invested in the development of PRTR systems. These registries have collected data since 1988 with the first health related publication using these data published in 1997. Our study has revealed that while the data and methods of analyses have limitations, the publication record shows the value of the data in research. There needs to be significant improvement in the quality of the data to create a powerful tool for these valuable data to be fully exploited. While the research output is currently small the volume of the data being collected holds huge potential for research that can influence public policy, environmental management practices, and ultimately human health. These findings will support future research by identifying limitations currently impacting the effective use of these data.

CONCLUSIONS

This scoping review has identified 184 scientific publications that used PRTR geocoded data to either investigate possible health outcomes or for other uses. While this number may appear small relative to the total number of scientific papers published over the same time interval, the number of human heath-related publications that involve the use of PRTR data has generally increased through the years, reflecting a growing interest in this field of research. Moreover the various uses of the PRTR data we found demonstrate the potential for a range of research studies using these data (such as association between pollutants and various health outcomes). For example, the use of PRTR data in a variety of research based on the US TRI illustrate that PRTR datasets are useful information sources and supports the idea that these datasets are a valuable research resource. However, it is clear that these data offer many more research opportunities than those that had already been explored. We have identified that there is a gap in knowledge that could be obtained from PRTR data, as a result of low exploitation of the data, as was previously identified (EPA 2012a). This knowledge gap may be attributed to the fact that this is a relatively new and evolving field of research, or relate to the complexity of this type of research and the multiple considerations, limitations and challenges involved in the use of these data. However, developing strategies to overcome these limitations (mainly limitations imputable to the PRTR data) as well as improving the PRTR reporting requirements could improve the overall quality of the data so that it can be better used for research, knowledge translation to the public and future policy applications.

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Table 1: List of identified health outcomes publications

	Year	Author	Title	PRTR Country	PRTR years	Outcome Studied	Population& location	Chemicals	Industry Sectors
						Cancer: adult or whole population			
1.	1998	(Thomas, Kodamanchaly et al. 1998)	Toxic chemical wastes and the coincidence of carcinogenic mortality in Texas	TRI (US)	1988 to 1994	Cancer mortality	Whole population; Texas, U.S. Counties	Carcinogens	Manufacturing
2.	1999	(Thomas, Noel et al. 1999)	An ecological study of demographic and industrial influences on cancer mortality rates in Texas	TRI (US)	1988 to 1994	Digestive, genital, lymphatic/hematopoietic and urinary cancer mortality	Whole population; Texas, U.S. Counties	Carcinogens	Manufacturing
3.	2001	(Thomas, Qin et al. 2001)	Environmental hazards and rates of female breast cancer mortality in Texas	TRI (US)	1988 to 1994	Breast cancer mortality	Women; Texas, U.S. Counties	Carcinogens	Manufacturing
4.	2002	(Thomas, Qin et al. 2002)	Economic and toxic chemical influences on rates of gynaecological cancer mortality in Texas	TRI (US)	1988 to 1994	Cervical and ovarian cancer mortality	Women; Texas, U.S. Counties	Carcinogens	Manufacturing
5.	2004	(Mitra and Faruque 2004)	Breast cancer incidence and exposure to environmental chemicals in 82 counties in Mississippi	TRI (US)	Unknown	Breast cancer incidence	Women; Mississippi, U.S. by county	All	All
6.	2005	(Coyle, Hynan et al. 2005)	An ecological study of the association of environmental chemicals on breast cancer incidence in Texas	TRI (US)	1988 to 2000	Breast cancer incidence	Whole population; Texas Counties, U.S.	carbon tetrachloride, formaldehyde, methylene chloride, styrene, tetrachloroethylene, trichloroethylene, arsenic, cadmium, chromium, cobalt, copper, and nickel	All
7.	2006	(Boeglin, Wessels et al. 2006)	An investigation of the relationship between air emissions of volatile organic compounds and the incidence of cancer in Indiana counties	TRI (US)	1988	Cancer incidence	Whole population; Indiana Counties, U.S.	VOCs	All
8.	2006	(Coyle, Minahjuddin et al. 2006)	An Ecological Study of the Association of Metal Air Pollutants with Lung Cancer Incidence in Texas	TRI (US)	1988 to 2000	Lung cancer incidence	Whole population; Texas Counties, U.S.	arsenic, cadmium, chromium, cobalt, copper, nickel, zinc, and vanadium	All

9.	2007	(Ho 2007)	Three essays on toxic chemical releases, house values, health and labor productivity	TRI (US)	1987 to 2000	Cancer mortality, house prices	Whole population; U.S. Counties	All	All
10.	2008	(Dahlgren, Klein et al. 2008)	Cluster of Hodgkin's lymphoma in residents near a non-operational petroleum refinery	TRI (US)	1990	Hodgkin's disease	Whole population; Sugar Creek, Missouri, U.S.	benzene	Manufacturing (one petroleum refining facility only)
11.	2008	(Ho and Hite 2008)	The benefit of environmental improvement in the south-eastern United States: Evidence from a simultaneous model of cancer mortality, toxic chemical releases and house values	TRI (US)	1987 to 2000	Cancer mortality	Whole population; South-eastern states, U.S. Counties	All	All
12.	2008	(Monge-Corella, Garcia-Perez et al. 2008)	Lung cancer mortality in towns near paper, pulp and board industries in Spain: a point source pollution study	EPER (SPA)	2001	Lung cancer mortality	Towns less than 10,000; Spain	All	Paper, pulp, board and cellulose manufacturers
13.	2009	(Garcia-Perez, Pollan et al. 2009)	Mortality due to lung, laryngeal and bladder cancer in towns lying in the vicinity of combustion installations	EPER (SPA)	2001	Lung, larynx and bladder cancer mortality	All towns; Spain	All	Combustion facilities
14.	2009	(Ramis, Vidal et al. 2009)	Study of non-Hodgkin's lymphoma mortality associated with industrial pollution in Spain, using Poisson models	EPER (SPA)	2001	Non-Hodgkin lymphoma incidence	All towns; Spain	All	All except farms
15.	2010	(De Roos, Davis et al. 2010)	Residential proximity to industrial facilities and risk of non-Hodgkin lymphoma	TRI (US)	Unknown	Non-Hodgkin lymphoma incidence	Whole population; Iowa state, LA County, Detroit Seattle metropolitan area, U.S.	Facility locations only	Manufacturing
16.	2010	(Garcia-Perez, Lopez-Cima et al. 2010)	Leukemia-related mortality in towns lying in the vicinity of metal production and processing installations	EPER (SPA)	2001	Digestive system cancer mortality	All towns; Spain	All	Metal production and processing installations
17.	2010	(Garcia-Perez, Lopez-Cima et al. 2010)	Mortality due to tumours of the digestive system in towns lying in the vicinity of metal production and processing installations	EPER (SPA)	2001	Leukemia-related mortality	All towns; Spain	All	Metal production and processing installations
18.	2011	(Conley 2011)	Estimation of exposure to toxic releases using spatial interaction modeling	TRI (US)	1987 to 1996	Lung cancer mortality	Whole population; U.S. Counties	Carcinogens	All
19.	2011	(Fortunato, Abellan et al.	Spatio-temporal patterns of bladder cancer incidence in Utah (1973-2004) and their	TRI (US)	1988 to 2004	Bladder cancer incidence	Whole population; Utah, U.S.	Facility locations only	All

		2011)	association with the presence of Toxic Release Inventory sites				census tracts		
20.	2011	(Luo, Hendryx et al. 2011)	Association between Six Environmental Chemicals and Lung Cancer Incidence in the United States	TRI (US)	1988 to 1990	Lung cancer incidence	Whole population; 215 U.S. Counties in 13 states	arsenic, 1,3 butadiene, cadmium, chromium, formaldehyde, and nickel	All
						Childhood cancer			
21.	2005	(Knox 2005)	Oil combustion and childhood cancers	PI (UK)	2001	Childhood cancer incidence	Children under 16; Great Britain	1,3-butadiene, benzopyrene, dioxins, benzene, nitrogen oxides, carbon monoxide, non-methane volatile organic substances, and fine particulates	All
22.	2006	(Choi, Shim et al. 2006)	Potential Residential Exposure to Toxics Release Inventory Chemicals during Pregnancy and Childhood Brain Cancer	TRI (US)	1987 to 1997	Childhood brain cancer incidence	Children under 10; Florida, New Jersey, New York (excluding New York City) and Pennsylvania, U.S.	known, probable and possible carcinogens	All
23.	2007	(Bhat 2007)	Toxics Release Inventory facilities and childhood cancer: geographic information systems based approach	TRI (US)	1995	Childhood cancer incidence	Children under 14; Texas, U.S.	All;	All
24.	2008	(Thompson, Carozza et al. 2008)	Geographic risk modeling of childhood cancer relative to county-level crops, hazardous air pollutants and population density characteristics in Texas	TRI (US)	1990 to 2002	Childhood cancer incidence	Children born from 1990 to 2002; Texas Counties, U.S.	1988 core chemicals	Petroleum refineries, petroleum refining and related industries, chemical industries and plastics production
						Neuro-development			
25.	2007	(Suarez, Brender et al. 2007)	Maternal Exposures to Hazardous Waste Sites and Industrial Facilities and Risk of Neural Tube Defects in Offspring	TRI (US)	1996 to 2000	Neural tube defect incidence	Whole population; Texas, U.S.	All	All

26.	2009	(Currie and Schmieder 2009)	Fetal Exposures to Toxic Releases and Infant Health	TRI (US)	1988 to 1999	Gestation, birth weight and infant mortality	Children under 1; U.S Counties	Known developmenta l toxicants	All
27.	2010	(Agarwal, Banternghans a et al. 2010)	Toxic exposure in America: Estimating fetal and infant health outcomes from 14 years of TRI reporting	TRI (US)	1989 to 2002	Infant and fetal mortality rates	Whole population; U.S. Counties	Developmenta l or reproductive toxins	All
						Congenital			
28.	2004	(Yauck, Malloy et al. 2004)	Proximity of residence to trichloroethylene-emitting sites and increase risk of offspring congenital heart defects among older women	TRI (US)	1996 to 1999	Congenital heart defect	Whole population; Milwaukee, Wisconsin, U.S.	trichloroethyl ene	All
29.	2009	(Langlois, Brender et al. 2009)	Maternal residential proximity to waste sites and industrial facilities and conotruncal heart defects in offspring	TRI (US)	1996 to 2000	Congenital cardiovascular malformations	Whole populations; Texas	Facility locations only, all with air emissions	All
						Autism			
30.	2006	(Palmer, Blanchard et al. 2006)	Environmental mercury release, special education rates, and autism disorder: an ecological study of Texas	TRI (US)	2001	Autism incidence; Special education rates	Whole population; Texas, U.S. Counties and school districts	mercury	All
31.	2009	(Lewandowsk i, Bartell et al. 2009)	An evaluation of surrogate chemical exposure measures and autism prevalence in Texas	TRI (US)	2000 to 2005	Autism incidence	Whole population; Texas, U.S. Counties	mercury	All
32.	2009	(Palmer, Blanchard et al. 2009)	Proximity to point sources of environmental mercury release as a predictor of autism prevalence	TRI (US)	1998	Autism incidence	Whole population; Texas, U.S. School districts	mercury	All
33.	2011	(Bartell and Lewandowski 2011)	Administrative censoring in ecological analyses of autism and a Bayesian solution	TRI (US)	2001	Autism incidence	Whole population; Texas, U.S.	mercury	All
						Mortality			
34.	1997	(Tiefenbacher , Konopka et al. 1997)	Airborne toxic emission hazards in Texas: measuring the vulnerability of place	TRI (US)	1990	Disease mortality: lung and respiratory cancers, all cancers, lung infections, asthma, emphysema, pulmonary	Whole population; Texas, U.S. Counties	All Airborne toxic chemicals	All

						diseases			
35	2010	(Hendryx, Fedorko et al. 2010)	Pollution Sources and Mortality Rates Across Rural-Urban Areas in the United States	TRI (US)	2008	Population mortality	Whole population; U.S. Counties	All	All
36	2011	(Hendryx and Fedorko 2011)	The Relationship Between Toxics Release Inventory Discharges and Mortality Rates in Rural and Urban Areas of the United States	TRI (US)	1988 to 2006	Population mortality	Whole population; U.S. Counties	All	All
						Other			
37	2001	(Meliker, Nriagu et al. 2001)	Spatial clustering of emergency department visits by asthmatic children in an urban area: South-western Detroit, Michigan	TRI (US)	Unknown	Emergency department admissions for asthma	Whole population; South-Western Detroit, Michigan, U.S.	All	Automobile manufacturing (two facilities only)
38	2005	(Downey and Van Willigen 2005)	Environmental Stressors: The Mental Health Impacts of Living Near Industrial Activity	TRI (US)	1995	Mental health	Whole population; 18 counties in Chicago, Illinois, U.S. Census tracts	All	All
39	2008	(Gregory, Shendell et al. 2008)	Multiple Sclerosis disease distribution and potential impact of environmental air pollutants in Georgia	TRI (US)	2002	Multiple sclerosis	Whole population; Georgia, U.S. Counties	Carcinogens and toxicant source emissions	All
40	2009	(Ho and Hite 2009)	Toxic chemical releases, health effects and productivity losses in the United States	TRI (US)	2002	Self-reported health status	Whole population; U.S. Counties	All	All

Table 2: Other uses of PRTR data in identified publications

Other uses of PRTR data:	
Assessment of the factors affecting environmental performance	41
Evaluation of human health risk and possible impact	29
Presentation of tools, models methods and methodologies for research using PRTR data	25
Presentation of chemical measurements and characteristics	18
Evaluation of emission amounts and the accuracy of the data	12
Analysis of PRTR data along with socio-economic variables to investigate relationships social justice and demographics	10
Examination of trends in chemical releases	6
Awareness and use of PRTR data by the community	3
Total	144

a. When studies fit into more than one category, they were classified by the main theme.

Table 3: Classifications of limitations imputable to PRTR data, identified from both health outcomes and other uses of PRTR data publications.

Limitations Identified Imputable to PRTR data	HO	Other	Total
Lack of non-threshold emissions reporting	8	36	44
Change in reporting requirements over time	2	27	29
Lack of tracking all chemicals in use	4	24	28
Lack of mobile and/or other area specific sources	8	16	24
Under-reporting of emissions	2	20	22
Incorrect facilities address, including geocoding.	7	13	20
Data requires expert interpretation		13	13
Incomparability in reporting requirements among PRTR systems		8	8
Estimation errors and assumptions in data reporting	4	3	7
Exposure can predate the first reporting year	4	1	5
Different facilities may report each year as emissions fluctuate within a facility under or above threshold	1	2	3
TOTAL	40	163	203

a. HO= health outcomes, Other = other uses.

Table 4: Classifications of other limitations using PRTR data, identified from both health outcomes and other uses of PRTR data publications.

Other Limitations Identified	HO	Other	Total
Lack of confounding variables	36	31	67
Lack of use of toxic potential	10	53	63
No dispersion modelling to estimate exposure	19	40	59
Aggregation of population data and exposure	16	6	22
Modified Areal Unit Problem	5	9	14
Assessment of lag time between exposure and health effects	12		12
TOTAL	98	139	237

a. HO= health outcomes, Other = other uses.

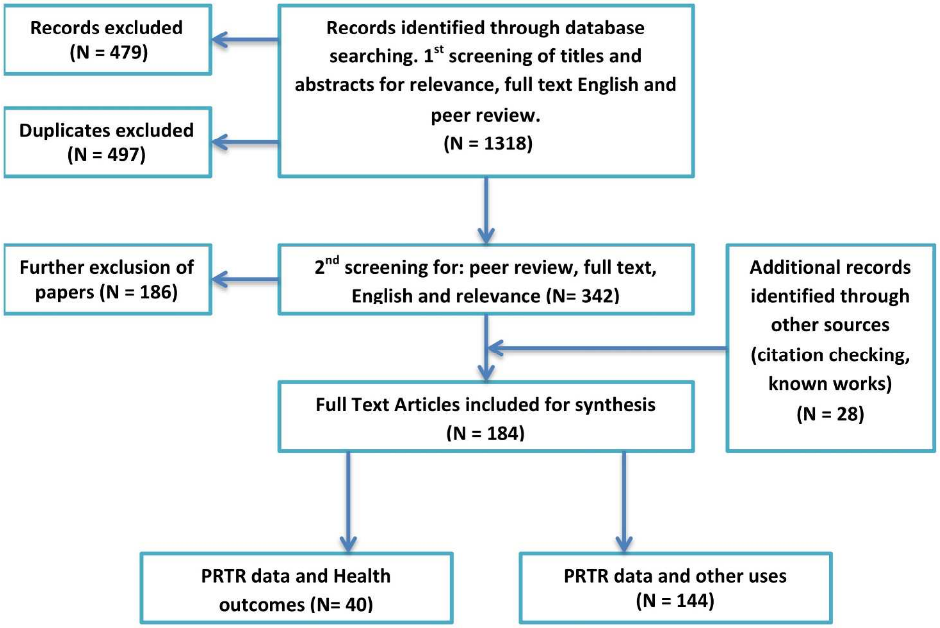

Figure 1: literature selection process
1057x789mm (72 x 72 DPI)

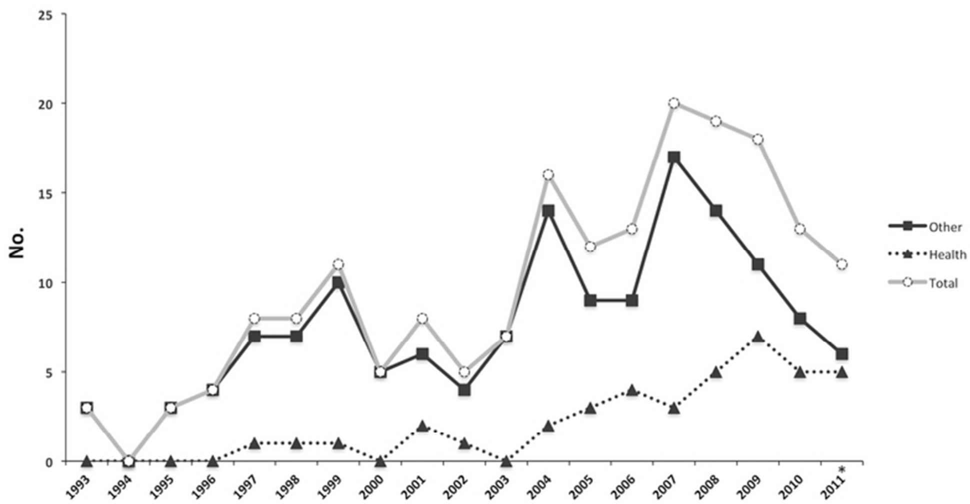

Figure 2: The figure presents the yearly distribution of all identified publications using PRTR according to the focus of the study: health outcomes and other uses. (*Jan-July 2011)
68x37mm (300 x 300 DPI)

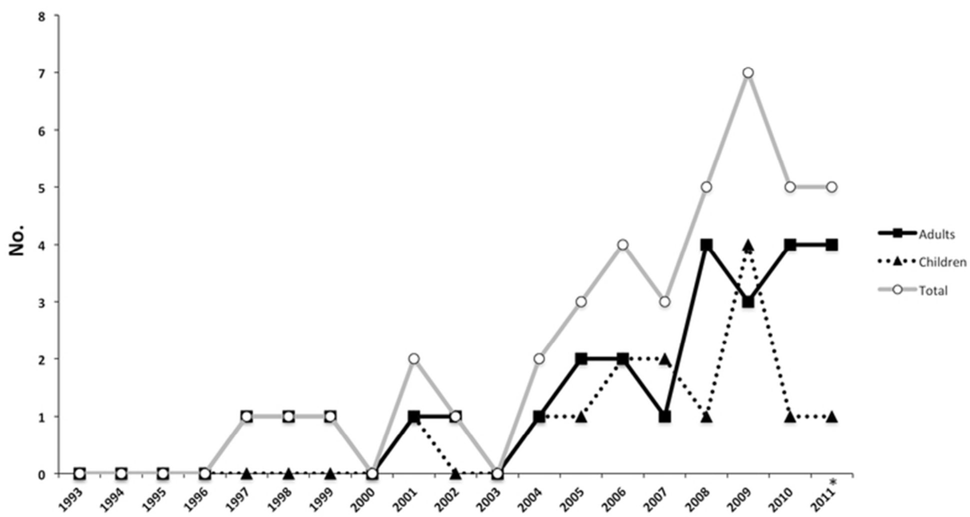

Figure 3: The figure displays the total number of included PRTR and health outcomes publications (1993 to 2011) as well the number of yearly publications focusing on children and adults.
68x37mm (300 x 300 DPI)