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Selection and prioritization of organic contaminants for monitoring in the drinking water value chain

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The occurrence of organic contaminants in the drinking water value chain is of growing concern for the drinking water industry and its consumers. Because of the need to protect consumer health and retain their confidence on the supply, it is necessary to monitor for organic contaminants of concern to health. However, it is crucial to select and prioritize those organic contaminants of local relevance given the limited resources in developing countries. A generic protocol for the selection and prioritization of organic contaminants for monitoring in the drinking water value chain (from catchment to tap) was developed for use by Rand Water and other water utilities. The protocol was successfully implemented in the Rand Water supply chain resulting in a list of priority organic contaminants. The methodology used, recognizes the use of available information on other databases and the use of criteria tailor made for the drinking water industry.

Introduction

In the 21st century, the society has become reliant on a vast number of manufactured chemicals and substances to enhance the quality of life with little thought given to the effects on the environment and humans once they have been used and discarded (Besse and Garric, 2008; Tilghman et al 2009). One of the pathways through which these chemicals can manifest their effects in humans is via the drinking of contaminated water, treated as well as untreated (Du Preez et al 2003; WHO, 2004). In order to protect the health of consumers and ensure that drinking water does not contain any substance that can be deleterious to human health and has an acceptable appearance (in terms of taste, odour and colour), standards and guidelines are set for the most common substances that can possibly be found in drinking water, and require regular monitoring and testing. For example, there are currently over 100 health-related chemicals or group of chemicals for which guideline values have been set by the World Health Organization (WHO, 2004). It is important to note that this list does not include the so called "emerging organic contaminants" such as human and veterinary pharmaceuticals, personal care products, surfactants and surfactant residues, plasticizers, polyfluorinated compounds, polychlorinated biphenyl ethers, phosphoric esters, various industrial additives and engineered nanoparticales. It is thus evident that preventive management of organic chemicals in drinking water requires practical and easily applicable tools for distinguishing the few chemicals of potential local or national concern from the unmanageably long list of organic chemicals of possible significance (Mitchell et al 2002; Roose and Brinkman, 2005; Besse and Garric, 2008). The objective of this paper is to provide the process followed to develop a generic protocol that would give guidance in the selection and prioritization of organic contaminants for monitoring in the drinking water value chain (from catchment to tap).

Methodology

In developing the protocol, a critical evaluation and synthesis of the available literature on the approaches for the selection and prioritization of organic variables of concern to the Drinking Water industry was conducted. From the reviewed approaches, a framework for developing the generic protocol for the selection

and prioritization of organic contaminants was developed (Ncube, 2009). This served as a model on which the protocol was built on. Based on this conceptual framework, the structural components of the protocol were identified (Figure 1). The framework on which the protocol was developed on consisted of three major steps, the selection of the "pool of contaminants", the screening and prioritization steps (Figure 1). For each step criteria reflective of the needs of the Drinking Water industry, was considered. (Figure 2).

The specific components of the generic protocol

The protocol (Figure 1) identifies seven major steps that should be followed in a multiple step in which evaluation of each list by the Drinking Water industry experts and related stakeholders is emphasized. The validation of the protocol in a prototype drinking water value chain is viewed as one of the most important parts in order to obtain a priority list that is relevant to local conditions.

Step I: Selecting the "pool of organic contaminants"

During this step it is prudent to consult as many information sources that are relevant to drinking water protection. Table 1 gives examples of possible information sources. The WHO Guidelines for drinking water quality is a very resourceful document for global use by the Drinking Water industry (WHO, 2004). The outcome of this step is a "pool of organic contaminants" arranged in an excel spreadsheet.

Step II: The validation of the "pool of organic contaminants" by Drinking Water industry experts and relevant stakeholders

The step is the validation of the "pool of organic contaminants" obtained in Step I by a group of experts from the Drinking Water industry and relevant stakeholders. This can be in form of a workshop, meeting, written questionnaires or a combination of these methods. During this step, some organic contaminants will be eliminated from the list based on the non-relevance to drinking water and the diversity of views and experience of the various experts. It is advisable that the group of participants cover all subject areas relevant to public health protection. The result is a "**Preliminary list of organic contaminants of possible concern (PLOCPC)" (Figure 1)**.

Step III: Screening the preliminary list of organic contaminants of possible concern (PLOCPC)

In this step, the list produced in Step II is checked and verified against the occurrence criteria and the potential to cause adverse health effects (NCUBE, 2009). In order to accomplish this, a literature review must be conducted. The focus of the review is on the occurrence of the organic contaminants in the drinking water value chain (from source to tap) and their potential to cause adverse health effects. In order to accomplish this, the following need to be determined:

- The occurrence of organic contaminants in the drinking water value chain (from source to tap) (literature review);
- The use of the persistence, bioaccumulation and toxicity (P,B,T) criteria (use of cut-off values) for screening the organic contaminants (NCUBE, 2009);
- The development of water quality monographs for selected organic contaminants in order to solicit more information and
- The use of "other criteria", such as endocrine disruption, relevance and concern to the Drinking water industry as evidenced by proprietary data, previous legislation and use during water treatment (Figure 1, Step III).

Potential organic contaminants in the drinking water value chain: a literature review

Occurrence in the drinking water value chain is important as it provides evidence for potential human exposure to organic contaminants. During this step, a literature review is conducted with the aim of identifying individual or group of organic contaminants that have been found to occur in the aquatic environment throughout the drinking water value chain. At the end of this review, a list of organic contaminants that has been found to occur in the drinking water value chain should be compiled. The review should also cover the potential adverse health effects. The occurrence of a chemical in the drinking water value chain is largely influenced by its physico-chemical properties (IEH, 2004). These properties can be used to predict the fate and behaviour of the contaminant in the drinking water value chain (IEH, 2004). The list produced from the literature review is compared with the "Preliminary list of organic contaminants of possible concern (PLOCPC)" (Figure 1). The list obtained from this step will form part of the preliminary list of organic contaminants of concern (PLOCC) to the Drinking water industry.

Application of the persistence, bioaccumulation and toxicity (P, B, T) criteria (use of cut-off values) to the list of organic contaminants obtained from the literature review

These parameters include: Persistence (P), bioaccumulation (B) and toxicity (T). Cut-off values are used to decide whether a compound is persistent, bio-accumulative or toxic and the response is added to the table (NCUBE, 2009). Based on the cut-off values, it should be decided whether to keep the contaminant on the preliminary list of organic contaminants of possible concern (PLOCPC) or add it onto the preliminary list of organic contaminants of concern (PLOCC). Values for each of the contaminants obtained from the above step are obtained from the literature and using a "Yes" or "No" decision making process a contaminant is characterized as "persistent" or "not persistent". The same is done for other parameters. This information is added to the table of organic contaminants of concern (NCUBE, 2009).

The development of Water quality monographs

The aim of this step is to gather additional information on each contaminant to further assist with the screening of organic contaminants (Figure 1, Step III).

Use of other criteria

Other than the use of water quality monographs, some organic contaminants might not have sufficient data to support the decision making process. "Other criteria" can therefore be used (NCUBE, 2009). The outcome of these four steps is a preliminary list of organic contaminants of concern (PLOCC) to the to the Drinking Water industry. The organic contaminants on this list are going to be screened for occurrence in the drinking water value chain and validated by the Drinking Water industry experts and relevant stakeholders before being accepted as the final list of concern to drinking water safety in Step IV.

Step IV: Testing for organic contaminants in a prototype drinking water value chain, validation of the list of organic contaminants of concern by industry experts and relevant stakeholders.

During this step, organic contaminants on the preliminary list of organic contaminants of concern (PLOCC) obtained from step III is assessed for occurrence in the drinking water value chain. Testing for organic contaminants should be done at this stage. This is achieved by determining the concentration of organic contaminants in biota (fish tissue), sediments and water samples (Figure 1). This is followed by a decision on whether the organic contaminant was positively identified or not in the drinking water value chain and whether it should pass onto the final list of organic contaminants of concern (FLOCC).

Step V: Establishment of Technical capability for the removal of organic contaminants through conventional water treatment, recommendations for the implementation of the FLOCC

Once the FLOCC has been arrived at, the decision to continue with the prioritization exercise should be done. During this step, consultation with the relevant stakeholders is also necessary. The step is based on the following assumptions:

- The spread of vector based diseases such as malaria has resulted in the use of organic contaminants especially pesticides in public health programmes. The WHO in its 3rd edition of the Guidelines for Drinking Water Quality identified pesticides that are commonly used or being considered for vector control in drinking water sources and containers (Harrison & Holmes, 2006). This is due to the fact that the diseases spread by vectors are significant causes of morbidity and mortality (Harrison & Holmes, 2006).
- Although it is known that the chemical can be successfully removed by conventional treatment, it is prudent to prioritize it to assess if it does not occur in the drinking water value chain.
- Some water utilities might not have the capacity to remove the organic contaminants on the FLOCC and some organic contaminants can escape the process and be a potential risk to the consumer.

In the situation whereby the water utility has no capacity for organic contaminant removal, the FLOCC should be taken as the list of priority organic contaminants for monitoring. The organic contaminants positively identified during these testing programs will be added to the "preliminary priority list of organic contaminants (PPLOC)" (Figure 1).

STEP VI: Prioritization of the organic contaminants on the final list of organic contaminants of concern (FLOCC)

It is well understood that the highest priority chemicals are those that have shown to cause human health effects as a consequence of exposure through drinking water. The high-priority chemical list can be modified if those chemicals are found not to be present, but a chemical not found in an initial investigation should not be forgotten (WHO, 2001). Those chemicals that are found to be present, call for the "occurrence criteria, as in Step IV" in form of testing for the organic contaminants in environmental samples. The preliminary priority list of organic contaminants obtained from the preceding steps is subjected to the prioritization criteria described below. In order to accomplish this, the organic contaminants on the final list of organic contaminants of concern (FLOCC) are organized in a table (NCUBE, 2009). The contaminants are then prioritized using criteria tailor made for the Drinking Water industry (NCUBE, 2009).

Occurrence criterion in the drinking water value chain

Evidence for occurrence of the organic contaminant has been collected in four tiers in preceding steps, that is from the literature, water quality monograph development process, experts knowledge and judgement and testing for the occurrence of organic contaminants in the drinking water value chain. The responses are indicated in a table under the column "Found in the drinking water value chain?". The response is qualitatively made in form of "Y"-Yes or "N"-No (NCUBE, 2009).

Adverse human health criterion

The information gathered from the literature review and water quality monographs is used at this stage. This information and that obtained from the preceding section is combined to assist in prioritizing the organic contaminants in four groups (NCUBE,2009). The approach considers and uses as many of the available types of health effects and occurrence data identified in the data source evaluation as practical (NCUBE, 2009).The potential adverse health effects are re-affirmed as presented by the water quality monographs. Based on these two aspects a "priority for analysis" decision is made (NCUBE, 2009).

Other prioritization criteria

This list is further subjected to analysis based on Drinking Water industry perspective and requirements. It is advisable that local conditions should define this process (NCUBE, 2009). Based on the above criteria, a semi-quantitative approach is used and three priority lists of organic contaminants are identified (NCUBE, 2009). The organic contaminants are prioritized into short-term (S), medium term (M) and long term (L) priority for analysis in the drinking water value chain. Those organic contaminants placed on the short-term priority list are adopted for immediate routine monitoring in the drinking water value chain.

Short-term (S).Organic constituents in this category are selected based on the following characteristics:

- The wide range of potential human health concerns via the drinking water ingestion route;
- The substance is known to cause water quality problems in the drinking water value chain such as the cause of offensive tastes and odours;
- There is evidence that the occurrence of a substance or group increases customers perception of risk;
- There are enough resources in place to support ease of monitoring;
- Poor removal efficiency using conventional water treatment methods;
- Availability of drinking water standards/guidelines to enable regulation;
- Proof of occurrence in the drinking water value chain especially those contaminants formed during drinking water treatment, distribution, storage and use.

At least four or more aspects must be satisfied.

Medium term (M) Organic constituents in this category are selected based on the following characteristics:

- The wide range of potential human health concerns via the drinking water ingestion route;
- The substance is known to cause water quality problems in the drinking water value chain such as the cause of offensive tastes and odours;
- No evidence that the occurrence of a substance or group increases customers perception of risk;
- No resources in place to support ease of monitoring;

- Moderate removal efficiency using conventional water treatment methods;
- Non-availability of drinking water standards/guidelines to enable regulation;
- Proof of occurrence in the drinking water value chain especially those contaminants formed during drinking water treatment, distribution, storage and use (NCUBE, 2009).

Long term (L) Organic constituents in this category are selected based on the following characteristics:

- Insufficient information on human health concerns via the drinking water ingestion route;
- Insufficient information on the impact of the organic contaminant on drinking water quality;
- No evidence that the occurrence of a substance or group increases customers perception of risk;
- No resources in place to support ease of monitoring;
- Removed from drinking water using conventional water treatment methods;
- Non-availability of drinking water standards/guidelines to enable regulation;
- Proof of occurrence in the drinking water value chain especially those contaminants formed during drinking water treatment, distribution, storage and use (NCUBE, 2009).

The outcome of this step is a preliminary priority list of organic contaminants (PPLOC) for monitoring in the drinking water value chain.

Step VII: Validation of the preliminary priority list of organic contaminants (PPLOC) by drinking water industry experts and relevant stakeholders

The preliminary priority list of organic contaminants obtained from step VI must be presented to a group of experts from the Drinking Water industry and relevant stakeholders for validation. The main aim of this step is to confirm if the organic contaminants on the PPLOC list should be adopted as a priority list for monitoring in the drinking water value chain.

Results

A generic protocol for the selection and prioritization of organic contaminants for monitoring in the drinking water value chain has been developed (Figure 1). The protocol entails of the steps described above, starting from the identification of a "pool of organic contaminants" to the identification of a priority list for monitoring in the drinking water. The protocol has been successfully implemented in Rand Water.

Discussion

The criteria used in this protocol are reflective of the Drinking Water industry practices for the selection and prioritization attributes as compared to other protocols published in the literature. A few of the approaches address drinking water contaminants, although they have illustrated how the identification, ranking and prioritization of multitudes of substances to much smaller numbers that will receive regulatory and research consideration has been approached in various countries. The protocol also serves to illustrate the importance of stakeholder consultation and expert judgment in these types of prioritization schemes.

New organic contaminants relevant to drinking water quality management might be introduced in freshwater systems at any moment. For example, the EAWAG is currently developing prediction models to facilitate the identification of transformation products of pesticides, biocides and pharmaceuticals whose concentrations and effects make them relevant to water quality (Bryner, 2009). It will therefore be crucial to review the priority organic contaminant list every five years (Figure 1).

Conclusions

A generic protocol for the selection and prioritization of organic contaminants for monitoring in the drinking water value chain has been successfully developed. If this protocol is generally accepted by the broader Drinking Water industry, it should provide guidance to Water Services providers in the selection and prioritization of organic contaminants for monitoring in the drinking water value chain.

The occurrence, potential exposure and human health effects criteria play a major role in selecting and prioritizing organic contaminants for monitoring in the drinking water value chain. Tailor made prioritization criteria reflective of the Drinking Water industry perspective are important and has proved to be successful in selecting and prioritizing organic contaminants for monitoring in the drinking water value chain.

Table 1. WEDC - Examples of possible sources of information for reference in selecting the "pool of contaminants" (NCUBE, 2009)

Content	Source	Country of Origin	Organization
Organic contaminants for monitoring in drinking water, fact sheets	Australian drinking water quality guidelines	Australia	National Health Medical Research Council (NHMRC)
Organic contaminants for monitoring in drinking water	Canadian drinking water quality guidelines	Canada	Health Canada
Drinking water quality guidelines/factsheets	WHO drinking water quality guidelines, 3rd edition	Geneva	World Health Organization (WHO)
Candidate contaminant lists	USEPA Website	United States of America	United States Environmental Protection Agency(USEPA)
List of pesticide residues	PAN-UK website	United Kingdom (UK)	Pesticide action Network (PAN-UK)
A-Z list of substances found in the environment, human health effects	Integrated Risk Information database	United States of America	USEPA
List of pesticides of concern	USEPA website	United States of America	USEPA
List of potential hazards and types of exposure	Monographs	International	(International Agency on Research on Cancer (IARC)
Endocrine disruptors	Scientific facts	International	International Programme on Chemical Substances (IPCS)
List of priority Substances	EU Website	Europe	European Commission (EC)

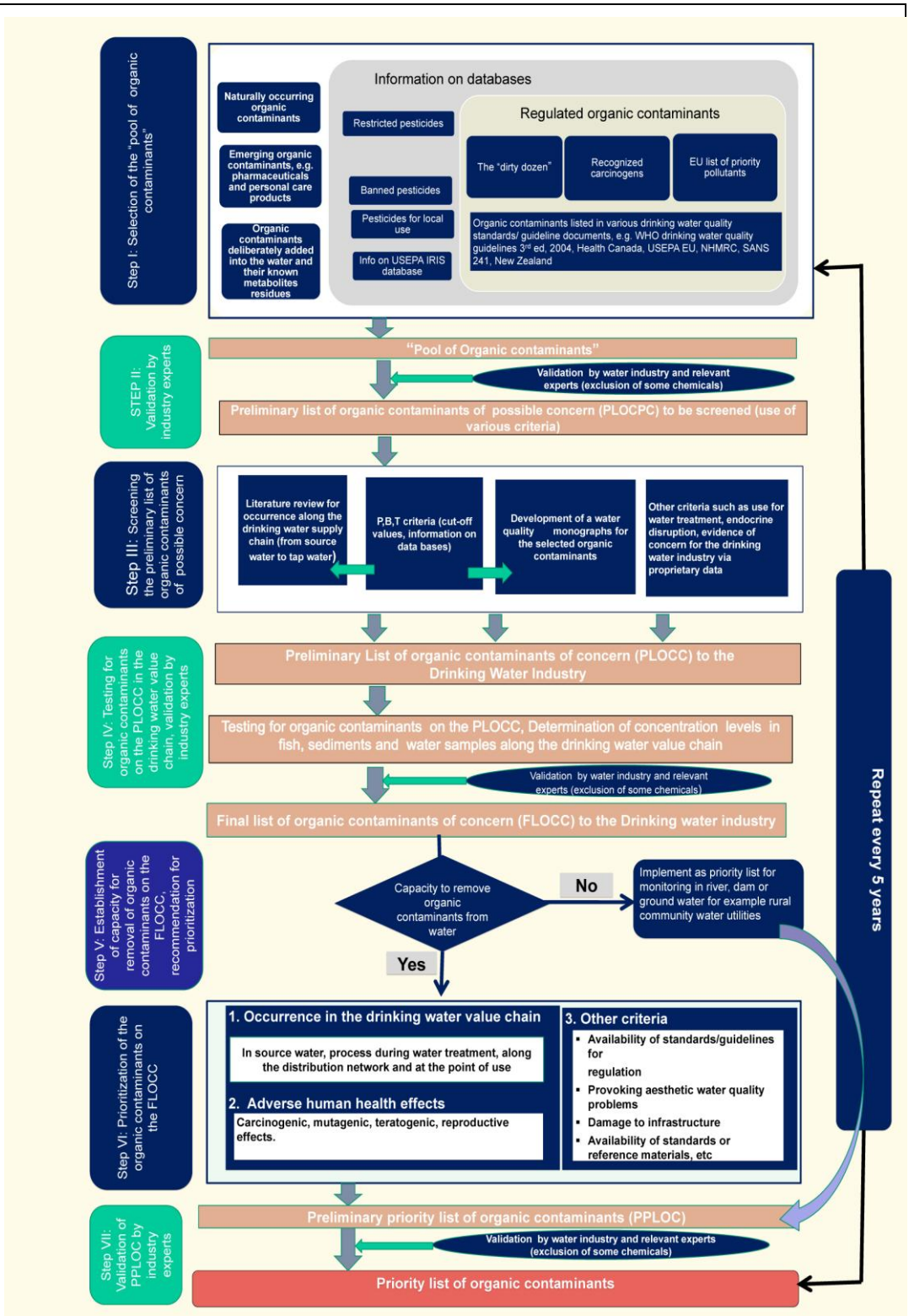

Figure 1. A generic protocol for the selection and prioritization of organic contaminants for monitoring in the drinking water value chain

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