Evidence of Wastewater Treatment Plant Worker Biohazard Exposure and Health Symptom Responses

Warren Kindzierski  
University of Alberta (warrenk@ualberta.ca)

Md. Aynul Bari  
University of Alberta (mdaynul@ualberta.ca)

Xiaoming Wang  
University of Alberta (xiaoming@ualberta.ca)

Tami Wetmore  
EPCOR Water Services Inc. (twetmore@epcor.com)

Rasha Maal-Bared  
EPCOR Water Services Inc. (RMaal-Bared@epcor.com)

Craig Michaels  
EPCOR Water Services Inc. (CMichaels@epcor.com)

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ABSTRACT Raw sewage ordinarily contains various biohazards (disease-causing organisms and their products), such as bacteria, viruses, fungi, helminths, and protozoa. Types, concentrations and survival of biohazards in sewage vary greatly depending on geographical and seasonal factors, and treatment levels within a wastewater treatment plant (WWTP). A review was undertaken to identify evidence of biohazard exposures and health symptom responses in WWTP workers who may be at increased occupational risk compared to the general population. Studies from 1990 onwards identified the following WWTP equipment or tasks as the most important for biohazard exposures: pre-treatment equipment (either indoors or in confined areas), sludge dewatering equipment, worker tasks involving water used for cleaning and contact with raw sewage. Twenty-eight epidemiological observational studies were identified that compared various markers
of biohazard exposure and/or health symptom responses in WWTP worker cohorts and non-worker cohorts for potential exposure to bacteria, viruses, molds and/or endotoxin. Most epidemiological studies comparing self-reported and/or actual health symptoms of WWTP workers to those of non-exposed controls do not show evidence of causality of health symptoms and/or biomarkers of biohazards commonly found in sewage and/or their findings indicate that occupational health risks to WWTP workers are small. Instances where evidence of causality is suggested tend to be based on self-reported outcomes. Caution is acknowledged in interpreting studies suggesting causality of self-reported symptoms because these studies can be influenced by awareness bias of subjects. Equipment, processes and work tasks associated with bioaerosol emissions and worker exposure controls at WWTPs are also discussed.

**Keywords:** Biohazard, wastewater collection and treatment, occupational risk

**INTRODUCTION**

Biohazards consist of live microorganisms in the waste stream that have the potential to cause infection, sickness and other diseases. Wastewater collection and treatment system workers may be exposed to biohazards – including bioaerosols, aeroallergens and other airborne organic particulates – that can carry a burden of pulmonary diseases. The viability of microorganisms is of little importance for effects such as chronic bronchitis, asthma, toxic pneumonitis, hypersensitivity pneumonitis, and lung function decline as these effects may also develop after exposure to non-viable microorganisms (Thorne et al. 2004). It cannot, however, be ruled out that viable microorganisms may provoke stronger responses, for example, if they produce antigens or toxins after deposition in the respiratory system.

A literature review of biohazards was undertaken to identify evidence of occupational exposure and symptom responses for wastewater collection and treatment system workers that may be of increased occupational risk compared to the general population. The primary exposure routes of intake and transmission of biological agents for sewage workers include (BauA 2010):

- Oral intake from splashes, contaminated foodstuffs, eating, drinking and smoking or colds where the hands are not washed beforehand, any hand-to-mouth contact via contaminated clothing or personal protective equipment.
- Intake through the respiratory system (inhalation) from bioaerosols (e.g. droplets, dust particles).
- Intake through the skin or mucous membranes, such as by penetration where there are skin injuries, from splashes into eyes and nose where there are reduced protective barriers (e.g., softened or diseased skin due to moisture), by all hand-to-face contacts, by contact with contaminated clothing or protective equipment.
- Penetration into deep tissue (muscles, subcutaneous fatty tissue) where there are injuries due, for example, to needle-stick or cutting injuries with contaminated devices.

All routes of intake and transmission of biological agents were considered in this review.

**METHODS**

The following electronic databases within the University of Alberta libraries system were used to conduct the review: Compendex, Scopus and PubMed. Compendex is an engineering bibliographic database indexing scientific literature pertaining to engineering, including bioengineering and
environmental engineering. Scopus is the largest electronic abstract and citation database of peer-reviewed literature, including scientific journals, books and conference proceedings related to the fields of science, technology, medicine, social sciences, and arts and humanities. PubMed is an electronic bibliographic database indexing biomedical literature and comprises more than 24 million citations from MEDLINE, life science journals, and online books.

After initially using general search terms and conducting preliminary searches, the following arrangement of search terms represented the broadest search strategy in terms of identification of relevant papers for the review for the time period back to 1990:

- ‘wastewater’ or ‘waste water’ or ‘sewage’ [within Title/Abstract]
- AND ‘collection’ or ‘distribution’ or ‘treatment’ [within Anywhere]
- AND ‘worker’ or ‘workplace’ or ‘occupation’ or ‘occupational’ [within Title/Abstract]
- AND ‘exposure’ or ‘risk’ or ‘risks’ [within Anywhere]

Papers about hazardous or medical waste, incineration and other infectious diseases were excluded. No language restriction was used in the literature search. However, foreign language papers were only identified and used when they were judged, on the basis of their English abstract, to add substantially to the review. The number of articles identified from each database included (from 1990 to current): 174 articles (Compendex), 628 articles (Scopus) and 94 articles (PubMed). Abstracts for all these articles were downloaded and reviewed. In many cases the same article was identified from each database search. After reviewing all abstracts, a total of 66 articles were considered relevant for the review in that they offered direct evidence of occupational exposure and/or symptom response of wastewater collection and treatment system workers to biohazards.

RESULTS AND DISCUSSION

Work-related Health Symptoms

Twenty-eight (28) epidemiological observational studies published between the period 1990 and 2015 were identified. Most of these studies were based on cohort designs that compared self-reported and/or actual health symptoms of workers at WWTPs (Figure 1) to those of non-exposed controls. More specifically, these studies evaluated and compared various health symptoms and/or biomarkers of WWTP worker cohorts from potential exposure to bacteria and/or bacterial endotoxin or viruses. These studies are summarized in Table 1 (bacteria and/or bacterial endotoxin) and Table 2 (viruses).

The majority of studies reported in Table 1 did not establish clear causality of bacterial infection and/or bacterial endotoxin exposure-related health symptoms and/or biomarkers of biohazards commonly found in sewage and/or their findings indicated that occupational health risks to WWTP workers were small. In six instances there was evidence of causality suggested; however five of these studies were based on ‘self-reported’ outcomes (i.e., endotoxin health symptoms - Thorn and Beijer 2004; asthma and respiratory symptoms - Friis et al. 1999; gastrointestinal symptoms - Khuder et al. 1998; and respiratory symptoms - Bener et al. 1998 and Zuskin et al. 1993).

Caution is acknowledged in interpreting results of studies suggesting causality of self-reported symptoms because these studies can be influenced by factors such as awareness bias of participants. Awareness bias is the tendency to report more illness because of concerns arising from proximity to a hazard in the absence of a measurable biological effect. Awareness bias is an important limitation in self-reported survey research. Awareness bias complicates the interpretation of self-reported symptoms in subjects potentially exposed to a hazard.
Table 1. Observational studies on WWTP worker cohorts indicating evidence of causality of bacterial infection and general health symptoms and/or health symptom biomarkers from biohazards commonly found in sewage (1990 to 2015).

<table>
<thead>
<tr>
<th>Country</th>
<th>Health Symptom</th>
<th>Sample Size</th>
<th>Evidence of Causality</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td><em>Helicobacter pylori</em> infection</td>
<td>317</td>
<td>250</td>
<td>No</td>
</tr>
<tr>
<td>Croatia</td>
<td>self-reported respiratory symptoms</td>
<td>74</td>
<td>35</td>
<td>Yes</td>
</tr>
<tr>
<td>Finland</td>
<td><em>Salmonella</em> antibodies</td>
<td>79</td>
<td>79</td>
<td>No</td>
</tr>
<tr>
<td>France</td>
<td>intestinal parasite carriage</td>
<td>126</td>
<td>363</td>
<td>Yes</td>
</tr>
<tr>
<td>Sweden</td>
<td>self-reported endotoxin health symptoms</td>
<td>59</td>
<td>55</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>self-reported asthma and respiratory symptoms</td>
<td>149</td>
<td>138</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>self-reported abdominal symptoms</td>
<td>142</td>
<td>137</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td><em>Helicobacter pylori</em> infection</td>
<td>151</td>
<td>138</td>
<td>No</td>
</tr>
<tr>
<td>Switzerland</td>
<td>respiratory health, lung-specific proteins from bioaerosols</td>
<td>247</td>
<td>304</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>surfactant protein-D, spirometry from endotoxin</td>
<td>316</td>
<td>395</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>endotoxin, serum pneumoprotein, surfactant protein-A</td>
<td>325</td>
<td>369</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td><em>Helicobacter pylori</em> infection</td>
<td>349</td>
<td>429</td>
<td>No</td>
</tr>
<tr>
<td>United Arab Emirates</td>
<td>self-reported respiratory symptoms</td>
<td>144</td>
<td>149</td>
<td>Yes</td>
</tr>
<tr>
<td>United States</td>
<td>self-reported gastrointestinal symptoms</td>
<td>150</td>
<td>54</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>self-report respiratory, skin and systemic symptoms</td>
<td></td>
<td></td>
<td>No</td>
</tr>
</tbody>
</table>

Self-reported illness tends to be influenced by both worry and proximity to a hazard, however Moffat et al. (2000) found that worry about a hazard had the greatest effect on self-reported illness. Moffat et al. (2000) suggested that because absolute certainty about the role and extent of awareness bias in environmental epidemiology studies is unlikely to be achieved; self-reported data should be supplemented with other observations.
Table 2. Observational studies on WWTP worker cohorts indicating evidence of causality of viral infection from biohazards commonly found in sewage (1990 to 2015).

<table>
<thead>
<tr>
<th>Country</th>
<th>Health Symptom</th>
<th>Sample Size</th>
<th>Evidence of Causality</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cases</td>
<td>Controls</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>hepatitis A infection</td>
<td>155</td>
<td>70</td>
<td>No</td>
</tr>
<tr>
<td>Greece</td>
<td>hepatitis A, hepatitis B infection</td>
<td>108</td>
<td>86</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>hepatitis B infection</td>
<td>a</td>
<td>a</td>
<td>Yes</td>
</tr>
<tr>
<td>Israel</td>
<td>hepatitis A infection</td>
<td>100</td>
<td>100</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b</td>
<td>b</td>
<td>No</td>
</tr>
<tr>
<td>Italy</td>
<td>hepatitis A infection</td>
<td>869</td>
<td>311</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>66</td>
<td>72</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>65</td>
<td>160</td>
<td>No</td>
</tr>
<tr>
<td>Switzerland</td>
<td>hepatitis E infection</td>
<td>349</td>
<td>429</td>
<td>No</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>hepatitis A infection</td>
<td>40</td>
<td>18</td>
<td>No</td>
</tr>
<tr>
<td>United States</td>
<td>hepatitis A infection</td>
<td>365</td>
<td>166</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>359</td>
<td>89</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>163</td>
<td>139</td>
<td>No</td>
</tr>
</tbody>
</table>

a Sample size not provided.
b Annual standardized incidence rate for hepatitis A infection of 11.77 per 100,000 for cleaning and sewage workers versus 15.32 per 100,000 for employees of all occupational categories in Israel for the period 1 January 1993 to 31 December 1994.

The majority of studies reported in Table 2 did not establish clear causality of viral infection. Only two Greek studies suggested evidence of clear causality of viral infection; whereas all investigations in France, Israel, Italy, Switzerland, United Kingdom and United States did not establish clear causality of viral infection. With regard to possible ways in which WWTP workers can acquire hepatitis A infections, two possible hypotheses were stated (Warlen and Hoff 1998): 1) community-acquired, or 2) the result of exposure to contaminated wastewater and by products at the worksite through improper or lack of use of protective equipment and/or by deficiencies in hygiene.

**Bioaerosol Emissions from Equipment, Processes and Work Tasks**

Different types of WWTP mechanical equipment/processes likely result in differing bioaerosol emissions; in addition, bioaerosol concentrations near equipment at different WWTP stages may be influenced by wind speed and daily inflow at the WWTP. Numerous studies indicate that bioaerosol emissions and concentrations associated with wastewater treatment processes are the highest in pre-treatment and aerated grit separation stages of the operation and decrease with subsequent treatment stages (Forestier et al. 2012, Heinonen-Tanski et al. 2009, Karra and Katsivela, 2007, Fracchia et al. 2006, Pascual et al. 2003).

These equipment/process activities involve nebulization and mechanical aeration (agitation) of wastewaters and sewage inflows leading to higher aerosol and bioaerosol emissions compared to other unit processes. In addition, sludge dewatering equipment has also been reported as a location where bioaerosol emissions and concentrations are high (Forestier et al. 2012).
Cleaning tasks involving hosing down (with or without high pressure) are identified as high priority activities leading to bioaerosol emissions and potential exposures for workers undertaking cleaning tasks (Duquenne et al. 2014, Forestier et al. 2012, Schlosser et al. 2011, Lee et al. 2007, Oppliger et al. 2005, Thorn et al. 2002). These tasks involve agitation of water and sewage. In addition, cleaning and maintenance of WWTP dryers and conveyors requiring equipment to be opened can result in higher task based personal bioaerosol exposures (Schlosser et al. 2011).

**Hazard Identification and Exposure Controls**

Several worker exposure controls were suggested for WWTPs by various researchers (Forestier et al. 2012, Sanchez-Monedero et al. 2008, Visser et al. 2006):

- Using air diffusers as an aeration system instead of systems involving mechanical agitation of wastewater, such as horizontal rotors and surface turbines.
- Isolating workers from equipment with high bioaerosol emissions using panes of glass or plastic curtains.
- Ensuring proper maintenance of ventilation systems in areas with equipment that have the high bioaerosol emissions.
- Organizing work tasks to prevent WWTP workers from spending long periods in areas where the highest bioaerosol concentrations are.
- Ensuring proper use of personal protective equipment for ‘hosing down’ activities.

Water used for cleaning appears to have a large influence on potential worker personal endotoxin (and likely other bioaerosol) exposures, particularly the use of wastewater effluent (Visser et al. 2006); whereas worker distance to an object being cleaned does not appear to significantly influence exposure. High-pressure water cleaning has recently been confirmed by Madsen and Matthiesen (2013) as a task in many work environments, not just WWTPs, causing high potential exposure to bioaerosols, including endotoxins.

Inconsistent use of personal protective equipment by WWTP workers represents a potential issue leading to higher personal bioaerosol exposures for workers involved in cleaning tasks. This includes taking unnecessary actions such as periodically neglecting to wear masks, respirators, gloves, or goggles for protection (Robinson et al. 2006). West and Locke (1990) reported that the actual risk of trained and properly protected sewage workers, either on-site or nearby, developing viral infections as a result of routine occupational exposure to aerosols produced on treatment plants is very low.

**FINDINGS**

The main findings of the review are:

1. Most epidemiological studies comparing self-reported and/or actual health symptoms of WWTP workers to those of non-exposed controls do not show evidence of causality of health symptoms and/or biomarkers of biohazards commonly found in sewage and/or their findings indicate that occupational health risks to WWTP workers are small. Instances where evidence of causality is suggested tend to be based on self-reported outcomes. Caution is acknowledged in interpreting results of studies suggesting causality of self-reported symptoms because these studies can be influenced by awareness bias of participants.

2. There are two possible ways in which WWTP workers can acquire hepatitis A infections: i) community-acquired, or ii) the result of accidental/unintentional exposure to contaminated wastewater and by products at the worksite. Most epidemiological studies in literature do not
support a need to vaccinate WWTP workers for hepatitis A as these studies suggest the former (as opposed to the latter) as being the more common way for WWTP workers. Preventing the latter emphasizes the importance of consistent use of personal protective equipment where the need exists.

3. Different types of WWTP mechanical equipment/processes likely result in differing bioaerosol emissions; in addition, bioaerosol concentrations near equipment at different WWTP stages may be influenced by wind speed and daily inflow at the WWTP.

4. Bioaerosol emissions and airborne concentrations associated wastewater treatment processes tend to be higher at the pre-treatment and aerated grit separation stages and decrease with subsequent treatment stages. The pre-treatment and aerated grit separation involve nebulization and mechanical aeration and agitation of wastewaters and sewage inflows leading to higher aerosol and bioaerosol emissions compared to other unit processes.

5. Cleaning tasks consisting of hosing down (with or without high pressure) involve agitation of water and sewage and are identified as high priority activities leading to bioaerosol emissions and potential worker exposures. Water used for cleaning appears to have a large influence on potential worker personal bioaerosol exposure, particularly use of wastewater effluent; whereas worker distance to an object being cleaned does not appear to significantly influence exposure.

6. Inconsistent use of use of personal protective equipment by WWTP workers represents a potential issue leading to higher personal bioaerosol exposures for workers involved in cleaning tasks. This includes taking unnecessary actions such as periodically neglecting to wear masks, respirators, gloves, or goggles for protection during certain work tasks.

7. With regard to hazard identification and exposure control opportunities at WWTPs, several actions have been suggested in scientific literature:
   - Using air diffusers as an aeration system instead of systems involving mechanical agitation of wastewater, such as horizontal rotors and surface turbines.
   - Isolating workers from equipment with high bioaerosol emissions using panes of glass or plastic curtains.
   - Ensuring proper maintenance of ventilation systems in areas with equipment that have the high bioaerosol emissions.
   - Organizing work tasks to prevent WWTP workers from spending long periods in areas where the highest bioaerosol concentrations are.
   - Ensuring proper use of personal protective equipment for ‘hosing down’ activities.

REFERENCES


