Developing occupational and health susceptibility personas for wastewater personnel in the United States in the age of COVID-19

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Abstract
Compared with the public, wastewater personnel, are at an increased risk of infection and illness from wastewater pathogens due to work-related tasks. Unfortunately, current risk assessment approaches do not consider individual personnel factors (e.g., age and health conditions) that may influence their susceptibility to a health effect. The objective of this study is to establish a baseline level of occupational and health factors among the wastewater personnel population, quantify these factors using a susceptibility evaluation scoring system, and examine relevant susceptibility features using the concept of “Personas.” Using survey data from 246 respondents and public health risk data on COVID-19 from the CDC, personnel clustered into three persona groups: “low susceptibility,” “high occupational susceptibility,” and “high health susceptibility.” Results highlight the intersectionality between gender, age, underlying health conditions, job tasks, and level of exposure to wastewater and provide context for incorporating individual variables into risk assessment methodologies with the goal of protecting this essential workforce.

Practitioner Points
• A risk assessment framework that combines health and occupational susceptibility factors was developed for wastewater treatment plant personnel.
• Wastewater personnel clustered into three persona groups: “low susceptibility,” “high occupational susceptibility,” and “high health susceptibility.”
• The intersectionality between job related activities and individual health provides a holistic approach to risk assessment for wastewater personnel.

Keywords
cluster, COVID-19, health risk, occupational risk, personas, survey, susceptibility, wastewater personnel

Yihan Zhang and Maureen Kinyua are members of Water Environment Federation (WEF).
INTRODUCTION

Compared with the general public, wastewater personnel involved in wastewater collection, treatment and laboratory operations are at an increased risk of infection and illness from wastewater pathogens due to work-related tasks (Chen et al., 2021; Melbostad et al., 1994; Westrell et al., 2004; Wright et al., 2019). Tasks such as sewer entry, sample collection, sensor cleaning among others increase their exposure and proximity to wastewater. In the advent of the COVID-19 pandemic, the presence of viral SARS-CoV-2 RNA in wastewater revived broad concerns about the public health safety of this vulnerable but essential workforce (Dada & Gyawali, 2021; Gholipour et al., 2021; Zaneti et al., 2021). Although no documented evidence has so far shown that wastewater contains infectious SARS-CoV-2 or plays a role in the transmission of SARS-CoV-2 (Brisolara et al., 2021; Gholipour et al., 2021), the ongoing COVID-19 pandemic has provided an opportunity to re-evaluate the risk of wastewater personnel to infection and or illness with the goal of protecting them from current and emerging pathogens.

Various approaches have been utilized to evaluate risk in the wastewater environment. The quantitative microbial risk assessment (QMRA) approach combines pathogen identification, exposure assessment, dose–response modeling, and risk characterization to estimate risk (Haas et al., 2014), while a Job Safety Analysis (JSA) is a methodology performed to identify, control, reduce, and eliminate occupational factors that influence risk (U.S. Department of Labor, 2002). Both approaches incorporate occupational susceptibility factors such as job task category (e.g., collection and preliminary treatment, biosolids handling, and disinfection systems), the use of personal protection equipment (PPE), and the level of exposure to wastewater when performing job tasks into risk evaluation (Brisolara et al., 2021; LeChevallier et al., 2019; Water Environment Federation [WEF], 2020). Unfortunately, the JSA does not provide targeted insight into varied personal factors that may influence individual susceptibility to a health effect. Meanwhile, the QMRA process has been utilized to evaluate factors that influence risk of SARS-CoV-2. For example, Dada and Gyawali (2021) performed an investigation on the risk of respiratory exposure and illness for wastewater personnel through aerosolized SARS-CoV-2 at varying population outbreak scenarios, while Denpetkul et al. (2022) evaluated the risk of respiratory transmission in public toilets based on three breathing scenarios and discussed mitigation factors that lower risk such as wearing masks. Other individual factors such as age, gender, demographics, and underlying health conditions also influence the risk and susceptibility to infection and illness. Health conditions such as diabetes, heart disease, and obesity have been shown to influence susceptibility to infection and illness (Goodman et al., 2020; Kompaniyets et al., 2021; Pennington et al., 2021). Overlooking the variations of these individual factors among wastewater personnel may contribute to the oversimplification of risk assessment.

Thus, acknowledging the significant role wastewater personnel play in protecting public health and the environment, it is necessary to develop a detailed framework that accounts for both health and occupational susceptibility factors with the goal of providing customized risk assessment and management solutions. The objective of this paper is to establish a baseline level of occupational and health factors among the wastewater personnel population, quantify these factors using a susceptibility evaluation scoring system, and examine relevant susceptibility features within this population. The “Personas” creation methodology was utilized to examine representative susceptibility features. A persona is a hypothetical archetypical fictitious person created based on information from a real population with the goal of understanding their behaviors, needs, and goals to inform decision making (Chang et al., 2008; Laporte et al., 2012; Salminen et al., 2020). The concept of personas was originally invented for marketing purposes but has since been applied in human behavior studies and the healthcare industry (Carey et al., 2019; Lee et al., 2020; LeRouge et al., 2013; Schiffer et al., 2019; Tauro et al., 2022). Although the application of personas is lacking in wastewater, it is a useful tool to establish a population specific framework that may enable the wastewater industry and other public health entities to identify susceptibility and integrate acceptable occupational and health principles to minimize risks and protect personnel health.

METHODS

The development of a population susceptibility framework was conducted in three phases, as shown in Figure 1: (1) an online survey of wastewater personnel, occurring in August 2020 to January 2021, (2) development of a susceptibility evaluation scoring system using public health risk data on SARS-CoV-2, and (3) a wastewater personnel personas analysis.

Survey data collection

The first phase of this study was carried out as a nationwide, web-based survey in the United States. The
objective of collecting data through surveys was to assess wastewater personnel occupational (e.g., use of PPE) and health factors that may influence their susceptibility to infection from wastewater pathogens. Results from the survey guided evaluation scores and personas analysis. Data collection occurred in partnership with California Water Environment Association (CWEA) and the WEF. A total of 246 survey responses were received. However, because some participants did not answer all questions in the survey, the number of responses to each question was not identical. One hundred twenty-nine survey responses were fully complete and therefore were used to calculate susceptibility scores for an unbiased result. Survey questions are provided in the Supporting Information. Each survey was reviewed for accuracy. The University of California Davis Institutional Review Board approved this research protocol.

Susceptibility evaluation scoring system

Susceptibility evaluation scores were developed for each individual survey participant. Health ($S_H$) and occupational ($S_O$) susceptibility scores were calculated using risk evaluation attributes. The health risk factors included types and number of underlying health condition, gender, and age. Risk ratios for each attribute (e.g., male vs. female) were derived from public health data on risk for severe COVID-19 (Goodman et al., 2020; Kompaniyets et al., 2021). Meaning, risk data on COVID-19 were used as a proxy to assess susceptibility within the wastewater workforce. These ratios are provided in Table 1. Among the 16 underlying health conditions surveyed (see the Supporting Information), six have been reported to increase an individual’s susceptibility to COVID-19 illness (Kompaniyets et al., 2021). They include heart disease, chronic obstructive pulmonary disease (COPD), neurocognitive disorders, chronic kidney disease, diabetes, and obesity. The health susceptibility score was expressed as

$$S_H = R_G \times R_A \times R_N \times \prod_{i=1}^{6} R_{U,i},$$

where $R_G$, $R_A$, and $R_N$ are the risk ratios associated with gender, number of underlying health conditions, and age, respectively. $R_{U,i}$ represents the risk ratio associated with each underlying health condition.

Occupational risk factors included PPE use, shift duration, job task category, and level of exposure to wastewater when performing tasks. Risk ratios for each attribute are provided in Table 2. A PPE use risk ratio was calculated based on prior research that determined commercial surgical masks have an average particle removal of 64% (Mueller et al., 2020). Using a baseline ratio of 1 for those who answered “No” to survey question 2.4 about PPE use, a risk ratio of 0.36 (1–0.64) was determined for participants who answered “Yes” to the same question. The risk ratios for shift duration (survey question 2.7) and self-reported levels of exposure to wastewater (survey question 2.8) were assigned based on the researchers’ general understanding of the wastewater industry and risk. Meaning an individual with exposed to wastewater 100% of their work shift received a higher risk ratio compared with an individual with a reduced exposure during their shift. The occupational susceptibility score was expressed as

$$S_O = R_{PPE} \times R_D \times R_E \times R_J,$$

where $R_{PPE}$, $R_D$, $R_E$, and $R_J$ are risk ratios associated with PPE use, shift duration, level of exposure to wastewater, and job task category, respectively.

Personas development

To derive survey-based personas, cluster analysis was utilized because it minimizes heterogeneity within groups.
**TABLE 1  Risk ratios for health susceptibility factors**

| Health susceptibility factor | Risk ratio | Reference |
|-----------------------------|------------|-----------|
| Gender (RG)                 | Female (1.00) | Male (1.30) | Goodman et al. (2020) |
| Number of underlying health conditions (RN) | No condition (1.00) | 1 condition (1.53) | 2–5 conditions (2.55) | 6–10 conditions (3.29) | >10 conditions (3.82) | Kompanijets et al. (2021) |
| Age (R₄)                    | 18–24 (1.00) | 25–34 (1.00) | 35–44 (1.60) | 45–54 (3.25) | 55–64 (4.30) | Over 65 (6.70) | - |
| Types of underlying health conditions (RU,i) | No condition (1.00) | Heart disease (1.14) | COPD (1.18) | Neurocognitive disorders (1.18) | Chronic kidney disease (1.21) | Diabetes (1.26) | Obesity (1.30) |

*The literature included risk ratios for age groups of 18–39 (1.0), 40–49 (2.2), 50–64 (4.3), 65–74 (6.7), 75–84 (8.5), and > 85 year old (10.6). Because the age group 35–44 and 45–54 years in the survey did not exactly align with the literature, the average value of two neighboring groups from the literature were used. For instance, a risk ratio of (1.0 + 2.2)/2 = 1.6 was assigned to age group 35–44 years in this study. The risk ratio of 6.7 was assigned to the over 65 years age group in the survey, with the assumption that all survey participants from wastewater industry were less than 75 years.

**TABLE 2  Risk ratios for occupational susceptibility factors**

| Occupational susceptibility factor | Risk ratio | Reference |
|-----------------------------------|------------|-----------|
| PPE use (Rₚₚₑ)                    | Yes (0.36) | No (1.00) | - | - | - | - | Mueller et al. (2020) |
| Shift duration (Rₒ)               | <4 h (1.00) | 4–8 h (2.00) | 8–12 h (3.00) | >12 h (4.00) | - | - | Based on the survey results from the present study |
| Level of exposure to wastewater (Rₑ) | 0% (0.00) | 25% (0.25) | 50% (0.50) | 75% (0.75) | 100% (1.00) | - | |
| Job task category (Rₗ)             | Disinfection system operation and maintenance (1.00) | Routine plant maintenance (2.00) | Routine plant operations (3.00) | Solid handling (4.00) | Preliminary equipment operation and maintenance (5.00) | Collection system operation and maintenance (6.00) | LeChevallier et al. (2019) |

*Commercial surgical masks marketed for medical use had mean particle removal efficiencies from 53% to 75% (Mueller et al., 2020). Therefore, an average particle removal of 64% was assumed in this study, resulting in a risk ratio of $1 - 0.64 = 0.36$ for participants with PPE use.
while maximizing heterogeneity between groups (Hartigan & Wong, 1979). First, health and occupational susceptibility scores calculated in Section 2.2 above were used to derive clusters. Then pertinent survey information was used to derive the representative features of each cluster, thus forming wastewater personnel persona groups.

The analysis was performed in RStudio using $K$-means clustering algorithm, which iterates the centroids of clusters until the within-cluster sum of squares are minimized (Hartigan & Wong, 1979). To obtain unbiased results, only those participants who completed all survey questions ($n = 129$) were used. Because the health and occupational susceptibility scores differed in scale, the scores were first standardized to an equal scale (mean $= 0$ and standard deviation $= 1$); then, the Hopkin’s statistic was calculated to validate the clusterability of the dataset. Hopkin’s statistic test evaluates the clustering tendency of a dataset by comparing the sum of distance from the real dataset to the sum of distance from a simulated dataset with a random uniform distribution. See the Supporting Information for more information. A value close to 1 (or far above 0.5) indicates that the dataset is clusterable (Banerjee & Dave, 2004). The optimal number of clusters ($k$) was determined based on the total within sum of square values and silhouette width at different cluster numbers. The result of cluster segmentation was visualized using R package factoextra Version 1.0.7 (https://cran.r-project.org/web/packages/factoextra).

Representative features of each persona group were derived by evaluating the statistical difference among clusters based on distinctive factors, for example, age, gender, and job task category. Appropriate statistical analysis methods were chosen for each survey attribute as shown in Table S1. If a significant difference among clusters was identified ($p < 0.05$), a post hoc pairwise comparison was conducted to identify which two clusters were significantly different. Statistically distinctive parameters were used to derive the features of each persona.

**RESULTS**

**Survey results**

Demographic and health-related results are shown in Table 3. The sample size for each parameter assessed was not identical because some participants did not answer all the questions. The gender distribution showed that the wastewater industry is male dominant, with 75% male and 25% female. Most of the participants were in

| Characteristics                          | Sample size | Number | Percentage |
|-----------------------------------------|-------------|--------|------------|
| Gender                                  |             |        |            |
| Male                                    | 163         | 122    | 74.8%      |
| Female                                  | 41          |        | 25.2%      |
| Age                                     |             |        |            |
| 18–24                                   | 163         | 3      | 1.8%       |
| 25–34                                   | 17          |        | 10.4%      |
| 35–44                                   | 33          |        | 20.2%      |
| 45–54                                   | 49          |        | 30.1%      |
| 55–64                                   | 52          |        | 31.9%      |
| Over 65                                 | 9           |        | 5.5%       |
| Self-evaluated fitness level            |             |        |            |
| Perfect                                 | 169         | 27     | 16.0%      |
| Good                                    | 71          |        | 42.0%      |
| Average                                 | 56          |        | 33.1%      |
| Poor                                    | 15          |        | 8.9%       |
| Unfit                                   | 0           |        | 0.0%       |
| Number of underlying health condition   |             |        |            |
| 0                                       | 167         | 63     | 37.7%      |
| $\geq 1$                                 | 104         | 62.3%  |
| 1                                       | 61          | 36.5%  |
| 2                                       | 31          | 18.6%  |
| 3                                       | 10          | 6.0%   |
| 4                                       | 2           | 1.2%   |

(Continues)
the age ranges of 45–54 (30%) and 55–64 (32%). Most participants were Caucasian/White (75%), followed by Asian (8%), Latino/Hispanic (4%), and other races/ethnicities. For education level, only 7% of the participants had less than a high school diploma. Self-evaluated fitness levels were as follows: 16% perfect level, 42% in good level, and 33% in average level. Among the 16 underlying health conditions asked, 62% of the participants had at least one underlying health condition with obesity (44%), hypertension (30%), diabetes (10%), and asthma (8%) being the most common ones (see Figure 2).

Occupation-related questions included PPE use when performing job duties, shift duration, level of exposure to wastewater, and job task category (Table 4). Seventy-three percent of the participants reported always wearing PPE while working. Seventy-three percent of the participants worked 8–12 h per shift, and the proportion of participants working >12 (4%) or <4 h (0.6%) was relatively low. Only 2% of the participants reported having 100% exposure to wastewater. Most of the participants (67%) worked in routine plant operations, followed by collection system operation and maintenance (17%) and solids

| Characteristics                  | Sample size | Number | Percentage |
|----------------------------------|-------------|--------|------------|
| Race/ethnicity                   |             |        |            |
| Caucasian/White                  | 163         | 122    | 74.8%      |
| Asian                            | 13          | 8      | 8.0%       |
| Latino or Hispanic               | 6           | 3      | 3.7%       |
| African-American or Black        | 5           | 3      | 3.1%       |
| Native America                   | 5           | 3      | 3.1%       |
| Two or more                      | 5           | 3      | 3.1%       |
| Other/unknown                    | 4           | 2      | 2.5%       |
| Prefer not to say                | 3           | 2      | 1.8%       |
| Native Hawaiian/Pacific Islander | 0           | 0      | 0.0%       |
| Degree of education              |             |        |            |
| Less than a high school diploma  | 163         | 11     | 6.7%       |
| High school diploma or equivalent| 49          | 15     | 30.1%      |
| Associate’s degree               | 44          | 13     | 27.0%      |
| Bachelor’s degree                | 36          | 11     | 22.1%      |
| Master’s degree                  | 14          | 4      | 8.6%       |
| Doctorate                        | 1           | 0      | 0.6%       |
| Other                            | 8           | 2      | 4.9%       |

FIGURE 2  Survey results of prevalence of underlying health conditions among wastewater personnel

TABLE 3 (Continued)
handling (7%), and preliminary equipment operation and maintenance (6%).

**Personas creation**

The goal of this study was to identify relevant occupational and health factors among the wastewater personnel population and use this information to derive and examine representative susceptibility features that may influence risk using the “Personas” creation methodology.

**Personas segmentation**

Survey-based personas were derived from health and occupational susceptibility scores and their representative features. First, the Hopkin’s statistic was calculated as 0.81, meaning the dataset was clusterable. Then, based on the results of total within sum of square and silhouette width at different cluster numbers (see Figure S1), an optimal cluster number of three was chosen. The three distinguishable clusters are shown in Figure 3. Cluster 1 \((n = 81)\) was assigned the name “low-susceptibility” group characterized by both low health and low occupational susceptibility scores. Cluster 2 \((n = 21)\) had low health but high occupational susceptibility scores, and was named “occupational susceptibility” group. Lastly, Cluster 3 \((n = 27)\) had high health but low occupational susceptibility scores and was given the name “health susceptibility” group.

**Personas representative features**

Statistical analysis showed that the three clusters were significantly different in terms of gender, age, number of underlying health conditions, PPE use, level of exposure to wastewater, and job task category. There was no significant difference in education level, self-evaluated fitness level, and shift duration. A post hoc analysis revealed pairwise differences between the clusters (see Table 5). Statistically distinctive attributes were then used to derive representative features of each persona group, as summarized in Table 6.

Post hoc analysis revealed that Cluster 2 (occupational susceptibility group) differed significantly from other clusters in PPE use, level of exposure to wastewater, and job task category. A significant difference was found in PPE use between Cluster 2 and other clusters \((p < 0.01; \text{Table 5})\). In fact, only 29% of the participants in Cluster 2 (Figure 4a) reported always wearing PPE when performing job duties. By contrast, PPE use was higher in Cluster 1 (80%) and Cluster 3 (78%). Cluster 2 was also found to have significantly higher level of exposure to wastewater compared with other groups (Figure 4b). For instance, around 86% of the participants

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**Table 4:** Occupational survey results for wastewater personnel

| Occupation factors and their attributes | Sample size | Number | Percentage |
|----------------------------------------|-------------|--------|------------|
| PPE use                                |             |        |            |
| Yes                                    | 179         | 130    | 72.6%      |
| No                                     |             | 49     | 27.4%      |
| Shift duration                         |             |        |            |
| <4 h                                   | 179         | 1      | 0.6%       |
| 4–8 h                                  |             | 40     | 22.3%      |
| 8–12 h                                 |             | 131    | 73.2%      |
| >12 h                                  |             | 7      | 3.9%       |
| Level of exposure to wastewater        |             |        |            |
| 0%                                     | 178         | 13     | 7.3%       |
| 25%                                    |             | 82     | 46.1%      |
| 50%                                    |             | 60     | 33.7%      |
| 75%                                    |             | 19     | 10.7%      |
| 100%                                   |             | 4      | 2.2%       |
| Job task category                      |             |        |            |
| Routine plant operations               | 162         | 108    | 66.7%      |
| Collection system operation and mainte|             | 27     | 16.7%      |
| Solids handling                        |             | 11     | 6.8%       |
| Preliminary equipment operation and ma|             | 9      | 5.6%       |
| Routine plant maintenance              |             | 5      | 3.1%       |
| Disinfection system operation and main|             | 2      | 1.2%       |

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**TABLE 5** Statistical analysis showing the differences in factors between three clusters

| Factors                          | Significance level among clusters | Significance level with post hoc analysis |
|----------------------------------|----------------------------------|------------------------------------------|
| Gender                           | $<0.001^{***}$                   | Cluster 1 0.092  <0.001***                |
|                                  |                                  | Cluster 2 0.558                           |
|                                  |                                  | Cluster 3 1.000                           |
| Age                              | $<0.001^{***}$                   | Cluster 1 1.000 <0.001***                 |
|                                  |                                  | Cluster 2 0.052                           |
| Number of underlying health condition | $<0.001^{***}$                    | Cluster 1 0.470 <0.001***                 |
|                                  |                                  | Cluster 2 0.002**                         |
|                                  |                                  | Cluster 3 1.000                           |
| PPE use                          | $<0.001^{***}$                   | Cluster 1 <0.001***                      |
|                                  |                                  | Cluster 2 1.000 0.003**                   |
| Level of exposure to wastewater  | $<0.001^{***}$                   | Cluster 1 <0.001***                      |
|                                  |                                  | Cluster 2 1.000 0.002**                   |
|                                  |                                  | Cluster 3 1.000                           |
| Job task category                | 0.022*                           | Cluster 1 0.010*                         |
|                                  |                                  | Cluster 2 0.249                           |
|                                  |                                  | Cluster 3 1.000                           |

*Note: Significant results in boldface.*

*p < 0.05. **p < 0.01. ***p < 0.001.
in Cluster 2 spent ≥50% of time during a regular shift exposed to wastewater. In Cluster 1 and Cluster 3, only 38% and 48% of the participants had ≥50% exposure to wastewater, respectively. Cluster 2 also differed significantly from Cluster 1 (the low-susceptibility group) in the job task category (Figure 4c). In Cluster 2, about 62% of the participants worked in the early-stage treatment processes, for example, the collection
and preliminary treatment systems, which are generally associated with high occupational risks. In Cluster 1, 70% of the participants worked in routine plant operations. Overall, the lack of PPE use, high level of exposure to wastewater, and job task category led to high occupational susceptibility for Cluster 2.

Cluster 3 was the health susceptibility group. This group was significantly different from other clusters in terms of gender, age, and number of underlying health conditions (Table 5). Cluster 3 was composed of 100% male, and this ratio was significantly higher ($p < 0.001$) than that of Cluster 1 (low-susceptibility group) which contained 65% male and 35% female (Figure 5a). In Cluster 3, all participants were ≥45 years old while in Cluster 1, 48% of the participants were <45 years old. Cluster 3 also differed significantly ($p < 0.001$) from Clusters 1 and 2 in the number of underlying health conditions that the participants reported (Figure 5c). In Clusters 1 and 2, 51% and 29% of the participants did not report having any underlying health condition, respectively. In Cluster 3, all participants had at least one underlying health condition, and the percentage of participants with two, three, and four underlying health conditions were 59%, 30%, and 7%, respectively.

**DISCUSSION**

In this study, a wastewater personnel population framework was developed to evaluate susceptibility factors that may influence risk of infection or illness using public health data on SARS-CoV-2 as a proxy pathogen. This means public health data related to risk of developing severe outcomes of COVID-19 were used as a proxy for assessing susceptibility groups within the industry. Results suggest that individual health and occupational factors need to be considered in risk assessment and management strategies and the framework developed may be used to improve personnel safety and empower the wastewater industry to make informed decisions about occupational exposure to current and future wastewater pathogens. Prior to the COVID-19 pandemic, surveys on wastewater personnel in the United States were limited and most studies concentrated on sanitation personnel in low- and middle-income countries (Bischel et al., 2019; Chen et al., 2021). While existing research in the United States has shown that the use of PPE plays a significant role in protecting the wastewater workforce (LeChevallier et al., 2019), clearly, the susceptibility to a health effect is a multifaceted issue. Yet quantifying the contribution of both individual health and occupational factors has received limited attention. Although occupational safety guidelines such as those provided in the JSA may not be sufficient to safeguard the health of wastewater personnel, interventions that address variations in individual health may have the ability to streamline safety protocols. Risk assessment tools and practices that incorporate health factors may be especially critical in the future when responding to novel and rapidly emerging pathogens.

Performing this research during the COVID-19 pandemic provided direct and timely information and exemplified the intersection between gender, age, health conditions, job tasks, and level of exposure to wastewater. Although wastewater personnel provide an essential service towards environmental and public health protection, results show that the potential for an occupation-related health impact may be most pronounced for men over the age of 44 with underlying health conditions (i.e., obesity, diabetes, and heart disease). The men with the highest risk of illness from wastewater pathogens are most likely
men who are already vulnerable due to underlying health concerns. As such, risk of a health effect may not impact all wastewater personnel the same. Recognition of this intersectionality makes consideration of occupational context and health variables essential in guiding risk assessment methodologies aimed at protecting wastewater personnel. The scoring system developed here combines health and job-related risk factors and examines their association within a susceptibility and risk assessment framework. Lastly, as humans face emerging pathogens, holistic approaches to risk assessment and response are needed. The overall risk framework developed here contributes to the discussion in the current evolving public health environment.

Limitations

According to the U.S. Bureau of Labor Statistics (BLS, 2022), there are about 122,000 water and wastewater treatment plant and system operators. Our study captured responses from 246 wastewater personnel from different regions of the United States. The study sample was from wastewater treatment plant personnel with whom the researchers had access to their email contact information. Findings are specific to those individuals and may not be generalizable to all wastewater personnel. At the start of the study, only California personnel received the survey. However, to increase the sample size the researchers later worked with professional organizations to distribute the survey more broadly to their national members. Overall, the sample group demographic trends (Table 3) aligned with those reported by the US Census Bureau. In 2019, about 93% of wastewater operators were male with a median age of 45.6 and 78.8% of them identified as White race or ethnicity (Data USA, 2022; United States Census Bureau, 2022). The low response rate may have been technical related—issues with accuracy of emails and general email recruitment. The low completion rate may have been due to the length and flow of the survey and general lack of motivation to complete the survey during the early months of the COVID-19 pandemic. However, the susceptibility trends observed for the sample group and the risk framework developed may serve as a guidepost and contribute to the discussion and reevaluation of risk for this essential workforce.

CONCLUSIONS

In this study, three survey-based personas were derived from a health and occupational susceptibility scoring system for wastewater personnel. Results show that individual health and occupational factors may impact the susceptibility of wastewater personnel to different degrees. Males over the age of 44 with underlying health conditions are more prone to health susceptibility, while wastewater personnel at early treatment stages without PPE use are more prone to occupational susceptibility. Results from this study highlight the intersectionality of health and occupational factors that could be incorporated into risk assessment evaluation for decision making in the wastewater industry.

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AUTHOR CONTRIBUTIONS

Yihan Zhang: Methodology; investigation; formal analysis; data curation; writing-original draft; writing-review and editing. Jessica Ha: Data curation; methodology. Maureen Kinyua: Conceptualization; methodology; project administration; writing-review and editing; funding acquisition; validation; resources.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

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**SUPPORTING INFORMATION**

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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