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Assessing State Preparedness for Drinking Water-Related Public Health Events

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M.P.H., Emory University, 2016

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An abstract of

A thesis submitted to the Faculty of the

Rollins School of Public Health of Emory University

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Abstract

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Background: Recent responses to drinking water-related public health events, such as water-associated illness and utility failure, suggest that there is a gap in state drinking water preparedness capacity. Studies assessing preparedness in a standardized process are few, and resources regarding preparation for drinking water public health events are even more lacking. With aging water infrastructure, the complexity of water-related public health events, and an increasingly variable climate, drinking water preparedness is a priority for public health. This goal of this study is to assess possible associations between supplementary, water-directed preparedness funds and level of state drinking water preparedness. **Methods:** States were assigned a drinking water preparedness index score through a web-based evaluation of state preparedness resources. Ordinal logistic regression was used to investigate associations between presence of water-directed preparedness funding and level of drinking water preparedness. A secondary investigation used existing climate preparedness index scores to examine similarities between state drinking water preparedness and climate preparedness. **Results:** While not statistically significant, states with water-directed funding were more likely to score in higher preparedness categories (Odds Ratio= 1.560, 95% Confidence Intervals= 0.488, 4.989). In addition, state drinking water preparedness scores and climate preparedness scores adapted from States at Risk were in 88% agreement in state scoring outcomes when including a 1-level degree of variation. **Conclusion:** The results suggest a need for further investigation of a possible association between state drinking water preparedness and water-directed funding. This study suggests that adding clear priorities in funding mechanisms may improve state capacity-building and preparedness.

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Table of Contents

INTRODUCTION AND BACKGROUND

Part 1: Introducing the Problem

Research in emergency preparedness has expanded in the years since 2001. The events on September 11, 2001 exposed the glaring weaknesses in the emergency preparedness infrastructure in the United States. Emergency preparedness planning has since become a top priority for the nation, with the development of a National Response Framework to unify emergency responses. However, the issue of drinking water preparedness- the capacity to respond to public health events related to drinking water supply- has been neglected. This major gap in preparedness research, a field inherently difficult to research, becomes apparent when public health issues rise to the forefront of public awareness. Most recently, an incident in Flint, Michigan resulted in lead leaching into public drinking supply. *Naegleria fowleri*, a climate-sensitive, free-living amoeba, has been isolated in Louisiana tap water on multiple occasions and has resulted in fatal cases of primary amoebic meningoencephalitis (PAM). Additionally, nitrate contamination of Columbus, Ohio water supply overwhelmed drinking water systems and caused levels of nitrates to surpass the 10 parts per million limit set by the EPA. State governments must be prepared for the potential for community-wide waterborne illnesses and water utility disruption. Responses to these drinking water-related events often do not include water-related public health planning or lack the appropriate tools (Yoder, 2016). Recent responses suggest that there is a gap in state drinking water preparedness capacity and capability.

Public water systems provide water for human consumption through pipes or other delivery methods. Public water systems provide drinking water for 90% of Americans (EPA, 2015) whereas the remaining population uses private water supplies such as wells. In the United States, this water is filtered and disinfected prior to distribution. This is how communities receive water for drinking, bathing, food service industries, manufacturing, agricultural practices, medical procedures, and other critical needs. An interruption in public water systems result in a loss of critical community functions and an increased risk to public health. There is opportunity for contamination at every level of the water distribution process. This includes groundwater or surface water contamination, inadequate filtering or disinfection techniques, or contamination post-disinfection via pipes or water main break. The system is complex, with drivers such as aging infrastructure and climate change impacting the frequency and severity of contamination (CDC, 2014).

An additional concern in the lack of data related to drinking water-related preparedness is the increasing variability in weather patterns. Climate change may become a driver of frequency and severity of weather events and potentially drinking water public health events (GlobalChange.gov, 2016). Climate change is expected to increase number and severity of algal blooms as well as the number of waterborne disease outbreaks (Hunter, 2003). Examples in the U.S. are becoming more frequent, such as cyanobacterial blooms in Lake Erie in 2007 (Paerl and Paul, 2011). Additionally, drought conditions are expected to increase, which will increase sediment and mineral concentrations in water supplies. (Safe Drinking Water Foundation, 2016). Without proper preparedness mechanisms in place, state and local governments may not be able to respond appropriately to these complex climate issues as they impact drinking water. A recent study has assessed state preparedness capabilities for general climate threats and provided grades based on the results (States at Risk, 2015). This quantitative study is the first of its kind and provides a foundational understanding of the need for further capacity-building at the state level. Climate change will have a direct impact on drinking water supply and production (Delpla et al, 2009). This suggests that both drinking water preparedness and climate preparedness are public health priorities. As a secondary analysis, this study compares state drinking water preparedness ratings with these climate preparedness ratings.

Part 2: Case Examples

The availability of consistent and reliable sources of safe drinking water plays a critical role in maintaining the stability of a community. When this supply is contaminated, it poses an imminent threat to public health. There are many types of contamination which can occur. Below, several case examples of recent drinking water public health events highlight various sources of contamination and the relevance of further investigation of drinking water preparedness.

Physical Contamination: Aging Infrastructure

When the city of Flint, Michigan switched their drinking water supply from Detroit's system to the Flint River for financial reasons in April 2014, the corrosiveness of the water caused lead to leach into the water supply at levels exceeding 100 ppb in some samples. (Lin, Rutter and Park, 2016) Increased cases of Legionnaire's disease and rashes have also been reported. The city of Flint did not use anti-corrosives to treat the water prior to distribution, leading to high levels of lead throughout the city (Torrice, 2016). This case is still evolving, but concern of lead poisoning is widespread and various levels of government were accused of negligence in recognizing and responding to this public health emergency in a timely manner. A public health preparedness and response plan that included a systematic procedure for responding to citizen complaints of poor water quality and water expertise at the state public health department could have led to prompt response to this crisis. Quick action may have led to the reversal of the water supply switch and better surveillance. It is clear that there was not sufficient reporting for drinking water-related concerns and there was a gap in communication with and regulation of water utilities. The public health department does not appear to have water-related expertise. In addition, this is an example of aging pipe infrastructure acting as a driver of drinking water contamination.

Climate Sensitivity

Climate change has been indicated as a factor for increasing cases of water-associated illnesses. A recent study found that a 1° C increase in mean monthly temperature was associated with an 8% increase in the incidence of diarrheagenic *Escherichia coli* (Philipsborn et al, 2016). *Naegleria fowleri*, a free-living ameba, has been isolated in Louisiana public water systems on multiple occasions in recent years, resulting in two deaths in 2011. These 2011 cases were the first in the United States associated with disinfected tap water. While not harmful to drink, *N. fowleri* causes primary amebic meningoencephalitis, a rare and often fatal brain disease, by traveling up the olfactory nerve into the brain (CDC, 2016). This can occur if contaminated water enters the nostrils, often during recreational use or through the use of

Neti pots for sinus relief. This is a climate sensitive organism and an emerging threat for public health. The extent of *N. fowleri* is broadening, with the first cases being found in Minnesota (2010) and Kansas (2011), which occurred after localized heat waves (Yoder et al, 2012). There was no guidance for responding to *N. fowleri* in drinking water and was challenging to properly communicate risk to the community. The United States did not have response protocols in place at the time of the 2011 cases, which contributed to the public concern surrounding the issue and the lack of surveillance. This incident has raised awareness on the importance on having existing protocols for drinking water public health events. It has also served as an example of the impact of climate change on threats to drinking water quality.

Biological Contamination of Source Water

In 2014, cyanobacterial algal blooms in Lake Erie resulted in the contamination of Toledo, Ohio drinking water supply. Algal blooms are a seasonal occurrence, but are exacerbated by agricultural practices and climate change. Exposure to cyanobacteria may cause gastroenteritis, skin irritation, and allergic responses. In high quantities, it can also affect the liver (CDC, 2011). This particular occurrence left approximately half a million residents without safe drinking water. There are currently no U.S. federal regulations for cyanobacteria in drinking water under either of the major drinking water policies- Safe Drinking Water Act and Clean Water Act (EPA, 2016). Therefore, there was no protocol in place for cyanobacterial surveillance or public health response. In this case, the Ohio governor declared a state of emergency when a water treatment plant tested positive for microcystin, a toxin produced by cyanobacteria. Boiling water does not eliminate these toxins and a ‘do not drink’ advisory was issued. (Florcruz, 2014) As these algal blooms continue and possibly increase in severity, this example points to a need for clear protocols for prevention and response plans.

In contrast to the above example, a recent outbreak of cryptosporidiosis in Baker City, Oregon demonstrated a prompt public health response. *Cryptosporidium* is a parasite that causes a diarrheal illness called cryptosporidiosis and can be found in every region of the United States as well as globally. In July 2013, the first outbreak caused by a public water system in 20 years occurred in Baker City, Oregon. This community received its water from a surface water source that was chlorinated but not filtered. *Cryptosporidium* is one of the few pathogens that are not killed by levels of chlorine used to treat water, but rather filtration or UV disinfection is needed to remove the parasites. The Environmental Protection Agency (EPA) requires surface water-supplied systems with exemptions to filtration requirements to have a Cryptosporidium-specific treatment in addition to chlorination. However, small systems (serving under 100,000 people) were not required to do so until October 2014 and Baker City had received an extension until October 2016 (DeSilva et al 2015). On July 31st, before the outbreak was officially linked to drinking water, the Baker County Health Department issued a boil-water. Despite strong surveillance and quick action by the public health department, approximately 2,780 people became ill over the course of the outbreak. This incidence highlights the need for maintaining multiple barriers for protection of drinking water. It demonstrates the importance of the requirements implemented by the EPA and the coordination required to identify and respond appropriately to drinking water public health events.

Chemical Contamination of Source Water

In January 2014, approximately 7,500 gallons of methyl-cyclo-hexane-methanol (MCHM) leaked from a tank at Freedom Industries into the Elk River in West Virginia. There is little known about this chemical, including its effects on human health, but after the January spill 369 individuals were hospitalized and experienced a range of symptoms including nausea, rash, vomiting, abdominal pain, and diarrhea (Toxnet, 2014). A 'do not use' order was issued for 300,000 residents and water utilities were closed downstream. Insufficient spill management resulted in a second spill two weeks later. There was industry resistance after the spill stating that there was no evidence that MCHM causes long-term health issues. The unknown properties of the chemical posed a risk during this public health event and contributed to the mishandling of crisis and emergency risk communication related to the spill. This event suggests a need for stronger drinking water protection policy to regulate industrial effluent impacting water supply.

Part 3: Measuring Preparedness

"Public health emergency preparedness is the capability of the public health and health care systems, communities, and individuals, to prevent, protect against, quickly respond to, and recover from health emergencies, particularly those whose scale, timing, or unpredictability threatens to overwhelm routine capabilities." (Nelson et al., 2007). The CDC has developed a set of 15 public health preparedness capabilities, which were designed to assist state and local health departments with strategic planning (CDC, 2011). This capability-based system is meant to identify gaps in preparedness, determine priorities, and build capacity. The following study considers these capabilities in designing a web-based method for evaluating state drinking water preparedness. This evaluation implements a standardized method for comparing levels of drinking water preparedness between states. It uses an approach which focuses on the shortage or absence of ingredients for preparedness, since this suggests that response efforts may be more likely to break down (Jackson, 2008).

Public health preparedness is a multi-billion dollar national investment. Funding to achieve public health preparedness has grown substantially, with over $9 billion being distributed to state governments and LHD's since 2006 from federal Public Health Emergency Preparedness (PHEP) funding alone (Pines, Pilkington, and Seabury, 2014). With the influx of funds being allocated, there is an acknowledged need for reliable metrics to evaluate preparedness as a science. Progress in this field is slow in development of evidence-based practices, performance measures, and standards due to the rarity of public health emergencies (Nelson et al, 2008). In addition, most public health preparedness funding is generalized, such as PHEP, or funding mechanisms which have capability-based eligibility requirements do not include drinking water-related metrics. A Department of Homeland Security report proposed performance measures for preparedness which included effective and targeted investments which move toward desired preparedness outcomes (Department of Homeland Security, 2010). This method would allow for a standardized approach for measuring preparedness as well as the effect of funding towards meeting preparedness goals.

However, in order to assess state-level preparedness for drinking-water preparedness, there must be measurable indicators. Measuring inputs alone, such as funding, cannot necessarily capture the capability to achieve desired response outcomes (Jackson, 2008). One method to address this issue may be to assess the impact of water-directed funding on state drinking water preparedness level. This study employs the above approach, comparing drinking water preparedness at the state level using water-directed funding as a primary exposure and preparedness level as an outcome. CDC has several funding outlets for state preparedness, none specifically focused on drinking water capabilities. While there are no funding mechanisms for drinking water preparedness, there are funding sources to increase state water capacity. This study uses two of these funding sources to investigate possible associations between directed funding and drinking water preparedness.

Part 4: Addressing the Gap

It is clear that studies assessing preparedness in a standardized process are few, and resources regarding preparation for drinking water public health events are even more lacking. This study implements a standardized method for assessing and comparing state drinking water preparedness and provide a baseline preparedness assessment. In addition to providing a comparative measure of preparedness, the study investigates potential associations between the presence of water-directed funding and level of drinking water preparedness. The study will also incorporate existing climate preparedness data to investigate potential relationships between drinking water preparedness and climate preparedness.

The main questions of this study are:

1) Is water-directed funding associated with an increase in level of state drinking water preparedness?

2) Is there a relationship between state drinking water preparedness and state climate preparedness?

Projected Significance

Our current knowledge of public health preparedness reflects a small pool of existing threats, which can lead to an overestimate of the capacity and capabilities of a state public health agency. The current evidence base neglects the resources required for most incidents outside the standard realm of threats, such as bioterrorism or pandemic flu (Hunter et al 2013). Table top exercises and simulations are often used as markers of preparedness, but only address certain aspects of preparedness. Through comparative analysis, we can learn about the impact of funding- general and water-directed- on state drinking water preparedness capabilities. In addition, we can investigate possible links between state drinking water preparedness and climate preparedness. With further investigation, policy and funding implications for drinking water may be revealed.

METHODOLOGY

Data Collection

Preparedness Measures:

Due to the lack of standardized preparedness metrics for public health preparedness, the investigator chose to create an index score of preparedness for each of the 50 states from five web-based evaluation questions. These questions were aimed at addressing drinking water preparedness related to public access to preparedness information, accessible state preparedness plans or guidance, resources for water utilities, 24/7 reporting for surveillance purposes, and presence of drinking water information on state public health sites. PHEP capabilities (CDC) were consulted prior to developing evaluation questions. Data were collected from the water quality page for the state, located either on the state public health and/or environmental quality/management website. The five evaluation questions focused on assessing the availability of data related to drinking water preparedness and were recorded as binary variables. The evaluation questions are as follows:

1) Does the state offer public drinking water preparedness resources?

2) Does the state have mutual aid/ utility association information for drinking water utilities?

3) Does the state list a 24/7 hotline for water emergencies?

4) Does the site have an accessible, online copy of a drinking water-related state emergency document?

5) Is water (ex. 'drinking water' or 'water systems') listed as one of the major topics and/or services listed on the state public health site?

As there was no evidence that one question should be valued higher than the others, the index score was tallied from the five evaluation questions for a range of scores from zero to five. See the Evaluation and Coding document in the appendix for further information on the coding and evaluation criteria used to calculate an index score.

Due to the subjective nature of the questions, a second evaluator performed an assessment for 10% (5) of the states. These states were chosen at random using an online random number generator (random.org). A weighted average of individual kappa values was calculated in SAS to determine level of inter-rater agreement and assess the validity of the index scores used in this study. The kappa statistic of 0.22 indicates a slight agreement between raters. However, the 95% confidence limits contain zero, which means we cannot reject the possibility of no agreement. This has implications for the design of future state preparedness evaluations.

Funding Measures:

The 2016 National Snapshot of Public Health Preparedness, prepared by the CDC's Office of Public Health Preparedness and Response, includes the 2014-2015 allocated Public Health Emergency Preparedness (PHEP) funding. PHEP is a cooperative funding agreement between CDC and state and local governments; awardees are able to choose how this money is spent. The total amount allocated is adjusted for state population. These data were used as a measure of general preparedness funding for this study. Initially, the investigators planned to assess which of these states had drinking water capacity activities in PHEP-reporting and conduct analyses on these states. However, only seven states reported any drinking water capacity and this sample size was considered too small for further analysis. Therefore, investigators chose to conduct an analysis of which states received water-directed funding to be used in further analyses. This investigator only had access to CDC sources of funding. To assess amount of water-directed state funding, the Waterborne Disease Prevention Branch at CDC provided funding information on annual Epidemiology Laboratory Capacity (ELC) funds. This funding is often to fulfill a singular improvement in capacity or improvement, but is water-specific. Additional CDC water-directed state funding information was retrieved from EHSNet Water. Both funding sources reported were from 2014-2015 data. This is not meant to be a cumulative view of total water-directed funding allocated to state governments, but rather a standardized snapshot of states receiving supplementary funding.

Additional Measures:

Covariates included in analyses due to possible interaction or confounding include: state population (categorized using quartiles), percent of state living in urban populations, percent of state using well water supply (categorized using USGS standards), and total number of state response laboratories (biological and chemical Laboratory Response Networks).

2010 Census data provided information on state population and percentage of population living in urban areas. The total percent of state populations using self-supplied water was found using online 2010 USGS data. This percent was categorized according to USGS standards. The number of state laboratories- biological and chemical Laboratory Reporting Networks, and Pulsenet- was found using the 2016 National Snapshot of Public Health Preparedness.

A climate vulnerability grade was adapted from a 2015 report by statesatrisk.org (analysis by Climate Central and ICF International). This report is the first quantitative assessment of state climate change preparedness; it includes grades (A+ through F) for each state by climate threat as well as a cumulative grade, which is used in the context of this analysis. The cumulative state letter grade was converted to a numerical grade to be compatible with the index score for analysis. A detailed technical methodology of how states were graded is available online.

Data Analysis

All analyses were conducted using Statistical Analysis Software (SAS) version 9.4.

Frequency distribution was examined for all variables. Covariate distribution by preparedness index score was also examined stratified by presence of water-directed funding.

Correlation Analysis:

The number of state biological and chemical Laboratory Response Network (LRN) labs were highly correlated (Pearson's Correlation $r=0.79$). Therefore, the total number of LRN labs were used for further analyses. However, state population and the total number of LRN labs were highly correlated (Pearson's Correlation $r=0.88$), suggesting a collinearity problem. Therefore, LRN labs were removed from the final model. The percentage of state populations living in urban areas was moderately inversely correlated with the percentage of state populations using well water supply (Pearson's Correlation $r=-0.40$).

Logistic Regression: State population was categorized into quartiles for statistical modeling purposes. Confounding was assessed using the backwards elimination method of model selection. Non-significant potential confounders, or those resulting in an estimate within 10% of the fully-adjusted model, were eliminated from the final model.

Model Selection:

Models that did not satisfy the proportional odds assumptions (chi-square test statistic < 0.05) were not eligible for consideration as a final model. Interaction was assessed for urban percentage, well percentage, and LRN laboratories. The investigator was not able to assess interaction for state population because proportional odds assumptions were not met.

In addition, a sensitivity analysis was conducted to determine if any of the evaluation question variables contributed more to the analysis. None of the results were significant at a significance level of 0.05. Therefore, the original index score was used for ordinal logistic regression modeling. This investigator found that using a collapsed, 3-category index score did not significantly impact results of the model. Therefore, a collapsed, 3-category index score which combined the lowest two scores, middle two scores, and highest two scores was used in the full and reduced models.

Full Model:

$$logitP(\text{3-category preparedness score})$$

$$= \beta_0 + \beta_1 (\text{water-directed funding}) + \gamma_1 (\text{state population quartile}) +$$

$$\gamma_2 (\text{private water source}) + \gamma_3 (\text{LRN labs}) + \gamma_4 (\text{state urban percentage}) +$$

$$\delta_1 (\text{water-directed funding * private water source}) +$$

$$\delta_2 (\text{water-directed funding * LRN labs}) +$$

$$\delta_3 (\text{water-directed funding * state urban percentage}) + \varepsilon$$

where: β_0 *is the intercept*

β_1 *is the slope*

$\gamma_{1\text{-}4}$ *are covariate estimates*

$\delta_{1\text{-}3}$ *are interaction estimates*

ε *is residual error*

Final Reduced Model:

$$logitP(\text{3-category preparedness score})$$

$$= \beta_0 + \beta_1 (\text{water-directed funding}) + \gamma_1 (\text{private water source}) +$$

$$\gamma_2 (\text{state urban percentage}) + \varepsilon$$

where: β_0 *is the intercept*

β_1 *is the slope*

$\gamma_{1,2}$ *are covariate estimates*

ε *is residual error*

RESULTS

Overall, 5 (10%) states received a score 0, 10 (20%) states received a score of 1, 12 (24%) states received a score of 2, 10 (20%) states received a score of 3, 6 (12%) states received a score of 4, and 7 (14%) states received a score of 5. This score distribution follows a relatively normal distribution. Only 17 (34%) states had water-directed funding. Only the 2 highest preparedness score categories (4 and 5) had at least 50% of the states receiving water-directed funding. The mean population for states without water-directed funding is 4,763,302, while the mean for states receiving water-directed funding is 8,881,638.

Table 1. Summary of state results from web-based drinking water preparedness evaluation.

	Frequency (%)
Location of state drinking water webpage	
- ***Public health department***	8 (16%)
- ***Environmental quality/management department***	23 (46%)
- ***Both health and environmental departments***	19 (38%)
Presence of public drinking water preparedness resources	27 (54%)
Presence of mutual aid/utility association information for drinking water utilities	22 (44%)
Presence of 24/7 phone hotline for water emergencies	25 (50%)
Presence of an accessible, online copy of a drinking water-related state emergency document	21 (42%)
'Water' is listed as one of the major topics/services listed on the state public health site	28 (56%)

Table 1 provides a summary of the state drinking water preparedness evaluation results. The primary web-based location of drinking water information was on the state environmental quality/management site (38%), but many states also housed drinking water information on their public health website (46%). Interestingly, no more than 28 (56%) states had any given evaluation question answered by material on their drinking water site.

Table 2 displays the results of the state drinking water preparedness scores stratified by the exposure of interest, water-directed funding. The only two preparedness categories which had at least half of the states in the category receiving water-directed funding were 4 and 5, the highest levels. In addition, of the 5 states who scored a 0, 4 (80%) did not receive any water-directed funding.

Table 2. Frequency and percentage of index preparedness score by presence of water-directed CDC funding. Increasing index scores indicate increasing level of preparedness.

	Water-directed CDC Funding	
Drinking Water Index Score	**No**	**Yes**
0	4 (80%)	1 (20%)
1	6 (60%)	4 (40%)
2	9 (75%)	3 (25%)
3	8 (80%)	2 (20%)
4	3 (50%)	3 (50%)
5	3 (42.86%)	4 (57.14%)
TOTAL	**33 (66%)**	**17 (34%)**

Using proportional scoring, the drinking water preparedness score and climate preparedness score adapted from States at Risk grading had 42% agreeability. This means that 21 of the 50 states were graded the same by both evaluations. If we include states with grades that differed by one category (i.e. rated 1 by this study and 2 by States at Risk or vice versa), this percent agreement increases to 88%. See Appendix for a table comparing raw scoring categories.

As shown in **Table 3**, 17 (34%) of states received water-directed funding from the CDC. States who received water-directed funding tended to have larger populations, in the 3rd or 4th quartile. Meanwhile, states without water-directed funding had a wider population distribution, with more than half of the states (63%) in the lower population quartiles (1st or 2nd quartile). The percentage of states using private water sources seemed to have consistent trends between states with and without water-directed funding. On average, states with water-directed funding had twice as many LRN laboratories as those without water-directed funding. The percentage of states who live in urban areas is similar for those states with and without water directed funding.

Table 3. Summary of state characteristics stratified by water-directed funding.

	Water-Directed Funding	**No Water-Directed Funding**
	Frequency (%) or Mean (SD)	Frequency (%) or Mean (SD)
TOTAL	17 (34%)	33 (66%)
State Population		
Q1: 0-1,826,341	2 (11.76%)	11 (33.33%)
Q2: 1,826,342-4,436,370	2 (11.76%)	10 (30.30%)
Q3: 4,436,371-6,724,540	8 (47.06%)	5 (15.15%)
Q4: 6,724,541-37,253,956	5 (29.41%)	7 (21.21%)
Percent of State Using Private Water Source		
0-10%	6 (35.29%)	10 (30.30%)
11-30%	9 (52.94%)	21 (63.64%)
31-42%	2 (11.76)	2 (6.06%)
Number of Laboratory Response Network Labs (Biological and Chemical)	4.06 (4.12)	2.85 (2.17)
Percent of State in Urban Areas	76 .69 (13.95)	71.98 (14.82)

To visualize the preparedness scores, ArcGIS was used to create a map-based representation of index scores. **Figure 1** below shows a geographic map of the state drinking water scores as assessed in this study. The cross-hatching refers to those states who received water-directed funding. **Figure 2** incorporates both state preparedness scores- drinking water and climate- for a combined score. Again, cross-hatching refers to those states who received water-directed funding.

Water-directed funding was associated with higher levels of preparedness compared with lower or medium levels of preparedness (Odds Ratio= 1.560, 95% Confidence Intervals= 0.488, 4.989). However, this association was not significant at a 0.05 significance level. Percentage of state populations living in urban areas and percentage of state populations using private water sources (such as well-water) were significant predictors in the final ordinal logistic regression model. The categorized variable for private water sources was right-skewed and the highest category had a limited size, resulting in unreliable measure for this category. When comparing the middle category to the low category, the odds ratio is 5.729 (95% confidence intervals= 1.519, 21.604).

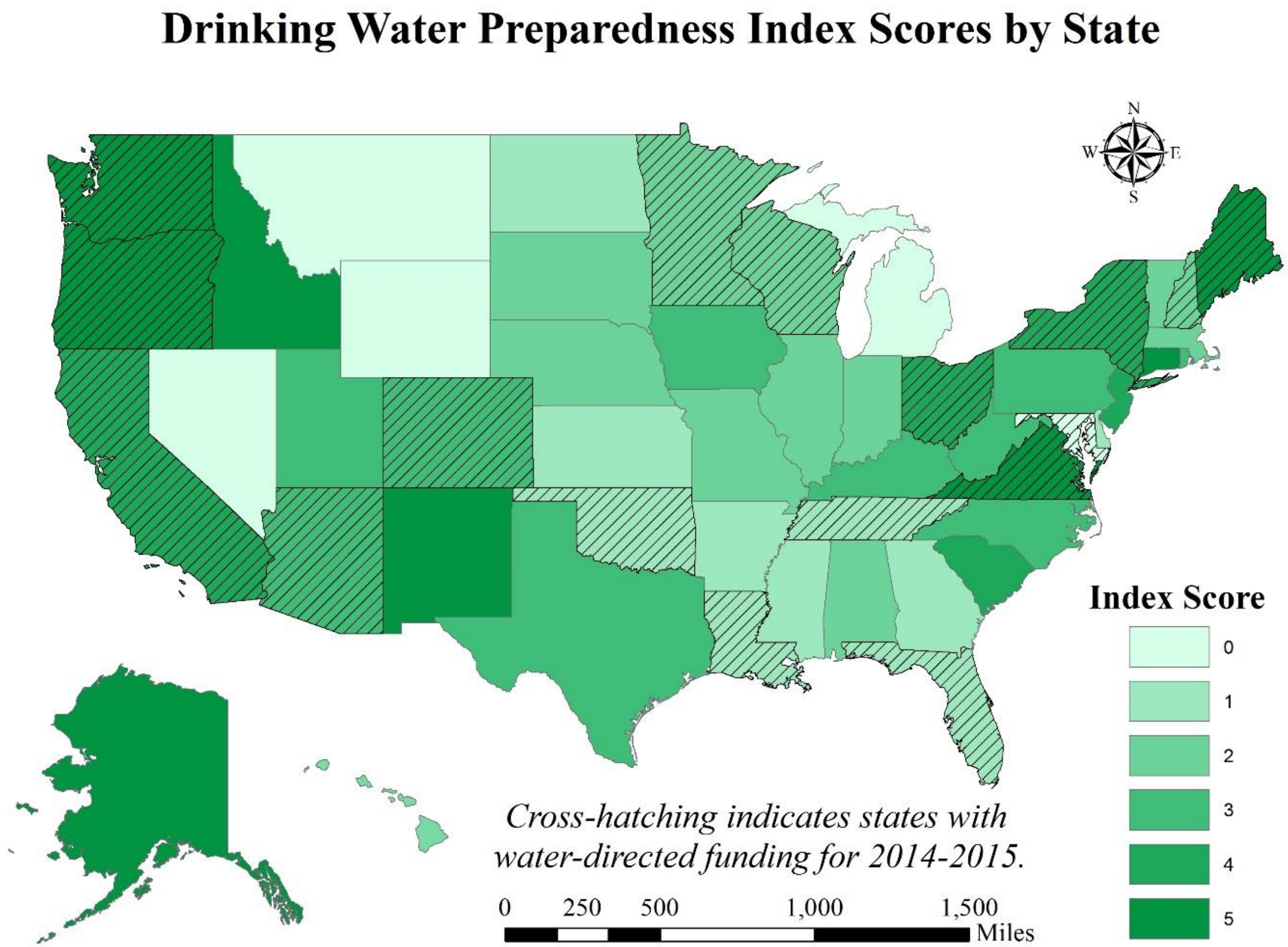

Figure 1. Map showing drinking water preparedness index scores by state. Scores are on an increasing scale from 0-5.

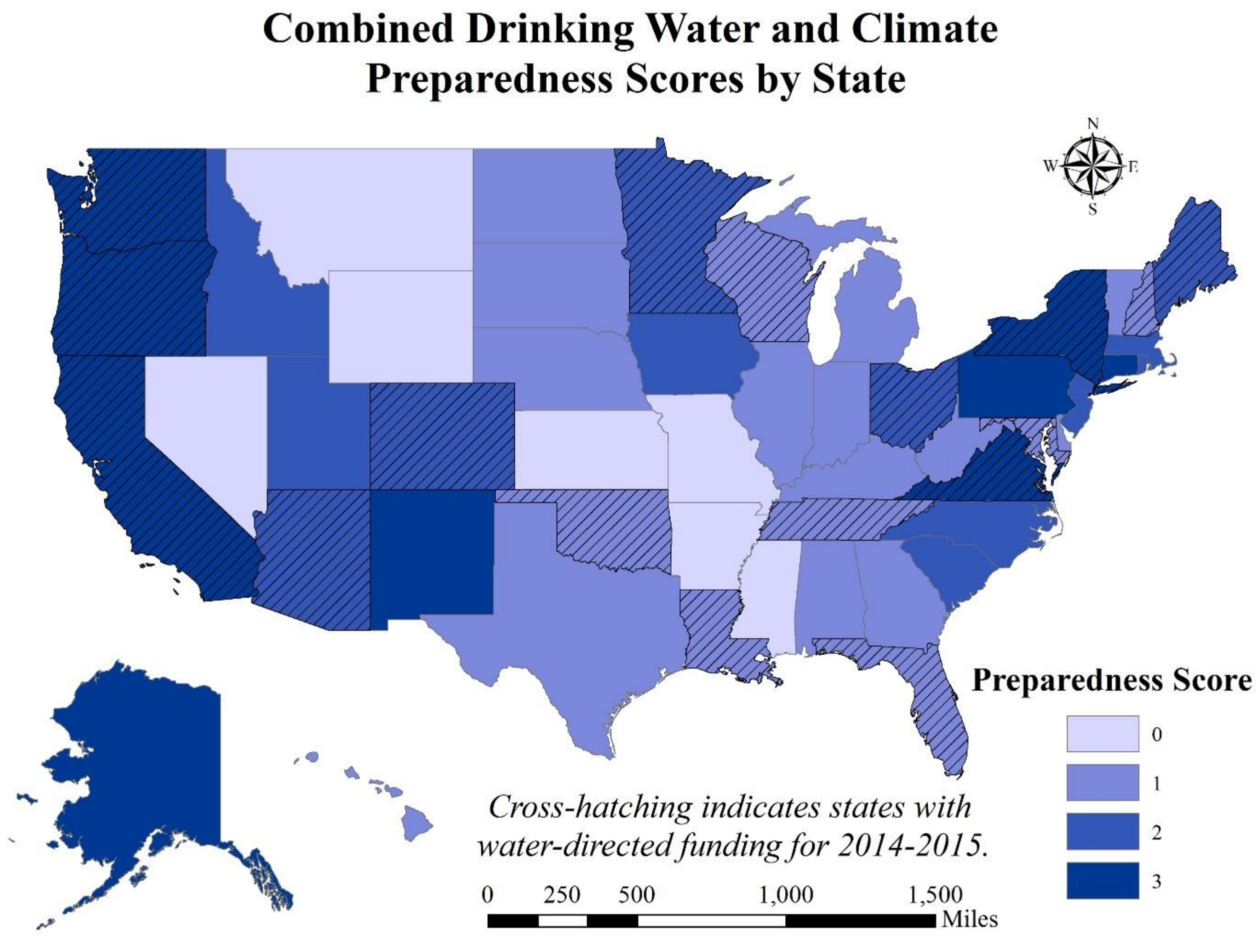

Figure 2. Map showing combined drinking water and climate preparedness scores by state. Scores are on an increasing scale from 0-3.

DISCUSSION

While this study does not conclusively find an association between water-directed funding and state drinking water preparedness, there appears to be a link between funding and level of preparedness. This study uses water-directed funding which are directed at building capacity, not directly related to preparedness. It suggests that increasing drinking water capacity at the state level may result in an increase in preparedness. Previous research has shown that funding directed towards a specific purpose is most effective towards producing a desired outcome (Nelson et al, 2008). This author suggests that having preparedness funds with drinking water metrics may have a stronger association with level of preparedness.

Results from the final ordinal logistic regression model found no significant association between water-directed funding and level of state drinking water preparedness. It is worth noting that all models, both crude and adjusted, had a point estimate odds ratio above the null. Descriptive statistics find a consistent trend between presence of water-directed funding and level of preparedness. States with water-directed funding tended to score in higher preparedness categories and states that scored in the higher preparedness categories (4 and 5) were more likely to have larger populations. However, population was dropped from the final model as it proved not to be a significant predictor. Percentage of state populations using private water sources and percentage of state populations in urban areas proved to be significant predictors in determining level of drinking water preparedness. Climate and drinking water preparedness scores were in 88% agreement, accounting for one level of difference, which suggests a possible link between drinking water and climate preparedness capabilities.

This study is the first to investigate the niche of drinking water and public health preparedness. It uses statistical methods to assess the role of water funding in increasing state preparedness for drinking water public health events. However, as the methods used to evaluate state preparedness were not standardized, outcome misclassification is a concern in this study. This study only used public data accessed on state public health and environmental quality/management websites as a way of standardizing evaluation and providing a snapshot of preparedness. The inter-rater reliability suggests that the evaluation metrics were subjective, limiting the generalizability of index scores found in this study. However, since all evaluations were conducted by one investigator, this provides a level of consistency between measurements. Exposure, or water-directed funding, misclassification is also a possibility in this study. The study was limited to two sources of water-directed funding from CDC. Had this investigator had access to a complete list of water-directed funding from state public health departments, this study may have captured more than 17 (34%) of states.

This study generates hypotheses regarding state drinking water preparedness, public health preparedness funding strategy, and possible links between climate and drinking water preparedness. Further investigation is needed to standardize appropriate measures of drinking water preparedness at the state level. As illustrated in the introduction, protection of public drinking water is critical in maintaining public health. Drinking water public health events, such as water-associated illnesses or infrastructure failure, impact a community's health, trust in the public health department, and can overwhelm facilities. This study's preparedness evaluation highlighted certain 'ingredients of preparedness' as a way to compare levels of preparedness between states. This includes: the presence of drinking water information on public health department websites, mutual aid information for public utilities, 24-hour reporting hotlines, online copies of preparedness guidance documents, and drinking water preparedness information for a public audience. Further study is needed to verify the impact of these capacity activities on level of state drinking water preparedness.

There are currently no tools to evaluate state drinking water preparedness capabilities and there are no metrics written into PHEP funding. Having clear priorities in funding programs may be key in improving drinking water public health preparedness. As only 7 states reported conducting water preparedness capabilities in their 2014-2015 PHEP report, it is apparent that most states do not pursue drinking water capabilities with generalized preparedness funds. Future studies will provide detailed evidence as to how specified funding impacts level of drinking water preparedness.

CONCLUSION

The continued occurrence of drinking water-related public health events, such as water-associated outbreaks and utility failure, stress the importance of developing drinking water preparedness at the state level. However, limited research has been conducted into understanding how to measure preparedness and how to best allocate preparedness funding resources. More rigorous modeling studies may better explain the role of private water sources, state populations, state urban populations, and number of laboratories have on level of drinking water preparedness. In addition, a non-statistical comparison between drinking water and climate preparedness scores suggest they may be linked. The impact of an increasingly variable climate as well as aging infrastructure on public water supply is a public health concern. This study highlights the need for expanding the knowledge base related to drinking water preparedness, as it lags behind general public health preparedness progress. This study also suggests that adding clear priorities and drinking water metrics in funding mechanisms may improve state capacity-building and preparedness. In order to prevent and respond to drinking water-related public health events, it is vital to incorporate drinking water expertise in developing preparedness plans and to include drinking water metrics in preparedness funding mechanisms.

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APPENDIX

Table 4. Frequency and percentage of index preparedness score by climate score (from States at Risk). Increasing scores indicate increasing level of preparedness.

	Climate Score					
Drinking Water Index Score	**0**	**1**	**2**	**3**	**4**	**TOTAL**
0	1 (20%)	2 (40%)	0 (0%)	2 (40%)	0 (0%)	5 (100%)
1	2 (20%)	1 (10%)	6 (60%)	1 (10%)	0 (0%)	10 (100%)
2	1 (8.33%)	5 (41.67%)	3 (25%)	2 (16.67%)	1 (8.33%)	12 (100%)
3	1 (10%)	1 (10%)	4 (40%)	3 (30%)	1 (10%)	10 (100%)
4	0 (0%)	2 (33.33%)	1 (16.67%)	1 (16.67%)	2 (33.33%)	6 (100%)
5	0 (0%)	2 (28.57%)	0 (0%)	4 (57.14%)	1 (14.29%)	7(100%)

Table 5. Summary of state results from web-based drinking water preparedness evaluation stratified by presence of water funding.

	Water-Directed Funding	**No Water-Directed Funding**
	Frequency (%)	
Location of state drinking water webpage		
- *Public health department*	3 (17.65%)	5 (15.15%)
- *Environmental quality/management department*	8 (47.06%)	15 (45.45%)
- *Both health and environmental departments*	6 (35.29%)	13 (39.39%)
Presence of public drinking water preparedness resources	10 (58.82%)	17 (51.52%)
Presence of mutual aid/utility association information for drinking water utilities	9 (52.94%)	13 (39.39%)
Presence of 24/7 phone hotline for water emergencies	9 (52.94%)	16 (48.48%)
Presence of an accessible, online copy of a drinking water-related state emergency document	10 (58.82%)	11 (33.33%)
'Water' is listed as one of the major topics/services listed on the state public health site	10 (58.82%)	18 (54.55%)

Table 6. State Characteristics stratified by 6-category index score of preparedness.

	0	1	2	3	4	5
	Frequency (%) or Mean (SD)					
TOTAL						
State Population						
Q1: 0-1,826,341	2 (40%)	2 (20%)	5 (41.67%)	2 (10%)	1 (16.67%)	2 (28.57%)
Q2: 1,826,342-4,436,370	1 (20%)	4 (40%)	0	4 (40%)	0	3 (42.86%)
Q3: 4,436,371-6,724,540	1 (20%)	2 (20%)	6 (50%)	2 (16.67%)	1 (16.67%)	1 (14.29%)
Q4: 6,724,541-37,253,956	1 (20%)	2 (20%)	1 (8.33%)	3 (30%)	4 (66.67%)	1 (14.29%)
Percent of State Using Private Water Source						
0-10%	1 (20%)	6 (60%)	4 (33.33%)	4 (40%)	1 (16.67%)	0
11-30%	4 (80%)	4 (40%)	7 (58.33%)	5 (50%)	4 (66.67%)	6 (85.71%)
31-42%	0	0	1 (8.33%)	1 (10%)	1 (16.67%)	1 (14.29%)
Number of Laboratory Response Network Labs	3.8 (2.05)	3.2 (1.81)	2.42 (0.90)	3.6 (3.41)	5.33 (6.80)	2.14 (0.38)
Percent of State in Urban Areas	75.32 (15.71)	69.50 (12.57)	70.56 (15.63)	75.78 (15.28)	81.30 (13.25)	73.60 (16.43)

Table 7. State Characteristics stratified by 3-category index score of preparedness.

	0	1	2
	Frequency (%) or Mean (SD)		
TOTAL			
State Population			
Q1: 0-1,826,341	4 (26.67%)	6 (27.27%)	3 (23.08%)
Q2: 1,826,342-4,436,370	5 (33.33%)	4 (18.18%)	3 (23.08%)
Q3: 4,436,371-6,724,540	3 (20%)	8 (36.36%)	2 (15.38%)
Q4: 6,724,541-37,253,956	3 (20%)	4 (18.18%)	5 (38.46%)
Percent of State Using Private Water Source			
0-10%	7 (46.67%)	8 (36.36%)	1 (7.69%)
11-30%	8 (53.33%)	12 (54.55%)	10 (76.92%)
31-42%	0	2 (9.09%)	2 (15.38%)
Number of Laboratory Response Network Labs	3.4 (1.84)	3.0 (2.40)	3.62 (4.70)
Percent of State in Urban Areas	71.44 (13.42)	72.93 (15.34)	77.15 (14.97)

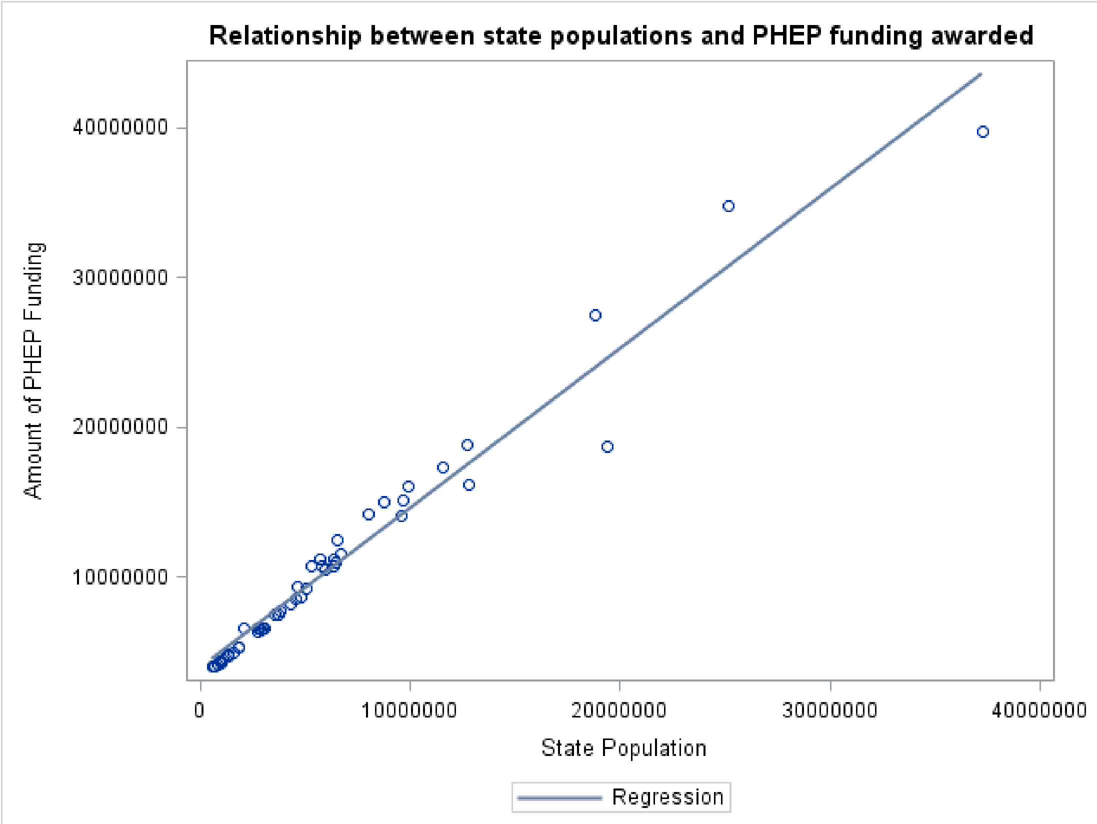

Figure 3. Explanatory graph proving that there is a direct positive correlation between state population and amount of PHEP funding awarded. Because of this relatedness, this study does uses crude PHEP funding for analyses.

Web-Assessment of State Drinking Water Preparedness- Evaluation and Coding

Evaluation Question/ Covariate	Coding	Evaluation Criteria and Comments
1. What is the location of drinking water information on the state website?	Variable Name: listing Not Listed: 0 Health Department: 1 Environmental Department: 2 Both: 3	- If drinking water (beyond the scope of permitting and regulations) is listed on both state public health and environmental sites, count both as locations. - If one site contains information for both environmental and health departments, list as both (3).
2. Does the state offer public drinking water preparedness resources?	Variable Name: preparedness Yes: 1 No: 0	- This must be located on same site as drinking water information. - If information is presented via link, this link must go directly to [a working] water preparedness resource. - This information must be directed at a public audience and include clear directions on treating water in service disruption and/or presence of contaminant. - The link must indicate that it contains information on personal water preparedness; it cannot be on a general resources page.
3. Does the state have mutual aid/ utility association information for drinking water utilities?	Variable Name: mutual_aid Yes: 1 No: 0	- This includes coordinating committees for utilities and links to state WARN sites. - May search via search bar embedded on website. However, may not be located within separate publication (i.e. newsletter).
4. Does the state list a hotline for water emergencies?	Variable Name: water_hotline Yes: 1 No: 0	- This must be located on drinking water page. - Cannot include spill reporting hotline - Link to EPA safe drinking water hotline is acceptable - Must state that line is 24/7

		- Cannot include public safety numbers
5. Does the site have an accessible, online copy of a drinking water-related state emergency document?	Variable Name: manual Yes: 1 No: 0	- Must be on same webpage as drinking water information. It cannot be on a general emergency preparedness webpage. - Can include information for state and local government and/or drinking water utilities during emergency situations - May consist of link to other organization's plan or template for emergency response operations or utility guidelines. - State emergency operations plan or planning guidance document (including template for emergency planning). - If link is to general planning document, must verify it contains emergency-specific information
6. Is water (ex. 'drinking water'/'water systems') listed as one of the major topics and/or services listed on the state public health site?	Variable Name: site_water Yes: 1 No: 0	- This can be found in an A-Z index or program dropdown menu. - If health and environmental topics are housed in single website, count as yes if water is listed on either.
7. Total PHEP funding	Variable Name: phep_funding	- Raw sum of PHEP funding awarded during 2014-2015 - Information Source: 2016 Preparedness Report - Note: LA County, Washington D.C., and New York City are separate PHEP awardees and are excluded from this funding total - 2014-2015 data
8. Total water-directed funding	Variable Name: water_funding	- Includes only water-related funding from CDC (ELC and EHS Net) - 2014-2015 data
9. Binary total water-directed funding	Variable Name: water_funding_yn	- Binary indicator of water-directed funding
10. Population	Pop_st	- Information Source: 2010 Census Data

11. Total percent of population in urban areas	Variable Name: urban	- Information Source: 2010 Census Data
12. Total percent of population using self-supplied water	Variable Name: well_raw	- Information Source: 2010 USGS Data
13. Categorical percent of population using self-supplied water	Variable Name: well_cat 0-10%: 1 11-30%: 2 31-42%: 3	- Information Source: 2010 USGS Data - Use USGS categorization (0-10, 11-30, 31-42)
14. Lab capacity (LRN=Laboratory Response Network) - Number of LRNB Labs - Number of LRNC Labs	Variable Name: lrn_lab	- Information Source: 2016 Preparedness Report - Combined biological and chemical LRN labs
15. Climate vulnerability grade	Variable Name: climate_grade	- Information Source: 2015 States at Risk Report (statesatrisk.org) - States were given A+ through F grades. For summary purposes + and – were not taken into consideration. - States were graded on vulnerability to: extreme heat, drought, wildfires, inland flooding, and coastal flooding - States were given grades by threat as well as an overall grade, which was used in this study