European Journal of Environment and Public Health
2022, 6(x), em00xx
e-ISSN: 2542-4904
https://www.ejeph.com

Research Article

Sea Level Rise and City-Level Climate Action

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Citation: Brennan, M. M., Whitmee, S., Braneon, C. V., Meinsma, N. and Green, R. (2022). Sea Level Rise and City-Level Climate Action. *European Journal of Environment and Public Health*, 6(x), em00xx. https://doi.org/10.21601/ejeph/xxxx

ARTICLE INFO

Received: 15 Mar. 2022

Accepted: 15 Apr. 2022

ABSTRACT

Background: Climate change is the greatest threat to global health in the 21st century. Rising sea levels are one particularly concerning manifestation of this and many of the world's largest cities are vulnerable to sea level rise (SLR). Thus, urban climate adaptation and mitigation policies are increasingly important to protect population health.

Objectives: This study aimed to determine whether being at risk of SLR was associated with city-level climate action. It also aimed to assess the wider drivers of climate action in cities, in order to guide ongoing efforts to motivate climate action, assess public health preparedness and identify research gaps.

Methods: This is an ecological cross-sectional study using secondary data from CDP, the Urban Climate Change Research Network (UCCRN), World Bank, United Nations Cities and EM-DAT (Emergency Events Database). The study population consisted of 517 cities who participated in CDP's 2019 Cities Survey. Multivariable logistic regression was utilized to assess the relationship between risk of SLR and city-level climate action, and secondly, to assess the wider determinants of city-level climate action.

Results: There was evidence of crude associations between risk of SLR and three outcome variables representing city-level climate action. However, after adjusting for confounding variables, these crude associations disappeared. World region, national income status and urban population were shown to be stronger predictors of city-level climate action.

Conclusion: It is concerning for population health that there is no association demonstrated between risk of SLR and climate action. This could indicate a lack of awareness of the risks posed by SLR within urban governance. To fulfil their health protection responsibilities, it is essential that public health professionals take a leading role in advocating for climate action.

Keywords: sea level rise, climate change, cities, climate action, population health

INTRODUCTION

Climate change is the greatest threat to global health in the 21st century. A warming world with rising sea levels and increased frequency of extreme weather events has numerous direct health effects including morbidity and mortality associated with extreme weather events, heat, and air pollution, but also many indirect effects such as increased spread of infectious disease, food and water insecurity, mental health impacts, and increased conflict. Currently, the impacts of climate change are intensifying and are felt on every continent, albeit disproportionately affecting those who have contributed least to the climate crisis (Watts et al., 2020). The landmark Paris Agreement agreed to hold temperatures to "well below 2°C above pre-industrial levels", and if possible to below 1.5°C. Unfortunately, anthropogenic activities are now estimated to have caused 1.07°C of heating and without significant reduction in greenhouse gas (GHG) emissions, it is thought likely that global warming will exceed 1.5°C between 2021 and 2040, and 2°C between 2041-2060 (IPCC, 2021).

Exceeding the limits set by the Paris Agreement threatens to undermine the past 50 years of public health gains and will further exacerbate global health inequalities (Watts et al., 2020). On the contrary, adhering to the goals of the Paris Agreement with well-designed mitigation policies could generate substantial public health gains in the long term by reducing the severity of long-term climate impacts, but also in the short-term through improved air quality, better diets and increased population level physical activity (Hamilton et al., 2021). As the world is already experiencing the effects of climate change, adaptation measures are also necessary to protect population health.

Cities are important settings in relation to climate change and population health for a number of reasons: Firstly, they are highly exposed to the effects of climate change due to their high concentration of industry, infrastructure and growing urban populations (UN-Habitat, 2011). Of note, the world's population is projected to grow to approximately 9.7 billion by 2050 then 10.9 billion by 2100 and more than 66% of the population are projected to reside in urban settings by 2050 (UN DESA, 2018, 2019). Secondly, cities face unique challenges such as the urban heat island effect as well as an increased risk of flooding due to concentrations of built materials and are, consequently, vulnerable to a variety of natural disasters (Masson et al., 2020; UNISDR and CRED, 2015). Lastly, global cities are estimated to be responsible for up to 70% of anthropogenic GHG emissions, although estimates vary widely depending on how emissions are counted. Regardless, there is consensus that urban areas are a significant contributor to climate change (UN-Habitat, 2011). Furthermore, it is estimated that measures taken by urban authorities could result in reductions in carbon dioxide (CO_2) emissions of 50-75% indicating that local governments are key actors in the climate crisis (Hakelberg, 2014). As cities are both vulnerable to, and drivers of climate change, it is well recognised that cities need to take a leading role in climate mitigation and adaptation. The prospects of averting climate breakdown and protecting global health seem limited without comprehensive decarbonisation and effective adaptation of urban areas (Solecki et al., 2018).

One of the most concerning manifestations of climate change is sea level rise (SLR). Flooding is already one of the most frequent natural disasters and carries multiple health and economic consequences (Alderman et al., 2012). Between 1995 and 2015, flooding accounted for 47% of all weather related disasters, affecting 2.3 billion people worldwide (UNISDR and CRED, 2015). As sea levels rise, urban areas along the coasts will be threatened with increased flooding and potentially inundation. All of these effects will be compounded by other climate impacts such as increases in the duration and intensity of storms. The impacts of climate change will be particularly severe in the low-elevation coastal zone (LECZ), where many of the world's largest cities are located (Mcgranahan et al., 2007).

However, all is not lost, a WHO assessment indicated that adaptive measures such as sea-based defences could significantly reduce the morbidity and mortality associated with rising sea levels (WHO, 2014). Furthermore, effective climate mitigation could slow the rate of sea level rise allowing more time for adaptation (IPCC, 2021). In light of the consequences that rising sea levels bear for urban areas in the near future, it is of public health importance that city leaders recognise this risk and act to protect health of their population through climate mitigation and adaptation strategies.

A number of studies have previously assessed whether coastal proximity, as a proxy for future risk from SLR, is a driver of climate action (Miao, 2019; Posey, 2009; Reckien et al., 2015; Yeganeh et al., 2019). Drawing comparisons across these studies is challenging as climate action has been defined in numerous, different ways. Additionally, previous research has focused on one country or continent with a large proportion originating from the United States (US). Furthermore, findings have been conflicting thus the potential relationship between future risk of SLR and city-level climate action remains unclear. Lastly, the majority of published studies (or the data used in these studies) predate the Paris Agreement. Since the Paris Agreement was signed in December 2015 there has been an increasing level of awareness and concern about climate change. This may translate into increased awareness of the risk posed to urban areas by rising sea levels.

This study aims to update and add to the literature investigating the relationship between the risk posed by SLR and city-level climate action. To the best of our knowledge, this is the first study to investigate this relationship utilising a global sample of cities and that assesses cities that have been identified as most vulnerable to SLR by the 2050s, rather than using coastal proximity as a proxy for risk of SLR. This study also seeks to investigate a range of potential determinants of city-level climate action including world region, national income status, past experience of floods with associated mortality, urban population and gender of mayor.

METHODS

Study Design

This is an ecological cross sectional study which uses and combines secondary data from CDP (CDP, 2019), the Urban Climate Change Research Network (UCCRN, 2018), the World Bank (World Bank Open Data, 2019), UN Cities (UNdata, 2020), and EM-DAT (international disaster database) (Guha-Sapir et al., 2018). CDP is a not-for-profit charity that runs the global environmental disclosure system for cities, states, regions, investors and companies. As part of their work, CDP conducts an Annual Cities Survey which enables cities to disclose their environmental impacts and what climate action they are undertaking. In 2019, 814 cities from all world regions participated in CDP's survey. Information on the number of cities who declined to participate was not available.

Cities at risk from SLR were identified by UCCRN in a 2018 study entitled "The Future We Don't Want". In this study, they defined the coastal cities that are most vulnerable to SLR as those which are within 10 km of the coast and have an average elevation of less than 5 meters. Then, they made SLR projections utilizing global climate models incorporating thermal expansion, changes in ocean height, land water storage, and loss of ice. With this approach, they identified 570 coastal cities with over 800 million residents that are at risk of at least 0.5 meters of SLR and coastal flooding by the 2050s, under a high GHG emissions (RCP 8.5) scenario (UCCRN, 2018). Of note, UCCRN restricted their study to cities with populations exceeding 100,000 which meant that it was necessary to exclude cities with populations <100,000 from the CDP sample leaving an analytical sample of 517 cities (**Figure 1**).

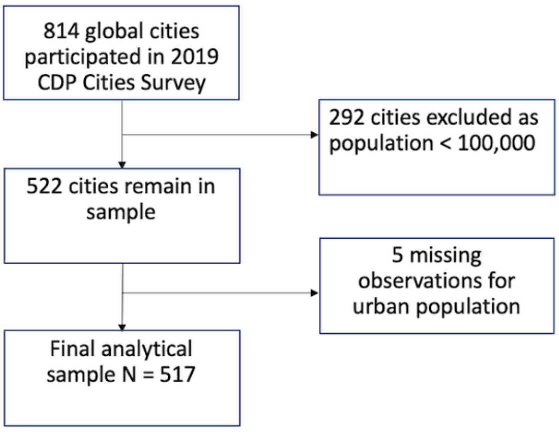

Figure 1. Inclusion in analytical sample

Variables

The primary exposure of interest was risk of at least 0.5m of SLR by the 2050s under a high GHG emissions scenario (UCCRN, 2018). This was a binary variable.

The overall outcome of interest is city-level climate action. In this study, this is represented by three variables obtained from the results of CDP's 2019 survey; completed climate change risk and vulnerability assessment, climate adaptation plan in place and climate mitigation plan in place. Within CDP's questionnaire, city leaders were provided with the options of answering; "Yes", "In progress", "Intending to undertake in the next 2 years", "Not intending to undertake", "Do not know". For the purposes of the analysis, these responses were dichotomized into a binary variable (i.e. yes/no). "Yes" responses were coded as yes; all other responses were coded as no with the rationale that there was no available evidence of the existence of a plan.

Additional variables included in the study were selected based on their plausibility as a confounder or effect modifier of the hypothesized relationship between future risk of SLR and current city-level climate action, and/or to be evaluated as a determinant of city-level climate action. Additionally, variable selection was contingent on the availability of comparable data.

1. World region: SLR is increasing faster in some world regions than other. It is likely that there are varying capacities/motivation to undertake climate action in different world regions. The World Bank classification of world regions was used which has seven categories; East Asia and the Pacific, Europe and Central Asia, Middle East and North Africa, North America, Latin America, and the Caribbean, South Asia and Sub-Saharan Africa (SSA). World region was considered a potential confounder and a likely determinant of city-level climate action.
2. National income level as per the World Bank: Lower-income countries have higher vulnerability to the risk associated with future SLR. Income status affects ability to undertake effective climate action (Heikkinen et al., 2020; Reckien et al., 2015; Woodruff, 2018). National income level was considered an a priori confounder and a likely determinant of city-level climate action.
3. Urban population was obtained from CDP and triangulated with UN cities. Cities with large urban populations may have more people exposed to the risks associated with sea level rise but also may have more resources available to undertake climate action (Pablo-Romero et al., 2015; Reckien et al., 2015; Salvia et al., 2021; Woodruff, 2018). Conversely, smaller urban areas can be institutionally weak, meaning that they may be unable to deliver effective mitigation and adaptation actions (UN-Habitat, 2011). Urban population was considered an a priori confounder and a likely determinant of city-level climate action. Urban population was analyzed as a categorical variable using the OECD classification for urban populations (small urban <200,000, medium-size urban=200,000-500,000, metropolitan=500,000-1.5 million and large metropolitan >1.5 million) and also as a continuous variable.
4. Gender of mayor or equivalent local authority figure: During the COVID-19 pandemic, there have been a number of ecological studies that have found an association between female political leadership and better outcomes (Coscieme et al., 2020; Purkayastha et al., 2020). Although these studies are ecological and suffer from a lack of power due to small numbers of political leaders and the causal links (if any) remain unclear, there are a number of theories for why this might be. These include that female leaders may act earlier to protect population health rather than prioritizing the economy, or that the political climate that facilitated female leadership may be more liberal and again, prioritize protecting population health (Coscieme et al., 2020). There are many parallels between the climate crisis and COVID-19 (Rosenbloom and Markard, 2020); thus, gender of mayor is hypothesized to be an effect modifier and a possible determinant of city-level climate action.
5. Experience of floods with associated mortality within the 10 years preceding the 2019 CDP survey: data for this was obtained from EM-DAT. Originally, it was hoped that it would be possible to localize this exposure to city-level but it was only possible to localize to regional level based on the available data. It was hypothesized that experience of an extreme weather event i.e. recent floods, with fatal consequences for human life, could act as a determinant of climate action by sensitizing local government to climate risk (Miao, 2019). This was treated as a binary variable.

Based on the literature and a priori assumptions, a conceptual diagram was created to illustrate pathways that may exist between the variables (**Figure 2**).

Statistical Analysis

All statistical analyses were completed using Stata v. 16.

Firstly, the distribution of each variable was explored. The distribution of urban population was profoundly right skewed; thus it was log transformed. Cross tabulations of each variable were performed with both the exposure and each outcome to check for sparsity in the data. World region was re-categorized as there were too few outcomes in some of the categories.

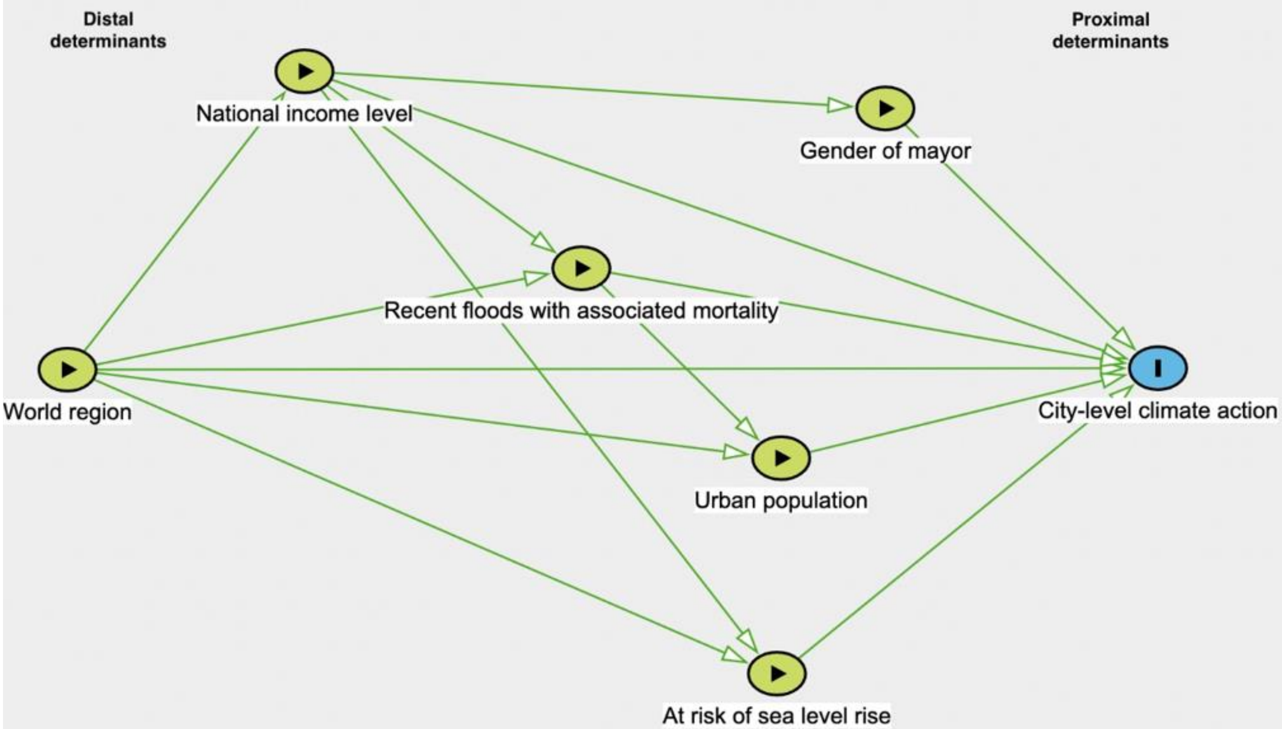

Figure 2. Conceptual diagram to illustrate potential relationships between variables

Middle East and North Africa was merged with Sub-Saharan Africa (SSA), and South Asia was merged with East Asia and Pacific as these were the closest geographically, leaving five categories. Chi squared tests were performed to assess crude associations between variables. The data was assessed for missingness; Dummy variables were created for the variables with the highest proportion of missing data; coded 0 for "not missing" and 1 for "missing". Regression models were run with the dummy variables to determine if the observations with missing values were different from those with non-missing values in relation to important variables. The relationships between urban population and the outcome variables were assessed for linearity.

Mantel-Haenszel analyses of the crude association between risk of SLR and city-level climate action were then performed, stratified by each explanatory variable to assess for potential confounding and effect modification.

Univariate logistic regressions were performed to assess crude associations between variables. Likelihood ratio tests (LRT) were performed to test the null hypothesis of no association for each of these. Variables were considered as potential confounders for inclusion in the multivariable logistic regression models if they were independently associated with the primary exposure and outcome i.e. OR>1.5 or p-value<0.05, and judged not to be on the causal pathway (McNamee, 2003).

The final logistic regression models for the association between risk of SLR and the three outcome measures representing city-level climate action were built using a forward modelling approach. A priori confounders (national income status and urban population) were added first and then other potential confounders were added one at a time to assess their effect on the effect estimate. A priori confounders along with the variables with the strongest effect on the effect estimate (at least >10%) were included in the multivariable models.

1. Model 1: Assessing the relationship between risk of SLR and completion of climate risk and vulnerability assessment included national income status, urban population and world region as confounders.
2. Model 2: Assessing the association between risk of SLR and having a climate adaptation plan in place included national income status, urban population and world region as confounders.
3. Model 3: Assessing the association between risk of SLR and having a climate mitigation plan in place included national income status, urban population and world region as confounders.

Lastly, the risk factor analysis models which aimed to identify wider determinants for the outcome of city-level climate action. The conceptual diagram (**Figure 2**) was utilized to decide the order in which to add the variables to the model. The variables that were considered for inclusion were world region, past floods, risk of SLR and gender of mayor with national income status and urban population included in each model as a priori confounders. Firstly, the a priori confounders were added to the model. Then variables were added as per the conceptual framework i.e. adding the most distal variables first and evaluating variables at more proximate levels adjusted for those at more distal levels. Variables with a strong (e.g. OR >1.5) or statistically significant effect (e.g. p <0.05) on the model were retained in the multivariable model.

Ethical Statement

This study received ethical approval from the MSc Research Ethics Committee at the London School of Hygiene and Tropical Medicine (LSHTM).

Table 1. Unadjusted associations with completed climate risk and vulnerability assessment (N=503)

		N (%)	CCR&VA (%*)	OR** (95% CI)	p-value***
At risk of SLR	No	388 (77.14%)	240 (61.86%)	1	0.0156
	Yes	115 (22.86%)	85 (73.91%)	1.75 (1.10, 2.78)	
Past floods ****	No	111 (22.33%)	80 (72.07%)	1	0.0647
	Yes	386 (77.67%)	242 (62.69%)	0.65 (0.41, 1.04)	
World region	Latin America & the Caribbean	157 (31.21%)	78 (49.68%)	1	<0.001
	Middle-East, North & SSA	46 (9.15%)	28 (60.87%)	1.58(0.81, 3.08)	
	North America	113 (22.47%)	80 (70.80%)	2.46 (1.47, 4.10)	
	South & East Asia & Pacific	86 (17.10%)	66 (76.74%)	3.34 (1.85, 6.03)	
	Europe & Central Asia	101(20.08%)	73 (72.28%)	2.64 (1.54, 4.51)	
National income level	High	256 (50.89%)	191 (74.61%)	1	<0.001
	Upper-middle	168 (33.40%)	83 (48.81%)	0.33 (0.22, 0.49)	
	Lower-middle	64 (12.72%)	43 (67.19%)	0.70 (0.39, 1.26)	
	Low	15 (2.98%)	9 (60%)	0.51 (0.18, 1.49)	
Urban population	Small urban	109 (21.67%)	68 (62.39%)	1	0.3369
	Medium urban	148 (29.42%)	94 (63.51%)	1.05 (0.63, 1.75)	
	Metropolitan	136 (27.04%)	84 (61.76%)	0.97 (0.58, 1.64)	
	Large metropolitan	110 (21.87%)	79 (71.82%)	1.54 (0.87, 2.71)	
Gender of mayor ****	Male	396 (80.16%)	240 (60.61%)	1	0.0001
	Female	98 (19.84%)	79 (80.61%)	2.70 (1.58, 4.64)	

Note. *Row percentage; **Unadjusted odds ratio for having completed a climate risk and vulnerability assessment; ***p-value from LRT; ****Missing observations; 6 for floods, 9 for gender of mayor; CCR&VA: Completed climate risk & vulnerability assessment

Table 2. Unadjusted associations with having a climate adaptation plan (N=477)

		N (%)	CAPinP (%*)	OR** (95% CI)	p-value***
At risk of SLR	No	364 (76.31%)	174 (47.80%)	1	0.0324
	Yes	113 (23.69%)	67 (59.29%)	1.59 (1.04, 2.44)	
Past floods ****	No	105 (22.29%)	65 (61.90%)	1	0.0092
	Yes	366 (77.71%)	174 (47.54%)	0.56 (0.36, 0.87)	
World region	Latin America & the Caribbean	142 (29.77%)	51 (35.92%)	1	<0.001
	Middle-East, North & SSA	43 (9.01%)	24 (55.81%)	2.25 (1.13, 4.51)	
	North America	111 (23.27%)	56 (50.45%)	1.82 (1.10, 3.01)	
	South & East Asia & Pacific	82 (17.19%)	57 (69.51%)	4.07 (2.27, 7.28)	
	Europe & Central Asia	99 (20.75%)	53 (53.54%)	2.06 (1.22, 3.47)	
National income level	High	251 (52.62%)	140 (55.78%)	1	0.0327
	Upper-middle	152 (31.87%)	62 (40.79%)	0.55 (0.36, 0.82)	
	Lower-middle	60 (12.58%)	32 (53.33%)	0.91 (0.52, 1.59)	
	Low	14 (2.94%)	7 (50.00%)	0.79 (0.27, 2.33)	
Urban population	Small urban	103 (21.59%)	48 (46.60%)	1	0.0377
	Medium urban	139 (29.14%)	65 (46.76%)	1.01 (0.60, 1.68)	
	Metropolitan	132 (27.67%)	63 (47.73%)	1.05 (0.62, 1.75)	
	Large metropolitan	103 (21.59%)	65 (63.11%)	1.96 (1.12, 3.42)	
Gender of mayor ****	Male	373 (79.70%)	177 (47.45%)	1	0.0176
	Female	95 (20.30%)	58 (61.05%)	1.74 (1.10, 2.75)	

Note. *Row percentage; **Unadjusted odds ratio for having a climate adaptation plan in place; ***p-value from LRT; ****Missing observations; 6 for floods, 9 for gender of mayor; CAPinP: Climate adaptation plan in place

RESULTS

Analytical Sample Characteristics

The analytical sample consisted of 517 cities, each with a population exceeding 100,000 participants. 22% of cities were deemed to be at risk of at least 0.5 meters of SLR by 2050. 65% of these cities have completed a climate risk and vulnerability assessment, 51% have a climate adaptation plan in place, and 59% have a climate mitigation plan in place. The cities originated from all world regions, with the largest proportion coming from Latin America and the Caribbean (32%). They originated from a variety of national income settings, although the largest proportion were based in high-income countries (50%). Cities varied substantially in the size of their urban population, with between 20 to 30% of the sample in each category of the OECD classification for urban areas. A substantial majority of city mayors are male (81%).

Unadjusted Analysis

In the unadjusted analysis, cities at risk of SLR had a 75% increase in the odds of having completed a climate risk and vulnerability assessment relative to cities that were not at risk of SLR. There was also evidence of crude association with past floods, world region, national income level and mayor gender (**Table 1**).

Cities at risk of SLR had a 59% increase in odds of having a climate adaptation plan in place relative to cities who were not at risk of SLR in unadjusted analysis. There was also evidence of a crude association with past floods, world region, national income level, urban population, and mayor’s gender (**Table 2**).

Table 3. Unadjusted associations with having a climate mitigation plan (N=454)

		N (%)	CMinP (%*)	OR** (95% CI)	p-value***
At risk of SLR	No	345 (75.99%)	194 (56.23%)	1	0.0674
	Yes	109 (24.01%)	72 (66.06%)	1.52 (0.97, 2.37)	
Past floods ****	No	101 (22.44%)	70 (26.42%)	1	0.0144
	Yes	349 (77.56%)	195 (73.58%)	0.56 (0.35-0.90)	
World region	Latin America & the Caribbean	137 (30.18%)	45 (32.85%)	1	<0.001
	Middle-East, North & SSA	39 (8.59%)	17 (43.59%)	1.58(0.76, 3.27)	
	North America	110 (24.23%)	77 (70.00%)	4.77 (2.76, 8.20)	
	South & East Asia & Pacific	76 (16.74%)	57 (75.00%)	6.13 (3.27,11.51)	
	Europe & Central Asia	92 (20.29%)	70 (76.09%)	6.51 (3.58, 11.82)	
National income level	High	243 (53.52%)	174 (71.60%)	1	<0.001
	Upper-middle	144 (31.72%)	57 (38.89%)	0.25 (0.16, 0.39)	
	Lower-middle	56 (12.33%)	31 (55.36%)	0.49 (0.27, 0.89)	
	Low	11 (2.42%)	5 (45.45%)	0.33 (0.10, 1.12)	
Urban population	Small urban	96 (21.15%)	49 (51.04%)	1	0.1598
	Medium urban	135 (29.74%)	78 (57.78%)	1.31 (0.78, 2.22)	
	Metropolitan	126 (27.75%)	74 (58.73%)	1.37 (0.80, 2.33)	
	Large metropolitan	97 (21.37%)	65 (67.01%)	1.95 (1.09, 3.49)	
Gender of mayor ****	Male	353 (79.33%)	194 (54.96%)	1	0.0008
	Female	92 (20.67%)	68 (73.91%)	2.32 (1.39, 3.90)	

Note. *Row percentage; **Unadjusted odds ratio for having a climate mitigation plan in place; ***p-value from LRT; ****Missing observations; 4 for floods, 10 for gender of mayor; CMinP: Climate mitigation plan in place

Table 4. Crude and adjusted estimates of the associations between risk of SLR and city-level climate action

	Crude OR (95% CI)	Adjusted OR** (95% CI)
Climate risk and vulnerability assessment	p=0.018*	p=0.590*
No	1	1
Yes	1.75 (1.10, 2.78)	1.15 (0.70, 1.90)***
Climate adaptation plan	p=0.034*	p= 0.844*
No	1	1
Yes	1.59 (1.04, 2.44)	1.05 (0.66, 1.67)****
Climate mitigation plan	p=0.071*	p=0.412*
No	1	1
Yes	1.52 (0.97, 2.38)	0.81 (0.48, 1.35)*****

Note. *Wald p-value; **All models were adjusted for national income level, urban population and world region; ***N=503 in the final multivariable logistic regression model; ****N=477 in the final multivariable logistic regression model; *****N=454 in the final multivariable logistic regression model

Lastly, cities at risk of SLR had a 52% increase in the odds of having a climate mitigation plan in place relative to cities that are not at risk, in the unadjusted analysis. However, the supporting statistical evidence for this association was weak. There was also evidence of a crude association with past floods, world region, national income status, urban population, and mayor gender (**Table 3**).

Multivariable Analysis

After adjusting for confounding variables, the significant associations seen in the unadjusted analyses disappeared. Therefore, in the adjusted multivariable models, there was no evidence of an association between future risk of SLR and having completed a climate risk assessment or, having a climate adaptation plan or a climate mitigation plan (**Table 4**). Of note, urban population was included as a continuous rather than categorical variable within the multivariable models as there was evidence to support a linear association between urban population and the outcome variables. There were no issues with multi-collinearity noted. The models were compliant with the rule of 10 outcomes for each estimated parameter (OR) thus there were no issues with data sparsity.

Risk Factor Analysis

In the multivariable model assessing the determinants for completion of a climate risk and vulnerability assessment, there was very strong evidence of an association with national income level; cities located in low-income countries had an 81% increase in the odds of having completed a climate risk and vulnerability assessment relative to cities located in high-income countries. Cities with female mayors were more than twice as likely to have completed an assessment compared to those with male mayors, and cities in Asia, North America, and Europe were all more likely to have completed an assessment than the reference category of cities in Latin America and the Caribbean. Cities with greater urban populations were also more likely to have completed a climate risk and vulnerability assessment (**Table 5**). Risk of SLR and past floods did not have a strong or statistically significant effect on the model, thus they were not retained in the final model.

Table 5. Determinants for completion of climate risk and vulnerability assessment (N= 494)

		Crude OR (95% CI)	Adjusted OR* (95% CI)
World region		p<0.001**	p=0.0306**
	Latin America & the Caribbean	1	1
	Middle East, North & SSA	1.58(0.81, 3.08)	1.89 (0.75, 4.75)
	North America	2.46 (1.47, 4.10)	0.91 (0.43, 1.91)
	South & East Asia & Pacific	3.34 (1.85, 6.03)	3.54 (1.49, 8.41)
	Europe & Central Asia	2.64 (1.54, 4.51)	1.21 (0.61, 2.41)
National income level		p<0.001**	p<0.001**
	High	1	1
	Upper-middle	0.33 (0.22, 0.49)	0.30 (0.16, 0.57)
	Lower-middle	0.70 (0.39, 1.26)	0.22 (0.08, 0.58)
	Low	0.51 (0.18, 1.49)	0.19 (0.04, 0.85)
Urban population***		p=0.0571	p=0.0097
		1.16	1.27 (1.06, 1.53)
Gender of mayor		p=0.0001**	p=0.0068**
	Male	1	1
	Female	2.70 (1.58, 4.64)	2.11 (1.20, 3.71)

Note. *Adjusted for all the other variables in the table; **LRT p-value; ***Continuous variable

Table 6. Determinants for having a climate adaptation plan in place (N=471)

		Crude OR (95% CI)	Adjusted OR* (95% CI)
World region		p<0.001**	p=0.0002**
	Latin America & the Caribbean	1	1
	Middle East, North & SSA	2.25 (1.13, 4.51)	3.70 (1.43, 9.57)
	North America	1.82 (1.10, 3.01)	1.16 (0.57, 2.33)
	South & East Asia & Pacific	4.07 (2.27, 7.28)	5.59 (2.43, 12.83)
	Europe & Central Asia	2.06 (1.22, 3.47)	1.14 (0.58, 2.24)
National income level		p=0.0327**	p=0.0045**
	High	1	1
	Upper-middle	0.55 (0.36, 0.82)	0.49 (0.26, 0.91)
	Lower-middle	0.91 (0.52, 1.59)	0.22 (0.09, 0.54)
	Low	0.79 (0.27, 2.33)	0.24 (0.06, 1.01)
Urban population***		p=0.0274**	p=0.0808**
		1.18 (1.02, 1.37)	1.17 (0.98, 1.38)
Past floods		p=0.0092**	p=0.0397**
	No	1	1
	Yes	0.56 (0.36, 0.87)	0.60 (0.36, 0.98)

Note. *Adjusted for all the other variables in the table; **LRT p-value; ***Continuous variable

In the multivariable model assessing the determinants for having a climate adaptation plan, there was strong evidence of an association with world region: cities located in South & East Asia & the Pacific had more than four times the odds of having a climate adaptation plan in place relative to cities in Latin America & the Caribbean. Cities in lower income countries also appeared less likely to have an adaptation plan in place, particularly cities in low-income and lower-middle income countries. Again, there was some evidence that a larger urban population was associated with more climate preparedness, although this relationship did not quite reach statistical significance. Interestingly, cities with past experience of floods were 40% less likely to have an adaptation plan in place than cities with no past experience of floods (**Table 6**). Risk of SLR and gender of mayor did not have a strong or statistically significant effect on the model, thus these variables were not retained in the final model.

In the multivariable model assessing the determinants of having a climate mitigation plan in place, there was strong evidence of an association with world region; cities in Europe & Central Asia had more than three times the odds of having a climate mitigation plan in place relative to cities in Latin America & the Caribbean. Having a greater urban population was associated with increased odds of having a mitigation plan in place, but cities in lower income countries were less likely to have a mitigation plan, although the relationship did not reach significance for cities in low income countries–likely due to the small sample size (**Table 7**). Risk of SLR, past floods and gender of mayor did not have a strong or statistically significant effect on the model, thus these variables were not retained in the final model.

Missing Data

The variables with the largest proportion of missing data are climate mitigation plan (12.19%) and climate adaptation plan (7.74%). The remainder of variables had very little missing data and were judged to be an unlikely source of major bias (**Table 8**).

Observations with missing data for climate adaptation plan have 74% reduction in the odds (OR 0.26, 95% CI 0.08, 0.86) of risk of SLR relative to observations with non-missing data. Observations with missing data for climate mitigation plan have 60% reduction in the odds (OR 0.40, 95% CI 0.18, 0.89) of being at risk of SLR relative to observations with non-missing data.

Table 7. Determinants for having a climate mitigation plan in place (N=454)

		Crude OR (95% CI)	Adjusted OR* (95% CI)
World region		p<0.001**	p<0.001**
	Latin America & the Caribbean	1	1
	Middle East, North & SSA	1.58 (0.76, 3.27)	2.03 (0.79, 5.20)
	North America	4.77 (2.76, 8.20)	2.69 (1.28, 5.64)
	South & East Asia & Pacific	6.13 (3.27,11.51)	8.01 (3.22, 19.92)
	Europe & Central Asia	6.51 (3.58, 11.82)	4.02 (1.95, 8.25)
National income level		p<0.001**	p=0.0108**
	High	1	1
	Upper-middle	0.25 (0.16, 0.39)	0.45 (0.23, 0.88)
	Lower-middle	0.49 (0.27, 0.89)	0.23 (0.09, 0.60)
	Low	0.33 (0.10, 1.12)	0.36 (0.08, 1.72)
Urban population		p=0.0682**	p=0.0361**
		1.16 (0.99, 1.35)	1.22 (1.01, 1.47)

Note. *Adjusted for all the other variables in the table; **LRT p-value

Table 8. Missing data (N=517)

	N	%
Sea level rise	0	NA
Past floods with associated mortality	6	1.16%
World region	0	NA
National income level	0	NA
Urban population	0	NA
Gender of mayor	11	2.13%
Climate risk & vulnerability assessment	14	2.71%
Climate adaptation plan	40	7.74 %
Climate mitigation plan	63	12.19%

DISCUSSION

The objectives of this study were to assess whether there was a relationship between risk of SLR by the 2050s and city-level climate action, and to investigate the wider determinants of city-level climate action, in a global sample of 517 cities.

In the unadjusted analyses, there was evidence of significant relationships between future risk of SLR and city-level climate action (**Table 1**, **Table 2**, and **Table 3**). However, these relationships disappeared in the adjusted multivariable analyses, indicating that the crude associations were due to confounding rather than risk of SLR (**Table 4**). Therefore, this study indicates that cities that are likely to be at risk from at least 0.5 meters SLR and coastal flooding by the 2050s, under a high GHG emissions scenario, are not more likely to be undertaking climate action relative to cities that are not at risk from SLR. This could indicate that there is a lack of awareness of the risks posed by SLR within urban governance.

Secondly, this study demonstrated that there is evidence that world region, national income status and urban population each independently impact the outcome variables representing city-level climate action. There was also evidence that gender of mayor was associated with increased odds of completion of a climate risk and vulnerability assessment and past experience of floods was associated with reduced odds of having a climate adaptation plan in place (**Table 5**, **Table 6**, and **Table 7**).

Drawing comparisons between the findings from this study and existing literature is somewhat challenging due to the heterogeneity of prior studies investigating the drivers of city-level climate action. For instance, studies use a variety of outcome measures to represent climate action including developing climate change plans or participating in climate networks. Furthermore, results in the literature have been contradictory.

Therefore, the finding that there is no association between future risk from SLR and current city-level climate action is consistent with some studies (Pitt, 2010; Reckien et al., 2015) and inconsistent with others (Miao, 2019; Posey, 2009; Yeganeh et al., 2019). Posey (2009) showed that anticipated impacts of climate change can induce membership in climate networks for cities at high risk from climate change in the USA which included those in close proximity to the coast. Miao's (2019) study also indicated that US states are more likely to plan for climate change adaptation if they have more economic activities in coastal regions. Additionally, a 2020 meta-analysis concluded that overall there was a relationship between coastal proximity and climate policy adoption within US municipalities (Yeganeh et al., 2019). Notably these studies all focused on the US, a high income setting. The incompatibility of these results with this study's findings may indicate that associations differ in different income settings, or it could reflect the heterogeneity of the literature. Conversely, Pitt (2010) found that coastal proximity was not associated with adoption of climate mitigation policies and an investigation of European cities found that coastal proximity was actually a significant barrier to climate change planning whereas location in the LECZ was not significantly associated (Reckien et al., 2015). Of note, Reckien et al. (2015) was the only study that assessed whether location in the LECZ was associated with climate change planning. Characterising future risk of SLR utilising location in the LECZ, rather than just coastal proximity, is most similar to the exposure used in this study which may explain why these results were compatible with each other and differ from other studies.

In this study, national income status was consistently a strong predictor of city-level climate action. Cities originating from high-income countries had higher odds of climate action relative to cities from other income settings (**Table 5**, **Table 6**, and **Table 7**). This is consistent with the literature suggesting that wealthier cities are more likely to undertake climate action (Heikkinen et al., 2020; Miao, 2019; Reckien et al., 2015; Yeganeh et al., 2019), which indicates that allocation of climate finance to lower income cities is necessary to enable climate action.

Previous research indicates that larger cities are more likely to enact climate planning or action (Reckien et al., 2015; Salvia et al., 2021). The results from this study are consistent with this, with strong evidence that increasing population size is associated with increased odds of completion of a climate risk and vulnerability assessment and of having a climate mitigation plan in place and suggestive evidence of an association with increased odds of having a climate adaptation plan in place (**Table 5**, **Table 6**, and **Table 7**).

This study indicates that world region is strongly associated with the odds of city-level climate action. For instance, cities based in the South/East Asia and the Pacific have a 701% increase in the odds of having a climate mitigation plan in place relative to cities in Latin America and the Caribbean (**Table 7**). This shows that some regions have a much greater level of preparedness for climate change. Interestingly, cities in industrialized regions like Europe, North America, and Central Asia seem to have a stronger relationship with mitigation actions than adaptation actions which may reflect their lower vulnerability to climate change. To the best of our knowledge, this is the first study which has investigated the relationship between city-level climate action and world region.

Cities with female mayors had 111% greater odds of having completed a climate risk and vulnerability assessment relative to cities with male mayors (**Table 5**). However, gender of mayor was not shown to be associated with the odds of having a climate adaptation or mitigation plan in place (**Table 6** and **Table 7**). This disconnect may indicate that a climate risk and vulnerability assessment is the first step taken by cities as regards climate action and subsequent to completion of said risk assessment, climate adaptation and mitigation plans are formulated. However, it must be noted that the variable used in this study was a binary variable focused on the current mayor's actions but there may actually be a threshold effect in city-level climate action i.e. one mayoral administration commences the process and subsequent administrations follow with periodic updates. Assessing this threshold effect was beyond the scope of our analysis. This relationship warrants further research. Again to the best of our knowledge, this is the first study assessing if there is an association between gender of meyer and city-level climate action.

Previous research indicates that recent experience of extreme weather events is associated with increased odds of adaptation planning (Miao, 2019). However, this study indicates that cities based in regions that had experienced floods with associated fatalities had 40% reduction in the odds of having a climate adaptation plan in place relative to cities that had not (**Table 6**). A potential explanation for this could be that many cities that are located in regions that are vulnerable to natural disasters may not have the adaptive capacity to enact climate action.

Strengths and Limitations

A major strength of this study was that the sample consisted of 517 global cities with a combined population of approximately 760 million. As there are 2586 cities with a population exceeding 100,000 in the world (UCCRN, 2018) this sample represented 20% of all cities of this size making this an interesting and worthwhile sample for analysis. However, this was not a randomly selected, representative sample as it consisted of cities who voluntarily participated in CDP's 2019 survey. CDP does not collect data on response rates or baseline data on cities who do not participate in the survey. Thus, it is likely that there is selection bias within this sample, as cities who participate in a transnational municipal climate network survey may be more climate aware or climate active than those who do not. This limits the generalizability of findings. There are a number of limitations associated with the outcome measures. These are self-reported by city government representatives and the data does not undergo independent validation. Cities are publicly ranked by CDP on their environmental performance which may mean the responses are subject to social desirability bias. Furthermore, two of the chosen outcome measures are based on the existence of climate planning documents. Therefore, this study does not assess the scope and ambition of said climate plans or indeed if the plans have been implemented. Lastly, there was quite strong evidence that cities with missing observations differed from non-missing observations with regard to risk of SLR which may have introduced bias.

Recommendations

Firstly, it is necessary for public health practitioners to redouble efforts advocating for urban climate adaptation and mitigation measures that can protect and promote population health. Ideally public health would work with city governments to develop and implement these measures. Secondly, as national income status was consistently a strong predictor of city-level climate action in the models in this study, it is essential for dedicated climate resources to be allocated to cities in lower income settings to enable them to undertake these measures. Lastly, further research on city-level climate action is warranted. There are a number of potential research topics which would follow on from this study. For instance, it would be useful to assess the comprehensiveness of city-level climate preparations and quantify the associated co-benefits and trade-offs for public health. This research could be used to inform and motivate effective climate mitigation and adaptation plans in urban settings. Future studies with a larger sample size could also investigate whether there is an interaction between income levels and climate action i.e. whether cities at greater risk of SLR are more likely to take action if they have higher incomes. Lastly, rising sea levels is only one of the major urban vulnerabilities to climate change. Others include, extreme heat, water and food insecurity and increased frequency of extreme weather events. Assessing whether there is an association between degree of urban vulnerability to climate change impacts and city-level climate action would be informative for public health preparedness.

CONCLUSION

This study found that there was no association between future risk of SLR and current city-level climate action. This could indicate that there is a lack of awareness of the risks posed by SLR, and indeed climate change, within urban governance. Although it is virtually certain that sea levels will continue to rise over the 21st century, the rate at which this occurs and the associated complications can still be influenced by the actions taken now (WHO, 2014; IPCC, 2021). In these vital years for climate action, renewed public health efforts to raise awareness about the health implications of climate change and work with city planners on climate adaptation and mitigation plans will be paramount in order to protect and improve population health.

Author contributions: MMB: conceptualized the study, created the dataset, analyzed the data and drafted the manuscript; **RG:** conceptualized the study, provided input and supervision throughout the study, reviewed draft manucript, provided feedback and were satisfied with final submission; **SW:** conceptualized the study, provided input and supervision throughout the study, reviewed draft manucript, provided feedback and were satisfied with final submission. **NM:** facilitated access to and assisted with queries re CDP's data, reviewed draft manucript, provided feedback and were satisfied with final submission. **CVB**: facilitated access to UCCRN's data, reviewed draft manucript, provided feedback and were satisfied with final submission.

Funding: SW and **RG** are supported by the Pathfinder Initiative, funded by Wellcome (Grant 221284/Z/20/Z) with support from the Oak Foundation (Grant OFIL-20-093).

Acknowledgements: The authors would like to thank UCCRN who kindly provided access to the results of their 2018 analysis "The Future We Don't Want".

Declaration of interest: The authors declare that they have no competing interests.

Ethics approval and consent to participate: This study received ethical approval from the MSc Research Ethics Committee at the London School of Hygiene and Tropical Medicine (LSHTM) (LSHTM MSc Ethics Reference number: 24047 dated 4 May 2021).

Availability of data and materials: Requests should be directed to the corresponding author.

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