Report

ENVIRONMENTAL RISKS OF CITIES IN THE EUROPEAN REGION: ANALYSES OF THE SUSTAINABLE HEALTHY URBAN ENVIRONMENTS (SHUE) DATABASE

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ABSTRACT

Introduction: In an increasingly urbanized world, cities are a key focus for action on health and sustainability. The Sustainable Healthy Urban Environments (SHUE) project aims to provide a shared information resource to support such action. Its aim is to test the feasibility and methods of assembling data about the characteristics of a globally distributed sample of cities and the populations within them for comparative analyses, and to use such data to assess how policies may contribute to sustainable urban development and human health.

Methods: As a first illustration of the database, we present analyses of selected parameters on climate change, air pollution and flood risk for 64 cities in the WHO European Region.

Results: Under a high greenhouse gas emissions trajectory (RCP8.5), the analyses suggest damaging temperature rises in European cities that are among the highest of any cities in the global database, while air pollution ($PM_{2.5}$) levels are appreciably above the WHO guideline level for all but a handful of cities. In several areas, these environmental hazards are compounded by flood risk.

Discussion: Such evidence, though preliminary and based on limited data, underpins the need for urgent action on climate change (adaptation and mitigation) and risks relating to air pollution and other environmental hazards.

Keywords: URBAN, CLIMATE CHANGE, AIR POLLUTION, FLOODING, EUROPE

INTRODUCTION

More than half the world's 7.5 billion people live in cities a number projected to grow by a further 2.5 billion people by 2050 and cities account for around 85% of global economic activity *(1)*. In Europe, approximately 73% of people live in urban areas *(1)*. It is increasingly recognised that the design, operation and governance of cities are crucial for achieving goals on sustainability and population heath particularly in areas such as responses to climate change and policies relating to energy, housing, transportation and food *(2-4)*. Urban living brings many environmental challenges, such as pollution, road injury, noise and social isolation *(2, 5)*, as well as opportunities for health, especially in the context of the low carbon transition *(6-8)*. Well-planned urban development is crucial for meeting many of the Sustainable Development Goals (SDGs) *(9)*, the objectives of the Paris Agreement on climate change *(10)*, and the New Urban Agenda *(11)*.

The Sustainable Healthy Urban Environments (SHUE) project is an initiative to support policy development in areas relating to these environmental and health challenges and opportunities. Its aim is to test the feasibility and methods of assembling data about the characteristics of a globally distributed sample of cities, and the populations within them, for comparative analyses, and to use such data to assess how policies may contribute to sustainable urban development and human health. Its specific objectives are to: understand the reasons for city-to-city differences in measures of sustainable development and health-related exposures and behaviours; assess the potential to improve population health through strategies for achieving greater environmental sustainability and resilience to evolving environmental threats; and identify possible policies and interventions whose impacts on health and sustainability may be subject to future evaluation studies.

The project is assembling data on a globally representative sample of cities. It is expected that the data contained within the database will help to improve the understanding of variations in urban characteristics, and to identify needs and opportunities for improved urban development with regard to health and sustainability. Once developed, the intention is for the database to become an open access resource for the research and policy communities.

In this paper, to introduce the database and demonstrate its potential, we present preliminary analyses of environmental and health parameters for the WHO European Region relating to climate change, air pollution and flood risk.

METHODS

The SHUE database comprises a random sample of 246 global cities with populations over 15 000 obtained from GeoNames *(12)* and stratified by: national wealth in terms of Gross National Income (GNI) per capita (<US$ 1045, US$ 1045-4125, US$ 4125-12 746, >US$ 12 746) *(13)*; population size (<100K, 100K-500K, 500K-1M, 1M-5M, >5M); and Bailey's Ecoregion "Domain" (Dry, Humid temperate, Humid tropical, Polar) *(14)*. An additional 63 deliberately selected cities were added to this sample making the total 309 based largely on their reputation for policies which aim to make them "sustainable cities". The geographical distribution of the cities is shown in Fig. 1. The 64 cities of the WHO European Regionfrom the database, including 55 which were selected randomly, are listed in Table 1.

FIG. 1. GEOGRAPHICAL DISTRIBUTION OF SHUE CITIES BY WHO REGION

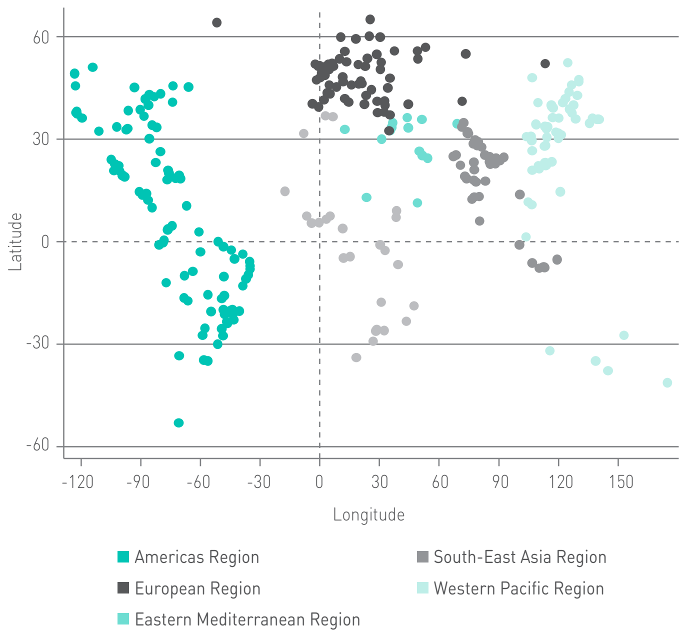


TABLE 1. CITIES (>15 000 INHABITANTS) IN THE SHUE DATABASE FOR THE WHO EUROPEAN REGION*

Country	Cities
Armenia	Yerevan
Belarus	Gomel, Hrodna, Lyepyel
Belgium	Namur, Oostend
Bulgaria	*Sofia*
Croatia	Zagreb
Denmark	*Copenhagen*
Finland	*Helsinki, Oulu*
France	Brunoy, Le Grand-Quevilly, Le Mans, Lyon, Marseille, Montpellier, Nantes, *Paris*
Germany	Berlin, Düsseldorf, Hamburg, *Munich*
Greece	Kateríni
Greenland	Nuuk
Hungary	Mezotúr
Israel	Hadera
Italy	Bressanone, Cava Dè Tirreni, Napoli, *Rome*, Vercelli
Netherlands	Rotterdam, Voorst
Norway	Oslo
Poland	Leczna, Lódz
Romania	Arad, Bucharest
Russian Federation	Chita, Izhevsk, Kazan, Moscow, Omsk, Saint Petersburg, Tolyatti
Serbia	Subotica
Spain	Madrid, SantVicençdelsHorts, Valencia
Sweden	*Stockholm*
Turkey	Adana, Ankara, Denizli, Karabük, Konya, Istanbul
Ukraine	*Kiev*, Simferopol, Zaporizhzhya
United Kingdom	Farnborough, Gloucester, London
Uzbekistan	Namangan

*Cities not selected by random sample are shown in italics

CLASSIFICATION OF ENVIRONMENTAL RISK FACTORS AND CITY CHARACTERISTICS

Data on environmental risk factors for each city was acquired from independent datasets. We concentrate here on selected variables relating to meteorological parameters, air pollution and flood risk, as follows:

- Climate/temperature projections: Simulated data on current and possible future climates was provided by the Climatic Research Unit (CRU) at the University of East Anglia, using estimates for SHUE cities extracted for the nearest model grid square (typically several hundred kilometres in resolution) derived from an ensemble of 18 global climate models (GCMs) for the years 2015, 2050 and 2100 under a "business as usual" high greenhouse gas emissions scenario (RCP8.5) *(15-18)*. The model simulations were from CMIP5 (Coupled Model Intercomparison Project Phase 5) *(19)*. Analyses were based on the monthly mean of daily mean temperatures for the hottest month of the year.

- Air pollution: Annual average concentrations of fine particulate matter ($PM_{2.5}$) for each city were obtained from the WHO's ambient air pollution in cities database 2016 *(20)*, which contains estimates based on measurements from monitoring stations covering the period 2010-2015.

- Flooding: Gridded estimates of exposures to flooding, ranging from 1 (low) to 5 (extreme), were obtained from the United Nations Environment Programme (UNEP) *(21)*. Each city's risk was estimated based on the grid cell (0.1 x 0.1 degrees) containing the city centre.

The above data was combined with data on the following city-level characteristics:

- Population size: Estimates of city populations, and of wider metropolitan areas where relevant, were obtained from the most recent census, government statistical data, the United Nations Statistics Division (UNSD) or, if absent, directly from GeoNames.

- Location: City coordinates were obtained from GeoNames, and city administrative outlines were obtained from the Global Administrative Areas database (GADM) *(22)*, OpenStreetMap *(23)*, or, if not available, traced from Google Maps.

- Wealth: Gross Domestic Product per capita (US $ PPP) was obtained from a number of sources, including the Brookings Institute, Organisation for Economic Co-operation and Development (OECD), or

World Bank. Where city-level data was unavailable, regional or national data was used.

- Ecoregion: Each city was classified according to its Bailey's Ecoregion, a hierarchical system based on climate, vegetation, geomorphology, and soil characteristics *(14)*. We used only the "Domain" level of classification.

ANALYSIS

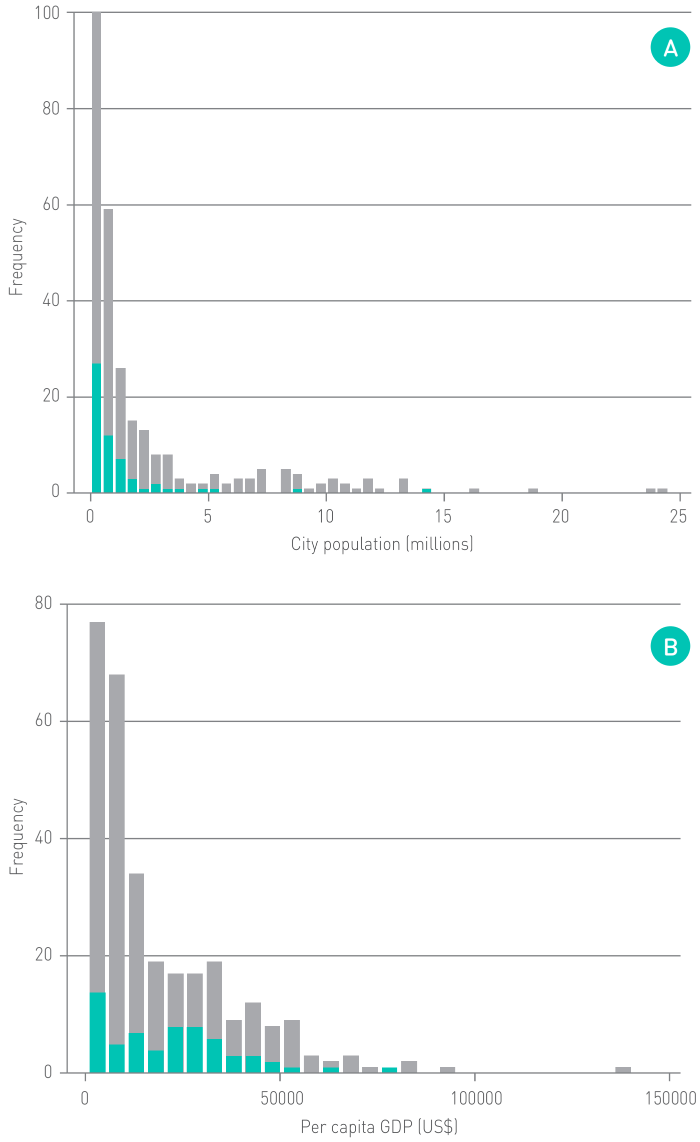
Data, from the most recent years of available data for each city, was analysed by simple tabulation and graphical methods to examine the uni-variate and bi-variate distribution of environmental characteristics across cities. Where there was no data for a given city, the city was excluded from that part of the analysis. We show data for all global cities in the database, with those for the WHO European Region highlighted to set the European data in the global context. For air pollution, we also present an analysis of the determinants of variation in city-level $PM_{2.5}$ concentrations to illustrate the degree to which levels for individual cities appear to be higher or lower than those of comparable cities. This analysis was based on a multiple regression model in which $PM_{2.5}$ concentrations were modelled as a function of three key determinants: the level of socioeconomic development (per capita GDP), city size (population of the wider metropolitan area), and the number of cities within 500 km of the index city. The relationship with each parameter was fitted using natural cubic splines of the relevant variable, implemented using Stata's *mkspline* function with three internal knots. All analyses were carried out in Stata v14 (StataCorp LP, College Station, TX, USA).

RESULTS

The distribution of WHO European Region cities with respect to population and socioeconomic development (per capita GDP) is shown in Fig. 2. Against the global distribution, European cities do not include the very largest cities ("mega-cities") but otherwise have a similar distribution to that of the global sample (Fig. 2.A). Only Istanbul, Moscow, London and Saint Petersburg have city populations of 5 million or more inhabitants, excluding wider metropolitan areas. The sample includes ten cities with populations below 50 000.

The SHUE sample of European Region cities has a somewhat higher per capita income than the global sample but includes some cities with very low average income (Fig. 2.B).

FIG. 2.HISTOGRAMS OF (A) CITY POPULATIONS AND (B) PER CAPITA GDP FOR ALL SHUE CITIES AND FOR SHUE CITIES IN THE WHO EUROPEAN REGION (GREEN OVERLAY).



CLIMATE CHANGE

Fig. 3 shows the monthly mean of daily mean temperatures under RCP8.5 in 2050 for the hottest month of the year derived from the ensemble mean of 18 CMIP5 GCMs.

In global terms, the SHUE cities of the European Region have some of the highest predicted temperature increases for the hottest month, with the mean projection for most cities being in excess

FIG.3.INCREASE IN THE MEAN OF DAILY MEAN TEMPERATURES FOR THE HOTTEST MONTH IN 2050: RESULTS FROM 18 CMIP5 GLOBAL CLIMATE MODELS FOR RCP8.5. (A) TEMPERATURE INCREASE VS.2050 MEAN TEMPERATURE FOR THE HOTTEST MONTH, AND (B) VS. PER CAPITA GDP (US$)

City codes: 1 Adana; 2 Ankara; 3 Arad; 4 Berlin; 5 Bressanone; 6 Brunoy; 7 Bucharest; 8 Cava DèTirreni; 9 Chita; 10 Copenhagen; 11 Denizli; 12 Düsseldorf; 13 Farnborough; 14 Gloucester; 15 Gomel; 16 Hadera; 17 Hamburg; 18 Helsinki; 19 Hrodna; 20 Istanbul; 21 Izhevsk; 22 Karabük; 23 Kateríni; 24 Kazan; 25 Kiev; 26 Konya; 27 Le Grand-Quevilly; 28 Le Mans; 29 Leczna; 30 London; 31 Lyepyel; 32 Lyon; 33 Lódz; 34 Madrid; 35 Marseille; 36 Mezotúr; 37 Montpellier; 38 Moscow; 39 Munich; 40 Namangan; 41 Namur; 42 Nantes; 43 Napoli; 44 Nuuk; 45 Omsk; 46 Oostend; 47 Oslo; 48 Oulu; 49 Paris; 50 Rome; 51 Rotterdam; 52 Saint Petersburg; 53 Sant Vicenç dels Horts; 54 Simferopol; 55 Sofia; 56 Stockholm; 57 Subotica; 58 Tolyatti; 59 Valencia; 60 Vercelli; 61 Voorst; 62 Yerevan; 63 Zagreb; 64 Zaporizhzhya

of 2 ˚C by mid-century. By 2100, in the cities of Arad, Bressanone, Bucharest, Kateríni, Lyon, Mezotúr, Montpellier, Simferopol, Sofia, Subotica, Vercelli and Zagreb, the temperature increase in average daily mean temperature for the hottest month exceeds 7 ˚C (data not shown). Although RCP8.5 is a "high-end" projection, the result sindicate a very substantial shift in the temperature distribution by 2100 that, without effective adaptation measures, would likely lead to frequent exposure to temperatures well beyond the upper limits of current distributions, resulting in a substantial burden on mortality/morbidity and limitations to physical activity*(24)*.

These large temperature increases occur in cities within the middle range of the current global temperature distribution, not with the globally highest temperatures, and largely in settings where there is likely to be appreciable diurnal variation in temperature, which may provide partial nocturnal relief from the daytime maximum. Most of the cities with the highest projected temperature increases are in the middle- to high-income part of the income distribution (Fig. 3.B).

AIR POLLUTION

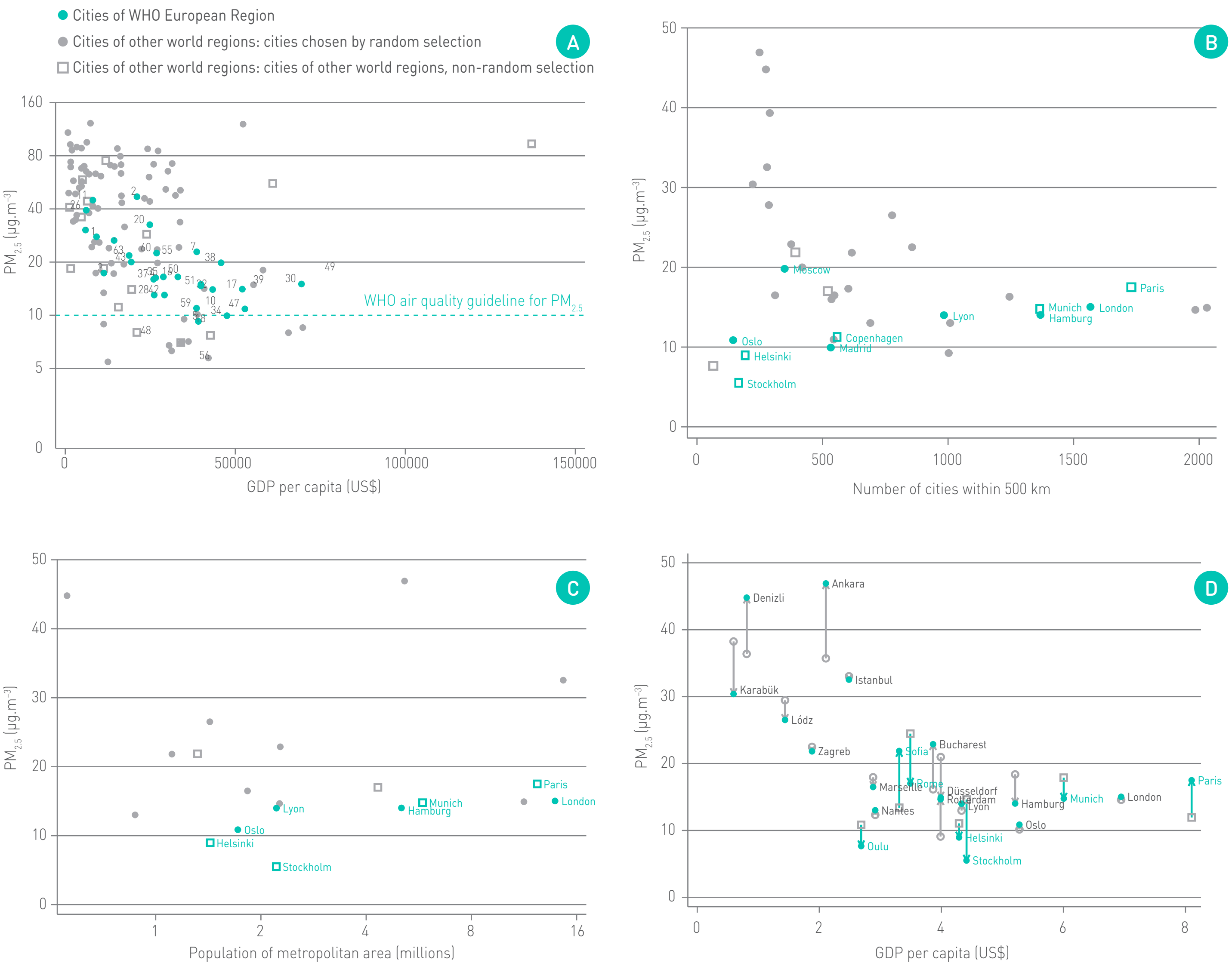
Only five of the 64 SHUE cities in the European Region have reported annual average concentrations of $PM_{2.5}$ under the WHO guideline *(25)* of 10 µg.m^{-3} (Fig. 4.A): Stockholm (5.51 µg.m^{-3}), Oulu (7.65 µg.m^{-3}), Helsinki (8.96 µg.m^{-3}), Bressanone (9.23 µg.m^{-3}) and Madrid (9.95 µg.m^{-3}). The highest annual average $PM_{2.5}$ levels were in Konya (39.34 µg.m^{-3}), Denizli (44.79 µg.m^{-3}) and Ankara (46.93 µg.m^{-3}), but with levels well below those of cities with the highest concentrations outside the European Region.

FID.4 (A), (B), (C) AND (D):

CITY ANNUAL MEAN PARTICLE AIR POLLUTION ($PM_{2.5}$) CONCENTRATION VS.PER CAPITA GDP. CITY NUMBERS AS IN FIGURE 3

(B) TO (D) DATA FOR CITIES OF WHO EUROPEAN REGION WITH AVAILABLE DATA:
- ANNUAL MEAN $PM_{2.5}$ VS.
- (B) NUMBER OF CITIES WITHIN 500 KM OF INDEX CITY AND
- (C) VS. POPULATION OF THE METROPOLITAN AREA

(D) OBSERVED (FILLED CIRCLES) AND PREDICTED (OPEN CIRCLE) $PM_{2.5}$ CONCENTRATIONS, WITH PREDICTED CONCENTRATIONS BASED ON REGRESSION OF $PM_{2.5}$ ON PER CAPITA GDP, THE NUMBER OF CITIES WITHIN 500 KM, AND THE POPULATION OF THE METROPOLITAN AREA. ARROWS POINT FROM PREDICTED TO OBSERVED $PM_{2.5}$ CONCENTRATIONS



As Fig. 4.A illustrates, city $PM_{2.5}$ concentrations have a broad relationship with per capita income, with levels tending to be lower in wealthier cities. There also appears to be a relationship with the number of cities within 500 km of the index city in the European Region (Fig. 4.B) and with city size as reflected by the population of the wider metropolitan area (Fig. 4.C). Unsurprisingly, $PM_{2.5}$ concentrations appear to be broadly linearly related to city size, a relationship which again is most clearly seen among higher income cities (Fig. 4.B).

The relationship with the number of cities within 500 km is weaker and somewhat different among cities with average per capita income in excess of US$ 40 000 compared with cities of lower per capita income. In higher income cities, there appears to be a small increase in $PM_{2.5}$ concentration with an increasing number of cities within 500 km (Fig. 4.B), while the opposite is the case for cities of lower income.

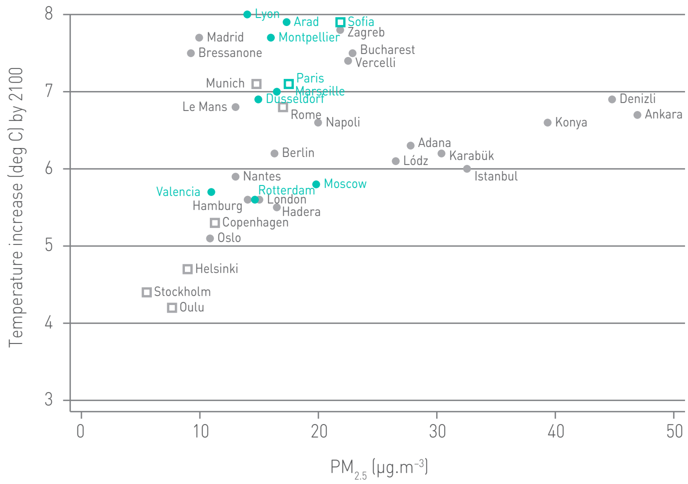
Given the limited number of cities and uncertainties over consistency of data definitions, the results of regressions of $PM_{2.5}$ on city characteristics should be interpreted cautiously as indicative only of general patterns of association. However, in models with mutual adjustment for per capita income, city (metropolitan) population and the number of cities within 500 km, there was clear evidence that both per capita income and city size were determinants of air pollution levels, while the number of cities within 500 km was not. Using, for simplicity, linear terms for each variable (in models with the other variables fitted as natural cubic splines), the adjusted changes in $PM_{2.5}$ levels (μg.m^{-3}) were: -5.10 (95% CI: -7.89, -2.31) for each US$ 10 000 increase in per capita GDP, 1.20 (0.23, 2.16) for each million increase in population, and -0.36 (-0.98, 0.26) for each additional 100 cities within 500 km.

Fig. 4.D illustrates the importance of these three determinants of air quality. For each city, the air pollution concentration,predicted from a regression model that takes account of each variable fitted as natural cubic splines, is joined by a vertical arrow to the observed level. Cities in which the observed level is greater than predicted are shown with upward pointing arrows, while those where the observed level is below predicted are shown by downward arrows. For example, London has broadly the level of air pollution expected for its income, size and the number of cities within 500 km, while Stockholm appears to perform better than expected. These differences between observed and predicted air pollution may reflect the relative importance of local sources of pollution. These comparisons should be interpreted with some caution, however, as they depend on many factors including the accuracy of the input variables, especially estimates of per capita income.

MULTIPLE RISK FACTORS

The relationship between air pollution, climate change and flood risk is illustrated in Fig. 5. Cities with the highest air pollution levels, including the Turkish cities and Łódz, also have high (though not the highest) potential increases in daily mean temperatures for the hottest month of the year by 2100. Cities with possible temperature increases above 7 °C include some with $PM_{2.5}$ concentrations above 15 μg.m^{-3}, including Arad, Bucharest, Sofia, Vercelli and Zagreb.

FIG. 5. MULTIPLE ENVIRONMENTAL HAZARDS FOR WHO EUROPEAN REGION CITIES: INCREASE IN DAILY MEAN TEMPERATURE FOR HOTTEST MONTH BY 2100 VS. CURRENT $PM_{2.5}$ CONCENTRATIONS.



Additional flood risk indicated by green markers.

Dots: cities chosen by random selection; unfilled squares: cities chosen by non-random selection

Some cities with high potential temperature increases also include those with historical flood risk (indicated by green markers), including cities such as Arad and Sofia which also have moderately high air pollution levels. High latitude cities in Scandinavia and elsewhere appear to have relatively low risk on all counts, as shown in the bottom left quadrant of Fig. 5.

DISCUSSION

The SHUE project is a "proof of concept" study aimed at developing a resource for the analysis of a representative set of cities to support policy formulation on healthy and sustainable urban development. It draws on existing data resources and aims to integrate and analyse them in ways that help to examine questions of principle about strategies for urban development. The analyses presented here, derived from the database, should be interpreted as a "data-driven" and "hypothesis-generating" process rather than as "hypothesis-testing": the data on which they are based is generally not sufficiently detailed or of documented quality, using standardized definitions to permit definitive interpretations of cause-and-effect relationships. Nor should they be used to evaluate the performance of any individual city. Nonetheless, by examining broad patterns of association across multiple cities of varying sizes and incomes, insights may be obtained about the mechanisms involved and the challenges and opportunities for promoting improved urban environments and health.

More detailed analyses will be reported in subsequent workas the database is developed. However,even from the relatively limited analyses presented here, it is possible to infer that the WHO European Region is likely to face substantial threat from unabated climate change, with some of the highest potential temperature increases under RCP8.5 of any cities in the database. The levels of temperature increase for the hottest month, if realised, would be very damaging, underlining the need for action to put in place adaptation responses and to accelerate steps for radical reduction in greenhouse gasemissions. Analyses of temperature–mortality relationships published elsewhere *(26)* suggest that urban populations are partly adapted to the temperature distributions to which they are currently exposed, and hence large rises in temperature suggest the potential for very large population health impact, assuming no further adaptation. Most of the cities with the highest projected temperature increases are in the middle- to high-income part of the income distribution (Fig. 3.B), which may be important for their capacity to adapt should mitigation efforts fail to limit temperature rises over this century. However, the magnitude of the potential threat emphasizes the urgency for mitigation action. While RCP8.5 may be considered unlikely following the Paris Agreement, there is still doubt about the extent to which the agreement will be implemented and we show the projections here for illustrative purposes.

Climate change mitigation is likely also to have beneficial effect in helping to reduce ambient particle concentrations, which remain above desirable levels for all but a handful of SHUE cities within the European Region. All cities, including those with the lowest levels, would benefit from further reduction in $PM_{2.5}$, which would likely follow from the transition towards a low carbon economy *(27)*. Important determinants include socioeconomic development, which explains some of the gradients in ambient concentrations across the region, and city size. While for higher income cities, which generally have better emission controls, ambient levels were somewhat correlated with the number of cities within 500 km; this correlation was not seen once adjustment was made for income and metropolitan population. Such a relationship is probable because of the long-range transport of polluted air masses, but the absence of clear relationship here may in part reflect the simplicity of the marker and the influence of other confounding factors.

The coincidence of several hazards – specifically climate change, air pollution and, in some cases, flood risk – presents particular challenges for cities. However, the co-benefits of action mean that there are potential additional dividends for health if policies are appropriately aligned.

The key limitations of attempting to assemble and analyse city-level data relate to the quality of the data itself because of uncertainties overcompleteness and comparability between cities. There are also limitations on the availability of data. Some metrics can only be obtained from population surveys that are often unavailable. In general, there are reasonable data available for larger, developed cities that are often collected by city administrations, whereas smaller cities and those in less wealthy countries have less data. There is particular advantage, therefore, in attempting to source data from globally monitored and modelled datasets. We also note that the GeoNames dataset from which cities were selected provides global coverage of cities but areas in Western Europe may have greater coverage than Eurasia *(12)*.

CONCLUSION

Despite these limitations, our hope is that, by exploiting the database as a shared resource, the availability and quality of its data will improve over time. There are multiple databases relating to city characteristics, but the unique contribution of the SHUE project is to assemble data and methods of analysis that have bearing on questions of both health and sustainability. Realising the potential of the database for the research and policy communities will be greater the more it is used. The current priority is to work with potential users to explore the degree to which city-to-city comparisons and modelling can best help support policy development in pursuit of health and sustainability goals.

The SHUE database is still in its development phase. Future research will concentrate on improving its underlying data and the analytical approaches applied to them. To help maximize the utility of the database, we will seek input from multiple user groups, but we also invite dialogue with interested researchers and policy makers about how the database should be developed and exploited.

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Conflicts of interest: None declared.

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REFERENCES

1. United Nations. 2014 Revision of World Urbanization Prospects. New York, NY, USA: UN Population Division, Department of Economic and Social Affairs; 2014 (https://esa.un.org/unpd/wup/, accessed December 2016).
2. Rydin Y, Bleahu A, Davies M, Davila JD, Friel S, De Grandis G, et al. Shaping cities for health. Lancet. 2012;379(9831):2079-108.
3. Kleinert S, Horton R. Urban design: an important future force for health and wellbeing. Lancet. 2016;388(10062):2848-50.
4. Whitmee S, Haines A, Beyrer C, Boltz F, Capon AG, de Souza Dias BF, et al. Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health. Lancet. 2015;386(10007):1973-2028.
5. World Health Organization. Urban health. Geneva, Switzerland: WHO; 2010 (http://www.euro.who.int/en/health-topics/environment-and-health/urban-health/urban-health, accessed December 2016).
6. Milner J, Davies M, Wilkinson P. Urban energy, carbon management (low carbon cities) and co-benefits for human health. Curr Opin Environ Sustain. 2012;4(4):398-404.
7. de Nazelle A, Nieuwenhuijsen MJ, Anto JM, Brauer M, Briggs D, Braun-Fahrlander C, et al. Improving health through through policies that promote active travel: a review of evidence to support integrated health impact assessment. Environ Int. 2011;37(4):766-77.
8. Haines A, McMichael AJ, Smith KR, Roberts I, Woodcock J, Markandya A, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: overview and implications for policy makers. Lancet. 2009;374(9707):2104-14.
9. United Nations. Sustainable Development Goals. New York: United Nations; 2016 (http://www.un.org/sustainabledevelopment/, accessed November 2016).
10. United Nations Framework Convention on Climate Change. The Paris Agreement. New York, NY, USA: UNFCCC; 2016 (http://unfccc.int/2860.php, accessed November 2016).
11. United Nations. The New Urban Agenda. UN Habitat III; 2016 (https://habitat3.org/the-new-urban-agenda/, accessed November 2016).
12. GeoNames. The GeoNames Geographical Database. 2015 (http://www.geonames.org/, accessed March 2017).
13. World Bank. GNI Per Capita. 2015 (http://data.worldbank.org/indicator/NY.GNP.PCAP.PP.CD, accessed March 2017).
14. Bailey RG. Ecoregions: The ecosystem geography of the oceans and continents. New York, NY, USA: Springer-Verlag; 1998.
15. van Vuuren DP, Edmonds J, Kainuma M, Riahi K, Thomson A, Hibbard K, et al. The representative concentration pathways: an overview. Clim Change. 2011;109(1):5.
16. Meinshausen M, Smith SJ, Calvin K, Daniel JS, Kainuma MLT, Lamarque J-F, et al. The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. Clim Change. 2011;109(1):213.

17. International Institute for Applied Systems Research. RCP Database (version 2.0). Vienna, Austria: IIASA; 2009 (http://tntcat.iiasa.ac.at:8787/RcpDb/dsd?Action=htmlpage&page=welcome, accessed September 2016).
18. Riahi K, Gruebler A, Nakicenovic N. Scenarios of long-term socioeconomic and environmental development under climate stabilization. Technol Forecast Soc Change. 2007;74(7):887-935.
19. Taylor K, Stouffer R, Meehl G. An overview of CMIP5 and the experiment design. Bull Amer Meteor Soc. 2012;93:485-98.
20. World Health Organization. WHO Global Urban Ambient Air Pollution Database (update 2016). Geneva, Switzerland: WHO; 2016 (http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/, accessed November 2016).
21. United Nations Environment Programme/United Nations Office for Disaster Risk Reduction. Global Risk Data Platform. Geneva, Switzerland: UNEP/UNISDR; 2013 (http://preview.grid.unep.ch, accessed March 2017).
22. Hijmans R, Garcia N, Wieczorek J. GADM: Database of Global Administrative Areas. 2010 (http://gadm.org/, accessed March 2017).
23. The American Association for the Advancement of Science. OpenStreetMap (http://openstreetmap.org, accessed December 2016).
24. Kjellstrom T, Briggs D, Freyberg C, Lemke B, Otto M, Hyatt O. Heat, human performance, and occupational health: a key issue for the assessment of global climate change impacts. Annu Rev Public Health. 2016;37:97-112.
25. World Health Organization. WHO air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005. Summary of risk assessment. Geneva, Switzerland: WHO; 2006.
26. Gasparrini A, Guo Y, Hashizume M, Lavigne E, Zanobetti A, Schwartz J, et al. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet. 2015;386(9991):369-75.
27. International Energy Agency. World Energy Outlook 2016. Paris, France: IEA; 2016.