Quistberg, D Alex; Diez Roux, Ana V; Bilal, Usama; Moore, Kari; Ortigoza, Ana; Rodriguez, Daniel A; Sarmiento, Olga L; Frenz, Patricia; Friche, Amélia Augusta; Caiaffa, Waleska Teixeira; +3 more... Vives, Alejandra; Miranda, J Jaime; SALURBAL Group; (2019) Building a Data Platform for Cross-Country Urban Health Studies: the SALURBAL Study. Journal of urban health, 96 (2). pp. 311-337. ISSN 1099-3460 DOI: https://doi.org/10.1007/s11524-018-00326-0

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Building a Data Platform for Cross-Country Urban Health Studies: the SALURBAL Study

D. Alex Quistberg · Ana V. Diez Roux · Usama Bilal · Kari Moore · Ana Ortigoza · Daniel A. Rodriguez · Olga L. Sarmiento · Patricia Frenz · Amélia Augusta Friche · Waleska Teixeira Caiaffa · Alejandra Vives · J. Jaime Miranda · the SALURBAL Group

Published online: 21 November 2018
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Abstract Studies examining urban health and the environment must ensure comparability of measures across cities and countries. We describe a data platform and process that integrates health outcomes together with physical and social environment data to examine multi-level aspects of health across cities in 11 Latin American countries. We used two complementary sources to identify cities with ≥100,000 inhabitants as of 2010 in Argentina, Brazil, Chile, Colombia, Costa Rica, El Salvador, Guatemala, Mexico, Nicaragua, Panama, and Peru. We defined cities in three ways: administratively, quantitatively from satellite imagery, and based on country-defined metropolitan areas. In addition to “cities,” we identified sub-city units and smaller neighborhoods within them using census hierarchies. Selected physical environment (e.g., urban form, air pollution and transport) and social environment (e.g., income, education, safety) data were compiled for cities, sub-city units, and neighborhoods whenever possible using a range of sources. Harmonized mortality and health survey data were linked to city and sub-city units. Finer georeferencing is underway. We identified 371 cities and 1436 sub-city units in the 11 countries. The median city population was 234,553 inhabitants (IQR 141,942; 500,398). The systematic organization of cities, the initial task of this platform, was accomplished and further ongoing developments include the harmonization of mortality and survey measures using available sources for between country comparisons. A range of physical and social environment indicators can be...
created using available data. The flexible multilevel data structure accommodates heterogeneity in the data available and allows for varied multilevel research questions related to the associations of physical and social environment variables with variability in health outcomes within and across cities. The creation of such data platforms holds great promise to support research with greater granularity the field of urban health in Latin America as well as serving as a resource for the evaluation of policies oriented to improve the health and environmental sustainability of cities.

**Keywords** Urban health · Latin America · Cities · Built environment · Social Environment · Multilevel Models · Mortality · Health Survey

**Introduction**

By 2050, at least 70% of the world’s population will live in cities [1]. Urban policies impact important determinants of health, health equity, and environmental sustainability [2]. However, there is limited empirical evidence on what factors may make some cities healthier, more equitable, or more environmentally sustainable than others [3–6]. Latin America, with over 80% of its population living in urban areas [1] and a diversity of geographies and socioeconomic circumstances, presents a unique opportunity to study the impacts of urban living on health.

Cities in Latin America are heterogeneous in size; have diverse physical, social, and economic environments; and are frequently characterized by large social inequalities [3, 7]. Cities of the region have also generated innovations in transportation, urban redevelopment, food policies, and social programs [8–12]. The SALURBAL (Salud Urbana en America Latina/Urban Health in Latin America) project launched in 2017 aims to leverage the heterogeneity and innovation observed across Latin American cities to study drivers of urban health, health equity, and environmental sustainability in order to inform urban policies worldwide [13].

A critical need in any cross-city comparison study is the creation of a data platform that can support between- and within-city comparisons and that can be flexibly linked to various types of data defined at different levels of aggregation [14–17]. In this paper, we (1) describe the design of the SALURBAL data structure, including how cities are operationalized; (2) summarize the approach to obtaining and harmonizing health data; (3) describe priority social and physical environment indicators; (4) provide examples of how the data structure can be used to answer meaningful research questions about within and between-city variation in health; and (5) discuss selected challenges in creating this resource. Our goal is to inform similar data compilation efforts in other regions in order to enhance the ability to understand drivers of urban health and the impact of various urban policies on health.

**A Flexible Multilevel Data Structure**

Conducting within-city and cross-city comparisons of urban health necessitates: (1) identifying the universe of “cities”; (2) operationalizing cities and geographic subunits within cities including neighborhoods in ways that permit linkages to available health and environmental data; (3) obtaining, processing, and harmonizing health data as well as data on social and physical environments; and (4) integrating all available information within a multilevel data structure that allows definition and measurement of constructs and investigation of questions at different levels. SALURBAL developed a data structure that accommodates information available for different geographic units and allows for heterogeneity, both geographically and over time. The process was guided by the principle that pragmatic albeit imperfect geographic definitions would be necessary to advance the project and that these definitions could be refined as the project progresses. The data structure developed allows for complementary analytical approaches that may be used to varying extents as the project evolves.

**Identifying and Operationalizing Cities**

There is no unique way to define a city, but there are at least three possible types of definitions: (1) administrative definitions based on political or administrative boundaries; (2) definitions based on social or economic functions, such as country-defined metropolitan areas, that capture interconnectedness between a core city and nearby areas; and (3) definitions based on the geographic extent of urban areas identified from satellite imagery using standardized criteria [14–16, 18–20].

An advantage of administrative definitions of cities is that they can be linked to administrative and political responsibility and are often easy to link to health data. A disadvantage is that in large urban areas administratively
defined cities often only capture a core city and may not fully represent the entire urban agglomeration. [21, 22]

Functional definitions such as metropolitan areas better capture the urban agglomeration around administratively defined core cities and have the important advantage of being based on social and economic relations between the core city and its surrounding areas. There are two broad types of functional definitions for these agglomerations. A first definition is based on networks, like water or road networks, while the second definition is based on travel patterns, which define labor or commute areas that are economically linked. Functional definitions receive a variety of names across different countries (e.g., metropolitan areas or urban agglomerations). Considerations of these broader geographic areas may be important to understand the drivers of urban health and the impact of urban health policies. However, these areas are defined using different criteria in different countries making cross-country comparisons difficult and may in some cases include surrounding areas that may not be thought of as urban [15, 16].

Definitions based on geographic extent of built-up areas characterize the physical footprint of the city. An important strength of this approach is that it can be applied systematically across countries and over time to track urban growth longitudinally. In addition it captures the boundaries of urbanized areas in a systematic and data-driven fashion [14, 19, 23, 24]. A key disadvantage is that it may be difficult to link other data such as census data or health data to these units because the boundaries identified do not necessarily correspond to any type of administrative area.

**SALURBAL Approach to Identifying and Operationalizing Cities**

Recognizing the complexity of defining cities and the need to be rigorous but practical in order to capitalize on easily available health data, SALURBAL used an approach that combines various criteria. First, we identified the universe of cities of interest. Second, we operationalized cities and their component units so that various data sources could be linked to them. We used a three-level tiered system to define cities and their subunits. We labeled “cities” as “level 1,” sub-city components as “level 2,” and neighborhoods as “level 3.”

**First Step: Identifying the Universe of SALURBAL Cities** The project identified “cities” with ≥100,000 inhabitants as of 2010 in the 11 SALURBAL countries as the universe of interest (here we use the term “cities” in quotes broadly to refer to units that may be an urban agglomeration or some form of administratively defined cities). The countries currently included in the SALURBAL cities platform are Argentina (AR), Brazil (BR), Chile (CL), Colombia (CO), Costa Rica (CR), El Salvador (SV), Guatemala (GT), Mexico (MX), Nicaragua (NI), Panama (PA), and Peru (PE). A cut-off population size of 100,000 inhabitants was selected because it is a threshold often used to define cities and allows the inclusion of “cities” of varying size [14–16, 20, 25]. Not all “cities” will be included in all analyses as there will likely be important heterogeneity in the data available to answer a given research question, but identifying the universe is critical to provide context for results.

We created a draft list of “cities” with 100,000 inhabitants or more by combining information from two sources: The 2010 Atlas of Urban Expansion (AUE) and a database of census data compiled at http://citypopulation.de (henceforth referred to as CP). The 2010 AUE [14] included 377 “cities” determined to have 100,000 population or more in the 11 SALURBAL countries. Because the AUE defines cities approximately based on their built-up area (analogous to the third definition above), the “cities” include both urban agglomerations (collections of nearby administratively defined areas) and single administratively defined cities. The CP is dedicated to collecting census data from countries worldwide, including lists of cities and other urban settlements. It is regularly updated with local population estimates [26]. Cities are defined based on a country’s administrative definitions such as a municipality or “a populated center, locality, or an urban area within a municipality.” The preferred year of population counts (or projections) was 2010 to match with the AUE population estimates. The CP list included 539 cities with population ≥100,000 in 2010 in the 11 SALURBAL countries.

We matched the AUE list of cities to the CP list by city name, country administrative sub-divisions, and country. All AUE-defined “cities” had a match in the CP list, but not all cities in the CP list matched to an AUE “city.” Satellite imagery in Google Earth (Google, Inc., Mountain View, California), NASA Earth Observatory Night Light Maps 2012 (NASA Worldview application, https://worldview.earthdata.nasa.gov/), and population data from both sources were used to assess whether the cities on the CP list that did not match the AUE list were actually already part of a larger AUE urban
agglomeration. If an unmatched city was not part of an AUE defined city, it was added to the list. The final result was a consolidated list of cities of ≥ 100,000 population that integrated information from both databases.

The draft list of cities was reviewed by each country team for face validity resulting in adjustments to the list. A few additional modifications to the list were made as a result of the operationalization of these cities as clusters of smaller sub-city units (which we describe below further) and as a result of the comparison of this list to country-defined metropolitan areas. The full process used to arrive at the final list of 371 cities is summarized in Fig. 1 and shown geographically in Fig. 2.

**Second Step: Creating Complementary Operational Definitions of “Cities” and Subunits Within Them** SALURBAL created four complementary definitions of cities or level 1 units: (1) L1Admin: based on the built-up urban extent approximated through clusters of administratively defined areas; (2) L1Metro: based on

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**Fig. 1** The process used to identify “cities” in 11 SALURBAL countries. Footnotes: (a) During the operationalization of cities as clusters of L2 units (see section on definition of L1Admin), it was observed that some L1 “cities” shared contiguous built-up areas. This resulted in adjacent L1 units being combined with other L1 units (N = 4) to create a consolidated “city”. Additionally, some administrative cities with populations of less than 100,000 were observed to share contiguous built-up areas with other nearby administrative cities such that together these units met the population eligibility requirement. This resulted in the addition of a small number (N = 4) of L1 units. (b) As a result of comparing the list of cities with what some countries deem as metropolitan areas, 3 new L1 units were added and 17 were merged with other L1 units. (c) MA = metropolitan areas.
country specific definitions of metropolitan areas; (3) L1UrbExt: based on the precise built-up urban extent identified systematically using satellite imagery; and (4) L1Excess: similar to L1UrbExt but including urban extents that spill over to neighboring non-SALURBAL countries, (for example Tijuana, Mexico’s built area spilling into San Diego, USA). In addition to defining “cities,” SALURBAL also defined sub-city units (level 2 or L2) and neighborhoods within cities (level 3 or L3).

A summary of the SALURBAL geographic definitions and “levels” is provided in Table 1.

**Defining L1 Administrative Units and Their Component Subunits** In order to link city data with health data, it was critical to have a practical definition of “cities” that could be operationalized as clusters of the smallest geographic units for which health data was either publicly available or easily available upon request (i.e.,
without requiring georeferencing). We therefore identified the “level 2” units (L2) in each country as the geographic administrative units for which health data was easily available and then proceeded to link each “city” on our list to the corresponding L2 units. Some “cities” encompassed only one L2 unit and others included multiple L2 units. In general, L2 units were defined as comunas, municipios, or similar units depending on the country. The cluster of L2 units that were attached to a given L1 was labeled the L1Admin.

A L2 unit was considered to be part of an L1Admin if it covered at least part of urban extent (initially determined by visual inspection of administrative boundaries and satellite imagery and then refined when the L1UrbExt was defined, see below). We included all L2 units that included any portion of the urban extent, even if they also captured areas outside the urban extent. In many cases, the population of the L2 unit will likely lie mostly within the most urbanized area. Subsequently, sensitivity analyses excluding L2 units that are not fully urban (based on census data) or that are only partly include the urban extent can be conducted. In cases where a L2 unit covered more than one “city,” it was assigned to the “city” with which it shared the largest amount of built-up area.

We identified neighborhoods or L3 units based on census hierarchies within each country. We looked for units that were comparable in size and that were nested within L2 units. L3 units facilitate examination of within-city variability when georeferenced health data are available and constitute building blocks for larger units (L2 units and L1UrbExt units) thus allowing linkage of these larger units to census and other data. In most countries, these units reflect the basic small-area census division for urban areas or for the entire country and were generally defined to facilitate census data collection. In some cases, the administrative units defined as L3 units did not cover the full country and were only available for country-defined “urban areas” (which may not coincide with SALURBAL L1Admin or L1UrbExt). In these cases, SALURBAL developed a strategy for creating SALURBAL defined L3 proxies in areas that were not covered. For details see Appendix Table 8. A summary of the definitions of L2 and L3 units for each country is provided in Table 2. A summary of the numbers of units at each level and their population sizes by country is provided in Table 3.

**Defining “Metropolitan Areas” or L1Metro** The second definition of Level 1 “cities,” L1Metro, was based on each country’s official definition of metropolitan areas (or similar areas). The definitions of L1Metro differed by country and are summarized in Appendix Table 9. L1Metro units may include multiple L1Admin units in their entirety or partially. In all countries except Argentina and Peru, L1Metro units are aggregates of L2 units. In Argentina, each L1Metro is composed of localidades and in Peru each L1Metro unit is composed of Centros Poblados. These units in both countries can be linked to L3 units.
Defining L1UrbExt and Its Spillover Extension L1Excess

While a qualitative assessment of the visual urban extent was used to help identify the L2 units linked to each L1 Admin, a more refined, systematic, and quantitative approach was needed to properly define the urban extent of each L1 unit. This process used the Global Urban Footprint (GUF) Dataset [28, 29] and followed procedures similar to those used by the Atlas of Urban Expansion to define urban extents with some modifications. The GUF is a worldwide mapping product derived using TerraSAR-X and TanDEM-X images, with a spatial resolution of 0.4 arcsec (~12 m), which classified pixels as built-up and non-built-up [28]. This classification was achieved by highlighting areas of images characterized by highly diverse and heterogeneous backscattering, then using an automated classifier, and followed by semi-automatic post processing. TerraSAR and TanDEM are two satellites designed to acquire high-resolution and good quality radar images covering the entire earth that are used for a wide range of applications, such as topographic mapping, land cover, and land use change detection [28–30]. In the process of defining urban extent, the pixels were identified as urban, suburban and rural according to the share of built-up pixels within a 1-km² area. Urban clusters were generated by merging the urban, suburban and urbanized open space. A hierarchical agglomerative process was used to join the urban clusters nearby following an inclusion rule. The largest urban cluster in each L1 Admin was defined as L1UrbExt.

The L1UrbExt analysis identified four potential cases that required further consideration, and if appropriate, modification of L1 Admin definitions. First was when the L1UrbExt extended beyond the geographic boundaries of the L1 Admin (as first defined using visual inspection of satellite imagery) and therefore the L1 Admin needed to be modified by adding a L2 unit (3 cases). Second, when L1UrbExt extended beyond the geographic boundary of the L1 Admin by less than 20% of the L1 Admin area, in which case we ignored the extra area (3 cases). Third, when the L1UrbExt spills into another L1 Admin, in which a case by case analysis identified that separate L1UrbExts were appropriate (2 cases) and no modifications to the L1 Admins were made.

Fourth, when the L1UrbExt spilled into a neighboring non-SALURBAL country (10 cases, spilling into Paraguay, Uruguay, the USA, and Venezuela), we created the level 1 excess (L1Excess) to include the non-spillover plus the spillover area into the neighboring country. This was done because even though health data outside of SALURBAL countries would not be linked to the L1 Admin, some measures of the L1UrbExt (such as air pollution) might be relevant to health on the other side of the border.

Linking Health and Environmental Data at Various Geographic Levels

A summary of the geographic hierarchies and possible linkages using the SALURBAL geographic levels is provided in Fig. 3. The L1 Admin, level 2, and level 3 hierarchy is straightforward as units are nested within each other (Fig. 3). In many cases, L1 Metros are also

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**Table 2** SALURBAL cities and definitions of Level 2 and 3 units by country

| Country | Cities | Level 2 unit | Level 3 unitb |
|---------|--------|--------------|---------------|
| Argentina | 33 | Departamento/Partido/Comunaa | Radio Censal |
| Brazil | 152 | Municipios | Setor Censitário |
| Chile | 21 | Comuna | Zona Censal |
| Colombia | 35 | Municipio | Sector Urbano |
| Costa Rica | 1 | Canton | Unidad Geoestadistica Basica |
| El Salvador | 3 | Municipio | Sector Censal |
| Guatemala | 3 | Municipio | Sector Censal |
| Mexico | 92 | Area Geoestadistica Municipal | Area Geoestadistica Basica |
| Nicaragua | 5 | Municipio | Sector Censal |
| Panama | 3 | Corregimiento | Barrio |
| Peru | 23 | Distrito | Zona Censal |

a Comunas in the Ciudad de Buenos Aires, Partido in the Provincia de Buenos Aires, Departamentos elsewhere
b As defined for country-designated urban areas
Table 3 Descriptive statistics and population sizes of L1Admin, L2, and L3 units by country. Population for L1Admin and L2 are from 2010 census projections from each country. L3 population sizes are from most recent census data available.

|      | L1Admin | | L2 | | L3 | |
|------|---------|-----------------|-----|-----------------|-----|-----------------|
|      | N       | Population (in 1000s) | Total A<sup>a</sup> | Units per L1Admin | Population (in 1000s) | Median (5th–95th percentile) | Max | Total N<sup>a</sup> | Units per L2 | Population Median (5th–95th percentile) | Max |
|      |         |                  | Median (5th–95th percentile) | Max | |                  | Max | | |
| AR   | 33      | 304.2 (123.0–1466.5) | 110 | 1 (1–6) | 51 | 188.8 (28.8–605.7) | 29,792 | 218 (34–606) | 1493 | 883 (250–1692) | |
| BR   | 152     | 231.4 (114.5–3070.4) | 422 | 1 (1–9) | 31 | 124.2 (15.6–798.2) | 164,107 | 183 (23–1074) | 18,953 | 646 (79–1251) | |
| CL   | 21      | 215.3 (126.8–994.6)  | 81  | 1 (1–10) | 36 | 137.9 (27.6–319.2) | 3,918 | 39 (14–114) | 172 | 2200 (0, 7787) | |
| CO   | 35      | 363.3 (119.9–2822.2) | 84  | 1 (1–6) | 15 | 115.0 (12.8–895.6) | 4,679 | 22.5 (2–170) | 643 | h |
| CR   | 1       | 2367.0 (2367.0–2367.0) | 29  | 29 (29–29) | 29 | 57.4 (22.7–251.6) | 944 | 28.5 (4–108) | 137 | 2361 (1425–3031) | |
| SV   | 3       | 261.9 (241.2–1704.8) | 22  | 1 (1–18) | 20 | 79.5 (9.3–267.3) | 4025 | 86 (21–688) | 1485 | 677 (312–1106) | |
| GT   | 3       | 242.0 (150.3–2633.0) | 20  | 5 (1–13) | 14 | 94.1 (22.8–516.4) | 32,921 | 32 (4–319) | 638 | 1749 (6–5636) | |
| MX   | 92      | 351.7 (134.9–1855.9) | 406 | 2 (–15) | 76 | 67.6 (7.1–774.5) | 8972 | 18 (1–53) | 147 | 116 (3–1150) | |
| NI   | 5       | 174.1 (117.6–936.0)  | 11  | 1 (1–5) | 6  | 76.8 (20.3–555.8) | 1,800 | 18 (1–53) | 147 | 116 (3–1150) | |
| PA   | 3       | 212.0 (209.4–1591.8) | 82  | 18 (12–50) | 53 | 20.1 (2.2–66.2) | 8972 | 18 (1–53) | 147 | 116 (3–1150) | |
| PE   | 23      | 281.5 (177.7–876.8)  | 9177.7 | 169 | 5 (2–18) | 55.9 (4.9–340.0) | 29,792 | 218 (34–606) | 1493 | 883 (250–1692) | |

<sup>a</sup>Total N<sub>a</sub> refers to the number of units across all SALURBAL cities

<sup>b</sup>Includes 385 proxy L3 units created by SALURBAL, median units per L2 = 3, max units per L2 = 17

<sup>c</sup>Includes 290 proxy L3 units created by SALURBAL, median units per L2 = 2, max units per L2 = 31

<sup>d</sup>Includes 388 proxy L3 units created for SALURBAL, median units per L2 = 1, max units per L2 = 1

<sup>e</sup>Includes 74 proxy L3 units created for SALURBAL, median units per L2 = 1, max units per L2 = 1

<sup>f</sup>Cartography and population for L3 units pending

<sup>g</sup>Population for L3 are from the following census years by country: AR, BR, MX, and PA are from 2010; CL and GT are from 2002; SV is from 2007

<sup>h</sup>Population for L3 from Colombia 2007 census is pending
clusters of L2 units, although they are sometimes larger and may encompass a different set of L2s than the L1Admins (Fig. 3). In countries where L1Metros are not defined using L2s (Argentina and Peru), they can be defined using L3s (Fig. 3a). L1UrbExts will be approximately linked to L3s (Fig. 3b). L3 units will be considered part of a L1UrbExt if they contain any portion of the area of the L1UrbExt. If necessary, weights may be used to attribute L3 data to the L1UrbExt in cases where the L3 is only partly covered by the L1UrbExt. A spatial representation of these linkages is shown in Fig. 3c.

In a small number of cases a variant of the L1UrbExt that extends outside the boundaries of the country (and the L1Admin) was created and called L1Excess. The L1Metro may include all L3 units within L2’s or only selected L3 units within them. The L1Metro may or may not overlap with the level 2 units that compose the L1Admin and may or may not include L2 units outside of the L1Admin. Depending on the country, the L1Metro may include all L3 units within L2’s or only selected L3 units within them. The L1Metro may include all L3 units within L2’s or only selected L3 units within them. The L1Metro is not shown but may include L2s or L3s beyond the L1Admin or may encompass only part of the L1Admin.
whenever possible, thus allowing for analyses at finer spatial resolution. In the meantime, analyses based on L1Admins or L2s can proceed as aggregate data for these units is more readily available.

The data structure proposed can be expanded to include time-varying health and environmental data linked to various geographic units. This is easily accomplished by adding calendar year indicators to spatial IDs. A challenge will be harmonizing units in cases where spatial definitions of administratively defined geographic units (such as L2 units, L3 units, or L1Metros) have changed over time. Definitions of L1UrbExts are designed to change over time in order to capture longitudinal changes in urban extent. If feasible, SALURBAL may explore approaches to harmonize geographic boundaries of selected units over time, as has been done in the USA [31, 32].

Obtaining and Harmonizing Health Data

Mortality Data

We obtained individual-level mortality records at L2 from each country (except Nicaragua) for as many years as possible. These records included at least age, sex, location of residence, and cause of death. Most countries had data on education of the decedent. We harmonized all variables to guarantee comparability. Sex was categorized as male, female, or missing. Age was operationalized in single-year intervals whenever possible (all countries except Colombia). Education was harmonized using the IPUMS international recode [33]. Causes of death were coded using either ICD9 or ICD10 codes (depending on the year) and grouped in categories using the World Health Organization Global Health Estimates (GHE) classification [34].

Three potential issues challenge the quality of mortality data, and we evaluated and addressed each one as follows. First, some mortality records have missing information on the variables of interest (age, sex, cause of death, location of residence, and cause of death). Most countries had data on education of the decedent. We harmonized all variables to guarantee comparability. Sex was categorized as male, female, or missing. Age was operationalized in single-year intervals whenever possible (all countries except Colombia). Education was harmonized using the IPUMS international recode [33]. Causes of death were coded using either ICD9 or ICD10 codes (depending on the year) and grouped in categories using the World Health Organization Global Health Estimates (GHE) classification [34].

The final product was a collection of datasets with information on each individual mortality record, on the observed distributions of each variable in their corresponding sex and cause of death (for age) or age and cause of death (for sex). Records with missing cause of death were imputed to either ill-defined diseases or injuries of ill-defined intent (see below), probabilistically by age and sex. Mortality records with missing location of residence at L2 were dropped, as these would not be linkable to a SALURBAL area.

Second, some mortality records had a cause of death coded as an ill-defined disease (e.g., R chapter of the ICD10 classification) or as an injury of ill-defined intent (e.g., codes Y10–Y34 and Y872 in the ICD10 classification). We evaluated this issue by computing the proportion of all deaths that were coded as ill-defined diseases or injuries of ill-defined intent (see Appendix Table 10). Given that these ill-defined deaths make it challenging to estimate the public health burden of diseases and injuries, we redistributed them to other GHE categories proportionally by age, sex, country, and year. This approach is similar to that used by the GHE study [34].

Third, not all deaths that occur in a country are registered in a vital registrations system. The phenomenon of lack of complete coverage or undercounting biases down the estimates of mortality. We evaluated this issue by obtaining estimates of undercounting from the United Nations Development Program (see Appendix Table 11). These estimates apply to the entire country, so we obtained more detailed estimates wherever possible. This is especially important in countries with wide geographic variability and high rates of undercounting such as Peru and Colombia, where (a) a national estimate of undercounting my underestimate or overestimate the lack of coverage and (b) this differentiation may be meaningful (as the overall rates are high). In countries where this distinction was less relevant, we applied a blanket correction for the entire country. Appendix Table 11 details the specific corrections we applied to each country, whether they are L2 specific (or at a higher level) and whether they are age or sex specific. Overall, we applied these correction factors by using them to estimate the number of missing deaths (for the entire country or each L2, for all age groups or a specific age group, and for both sexes or each specific gender, see Appendix Table 11). Once we estimated the number of missing deaths, we sampled this number with replacement (hot deck imputation) from the observed deaths following similar procedures as the GHE.

The final product was a collection of datasets with information on each individual mortality record,
including year, country, location of residence (at L2), age (in single or 5-year groups), sex, education (if available), and cause of death (3 variables: ICD-10 code, GHE classification, and GHE classification with redistributed ill-defined diseases and injuries of ill-defined intent). Moreover, we created an aggregated dataset, summing the number of deaths in each year, L2, 5-year age category, sex, education (if available), and cause of death using the GHE classification (with and without applying the redistribution of ill-defined diseases and injuries of ill-defined intent). These aggregated datasets contained both the number of deaths corrected for lack of complete coverage and the uncorrected number of observed deaths.

Population Data

In order to use mortality records to estimate mortality rates, we had to obtain estimates of the population counts by year, location of residence (L2), age, and sex. These population projections were obtained from the census bureaus of each country. In most countries, estimates by age and sex were available at L2. In some cases (Peru and El Salvador), estimates by age and sex were only available at higher administrative levels instead of L2, while data for L2 was available by either age or sex. In these cases, we estimated L2 population counts by age and sex by redistributing the counts by age or sex to the proportions observed at higher levels. More details are available in Appendix Table 12.

Survey Data

SALURBAL plans to compile health surveys and any available cohort studies in order to develop harmonized measures of health behaviors and other risk factors. Our initial focus has been on national health surveys with a focus on non-communicable disease risk factors. The design and sampling approaches differ somewhat across countries, but all allow linkage to SALURBAL L2 units (and may in the future also allow linkages to L3 units). Some surveys are based only on self-report information, but others include objective measurements such as height, weight and blood pressure [35]. A data harmonization effort was launched to create comparable measures of selected domains. The design of the surveys implies that their geographic level or representativeness may differ (Appendix Table 13). This will be taken into consideration if prevalence estimates for specific cities are generated. In addition, we will use statistical approaches that can be leveraged to derive small area estimates even when the survey was not specifically designed for that purpose [36–39]. For the most part, however, survey data will be used in multilevel analyses to estimate associations of city or neighborhood-level factors with individual-level outcomes. Sampling design and weights will be taken into consideration, if appropriate, as has been done in prior work [40–43]. Appendix Table 13 summarizes methodological and geographic characteristics of surveys selected for initial harmonization.

SALURBAL developed a process for harmonization of priority domains that included the following: (1) identifying and collating questions and responses by domain, with attention to skip patterns and respondent universe; (2) reviewing surveys conducted by others such as the Centers for Disease Control and Prevention or the World Health Organization for standard variable definitions as well as harmonization approaches proposed by other projects [33, 44, 45]; (3) proposing harmonized variable definitions and response categories with attention to differences in wording across countries; and (4) applying the harmonization and revising the protocol as needed, based on descriptive statistics of initial harmonized variables. In some cases, multiple versions of a variable were created due to country differences that did not allow a single harmonized variable. The harmonized data will be linked to L2 and L3 whenever possible. In addition SALURBAL is exploring other methods to combine heterogeneous data across countries using approaches, such as differential item functioning [46], meta-analysis approaches [47, 48], and fused LASSO models or other machine learning approaches [49]. Priority domains of interest and variable definitions are shown in Table 4. Other domains will be harmonized as the study advances.

Characterizing Urban Social and Physical Environments

Several key social and physical environment domains were identified as potentially relevant to health and health inequalities in cities by the SALURBAL team. The domains as well as selected indicators for these domains and the data sources that are being used to estimate them are summarized in Tables 5 and 6. Indicators may be defined for L3, L2 or L1Admin, L1Metro, and L1UrbExt based on the construct and data availability.
Table 4  SALURBAL health survey domains and selected measures.

| Domain          | Variables                  | Definitions                                                                 | Sourcea |
|-----------------|----------------------------|-----------------------------------------------------------------------------|---------|
| Demographics    | Age                        | Age in years                                                                 | N/A     |
|                 | Sex                        | Male or female                                                               |         |
| Education       | Presence of diabetes diagnosis by a health care provider among all adults (excluding diagnoses during pregnancy) | IPUMS-I [33, 44] |
|                 | Gestational diabetes       | Presence of gestational diabetes diagnosis among all adult female respondents with a history of pregnancy | WHO [51, 52] |
| Diabetess        | Presence of diabetes diagnosis by a health care provider among all adults (excluding diagnoses during pregnancy) | CDC [50] |
| Diabetes treatment |                             | Any pharmacological treatment among those with diabetes                        |         |
| Hypertension    | Presence of hypertension diagnosis by a health care provider among all adults (excluding a diagnosis during pregnancy) | CDC [53] |
| Health status   | Respondent’s self-rated health categorized as very poor to very good or excellent | OECD [56] |
| Tobacco use     | Cigarette smoking status   | Cigarette smoking status as current, former, or never smoker among adults      |         |
| Alcohol use      | Varied by country: defined as 3 or 4 or 5 alcoholic drinks for women and 4 or 5 alcoholic drinks for men in the past 30 days on one occasion | CDC [60] |
|                  | Any consumption of alcoholic beverages in the past 30 days | WHO [61] |
| Nutrition       | Number of days per week in the last week | WHO [65] |
| Physical activity | Total minutes of self-reported physical activity in the past week | IPAQ [63] |
| Height (measured) | Measured                  | WHO [62] |
| Weight (measured) | Measured                  | GPAQ [64] |
| Height (self-reported) | Reported by respondent | N/A                  |
| Weight (self-reported) | Reported by respondent | N/A                  |
| Body mass index (BMI based on self-reported or measured height and weight) | Reported by respondent or measured | N/A                  |
| Global physical activity | Total minutes of self-reported physical activity in the past week | N/A |
| Transportation physical activity | Total minutes of self-reported transportation-related physical activity in the past week | N/A |
| Leisure physical activity | Total minutes of self-reported leisure physical activity in the past week | N/A |
| Total walking | Total minutes of self-reported walking in the past week | N/A |
| Fruit consumption frequency | Number of days per week in the last week | WHO [65] |
| Vegetable consumption frequency | Number of days per week in the last week | IARC [66] |
| Soda consumption | Number of days per week in the last week | CDC [67] |
| Dessert foods consumption | Number of days per week in the last week | N/A |

a Data source used to inform harmonized definition

IPUMS-I Integrated Public Use Microdata Series, International, CDC Centers for Disease Control and Prevention, WHO World Health Organization, GTSS Global Tobacco Surveillance System, NCD RisC Non-Communicable Disease Risk Factor Collaboration, OECD Organisation for Economic Co-operation and Development, WHL World Health League, BRFSS Behavioral Risk Factor Surveillance System, IARC International Agency for Research on Cancer
| Domain                                   | Indicator                          | Definition                                                                                     | Level  | Data source(s)                        |
|-----------------------------------------|------------------------------------|-----------------------------------------------------------------------------------------------|--------|---------------------------------------|
| Economic                                | Poverty                            | Proportion of population living below the nationally defined income-based poverty level         | L1–L3  | Census or national household surveys  |
|                                        | Income-based Gini Index            | A measure of inequality in the distribution of income                                           | L1     | Census or national household surveys  |
| Employment                              | Unemployment                       | Proportion of persons 15 years or older in the labor force who are not working but seeking employment | L1–L3  | Census or national household surveys  |
|                                        | Labor force participation          | Proportion of persons 15 years or older who are working or seeking employment                   | L1–L3  | Census or national household surveys  |
| Social                                  | Education                           | 15–17 years old in school                                                                     | L1–L3  | Census                                |
|                                        | Adults with completed secondary     | Proportion of people 25 years and older with completed secondary education or higher           | L1–L3  | Census                                |
|                                        | education or more                  |                                                                                               |        |                                       |
|                                        | Education-based Gini Index          | A measure of inequality in the distribution of education                                       | L1     | Census                                |
| Gender empowerment                      | Female labor force participation    | Proportion women 15 years or older who are working or seeking employment                        | L1–L3  | Census or National household surveys  |
|                                        | Female government leadership        | Proportion of city leadership (e.g., city council members) who are female                      | L1     | National government sources          |
| Violence and disorder                   | Violent deaths                      | Age-standardized homicide rate per 100,000 population of homicides                            | L1–L2  | Mortality                             |
|                                        | Crime/safety                        | Proportion of individuals reporting being a victim of a crime in the past 12 months           | L1–L2  | Selected national surveys,            |
|                                        |                                    | Safety perception score                                                                       |        | CAF Survey [68]                       |
| Social cohesion and social capital      | Social disorder                     | Social disorder/incivilities scale                                                             | L1–L2  | CAF Survey                            |
|                                        | Election participation              | Proportion of eligible individuals voting in the last presidential election                    | L1–L2  | CAF Survey                            |
|                                        | Community organization membership  | Proportion of individuals who are part of a community or neighborhood organization.           | L1–L2  | CAF Survey                            |
|                                        | Neighborhood connectedness          | Neighborhood connectivity scale/social support scale                                           | L1–L2  | CAF Survey                            |
|                                        | Discrimination                      | Proportion of individuals reporting discrimination                                             | L1–L2  | CAF Survey                            |
| Housing                                 | Water connection                    | Proportion of households without piped water                                                  | L1–L3  | Census                                |
|                                        | Sewage connection                   | Proportion of households lacking a connection to the municipal sewer system or a septic tank | L1–L3  | Census                                |
|                                        | Overcrowding                        | Proportion of households with 3 people per room or more                                      | L1–L3  | Census                                |
|                                        | Housing materials                   | Proportion of households with non-durable wall materials                                       | L1–L3  | Census                                |
A Typology of Multilevel Urban Health Questions

The data structure created by SALURBAL can be flexibly used to answer a number of different types of research questions relevant to understanding the drivers of urban health in cities and the policies that may be most effective in improving population health and reducing health inequities. By capitalizing on heterogeneity across cities and within cities, we can identify important city-level and neighborhood-level drivers of variability in health and in health inequities thus obtaining clues on causes of population health and health inequities.

The types of questions that can be explored with the data platform we developed include, for example (1) questions about factors associated with between-city differences in health; (2) questions about factors associated with within-city (neighborhood) differences in health; (3) questions about the impact of city context on inequities in health; and (4) longitudinal questions about factors associated with changes over time at the city or neighborhood level. By exploring these questions, we will obtain evidence important to identifying what strategies can be used by cities to promote health and health equity. A simplified typology of selected questions is shown in Table 7. Many additional possibilities will be possible.

Challenges

Data Availability, Heterogeneity, and Quality Finding and obtaining the data necessary to answer important questions about environments and health in cities remains an important challenge. For example, mortality data at L2 have been generally easy to obtain, but health survey data have been more complicated to access, even for larger geographic areas, like L2 units. Social and physical environment data have to be compiled from multiple heterogeneous data sources with differences across countries in what information is available. Although many countries have rich health surveys, details on the wording of the questions and the skip patterns used can make harmonization difficult. Data quality also varies both within countries and between countries. The team has devised strategies to address quality issues whenever possible via evidence-based corrections (as described for the mortality data) or through sensitivity analyses.
| Domain                        | Definition                                                                 | Indicators                                                                 | Level | Data source                                                                 |
|-------------------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|-------|-----------------------------------------------------------------------------|
| Urban form and population metrics | Measure of the number of people living per unit of an area or within a geographic boundary | Total population, population density, Gini coefficient of the population distributions | L1–L2 | Census or population projections[^a]                                     |
| Population distribution       | Measure of concentration population within geographic boundary             | Gini coefficient of population distribution                               | L2–L3 | WorldPop[^b] [69]                                                           |
| Neighborhood centrality       | Measure of the distance to the city center                                 | Neighborhood centrality                                                   | L2–L3 | Local sources                                                               |
| Urban landscape metrics       | Measure of the urbanized area inside a geographic boundary                 | Total urban area, percentage of urban area, coefficient of variation of urban patch[^b] area, area-weighted mean urban patch area, mean urban patch area, effective mesh size | L1–L3 | Global Urban Footprint (GUF) Dataset derived by TerraSAR-X and TanDEM-X images [28, 29] |
| Area                          | Measure of compactness and complexity                                      | Area-weighted mean shape index                                            |       |                                                                             |
| Shape                         | Measure of fragmentation of urban expansion. It is the relative share of open space in the urban landscape | Number of patches, patch density, mean patch size, effective mesh size     |       |                                                                             |
| Fragmentation                 | Measure of the tendency for patches to be relatively clustered or isolated in space. It is the mean distance to the nearest urban patch within the geographic boundary | Area-weighted mean euclidean nearest neighbor distance                     |       |                                                                             |
| Isolation                     | Measure of fragmentation and shape complexity. It is the boundary between urban and non-urban patches | Edge density, area-weighted edge density                                   |       |                                                                             |
| Edge                          | Measure of the tendency of clumping of urban patches                       | Aggregation index                                                         |       |                                                                             |
| Street design and connectivity metrics | Measure of street network density Measure of the amount of intersections within the street network | Street density, large road density Intersection density, intersection density 3-way, intersection density 4-way, streets per node average, streets per node standard deviation | L1–L3 | OpenStreetMap and OSMNx [70]                                               |
| Street network length and structure | Measure of street network structure                                    | Street length average, circuity average                                   |       |                                                                             |
| Transportation metrics        | Bus-based transit system that includes dedicated lanes, traffic signal priority, off-board fare collection, elevated platforms, and enhanced stations | Presence of BRT, BRT length, BRT daily users, BRT price per ride, BRT supply length, BRT demand, BRT payment capacity | L1–L3 | BRTData, OpenStreetMap, minimum wage of Latin America and local sources |
| Subway, light rail, and/or elevated train (SLRET) transport systems | Mass rapid transit, including heavy rail, metro or subway | Presence of SLRET, SLRET length, SLRET daily users, SLRET price per ride, SLRET supply length, SLRET |       | OpenStreetMap and local sources                                             |
The informativeness of health data is maximized if the data can be georeferenced. Currently, most SALURBAL data are available at L1Admin and L2, though each country team is advancing efforts to geocode mortality, live births, and health data to at least L3. The challenges of georeferencing have included coming to agreement with appropriate government institutions, selecting a method for georeferencing and a high-quality source of geocoding while maintaining confidentiality, and obtaining the appropriate geodatabases of the geographic boundaries of the L3 or smaller units.

A goal of the SALURBAL project is to be able to measure changes in the physical and social environment over time and their effect on health outcomes. Some countries will have more data going further back in time than others. While some data may be available going back 20 or 30 years or more, the quality of older data may not be suitable for the project or may not be available at the city or smaller spatial resolution levels; thus, some longitudinal analyses may not include all countries or all cities. Accommodating differences in spatial definitions of L1Admins and other units over time will also present important challenges.

Table 6 (continued)

| Domain                     | Definition                                                                 | Indicators                                                                 | Level | Data source                                      |
|---------------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|-------|-------------------------------------------------|
| Aerial Tram transport system | Transport lift systems integrated into the city’s public transport network that provide mobility options for those living in hillside neighborhoods | Presence of aerial tram, aerial tram length                               |       | OpenStreetMap and local sources                 |
| Bicycle facilities        | Public infrastructure for exclusive or shared use of bicycles              | Total length of bike lanes, bike lane km per population, presence of Open Streets program and length of Open Streets programs |       | OpenStreetMap, CAF data, and local sources      |
| Urban travel delay index   | Measure of congestion                                                     | Measures the increase in travel times due to congestion in the street network | L2    | OpenStreetMap and Google Maps Distance Matrix API |
| Gasoline price            | Adjusted gasoline price                                                   | Price per gallon adjusted by minimum wage                                 | L1    | Local sources                                   |
| Air pollution and green space metrics | Measures of parks or green space availability                             | Parks area, parks density                                                  | L1–L3 | Local sources                                   |
| Parks and green space     | Annual mean value by existing monitoring station                          | Annual average in μg/m³                                                    | L1–L3 | Local sources                                   |
| PM10, NOx, SO4, O3        | Annual mean value from satellite measurements                             | Annual average in μg/m³                                                    | L1–L3 | Dalhousie University [71–73]                    |
| Urban travel delay index   | Measure of congestion                                                     | Measures the increase in travel times due to congestion in the street network | L2    | OpenStreetMap and Google Maps Distance Matrix API |
| Gasoline price            | Adjusted gasoline price                                                   | Price per gallon adjusted by minimum wage                                 | L1    | Local sources                                   |
| Air pollution and green space metrics | Measures of parks or green space availability                             | Parks area, parks density                                                  | L1–L3 | Local sources                                   |
| Parks and green space     | Annual mean value by existing monitoring station                          | Annual average in μg/m³                                                    | L1–L3 | Local sources                                   |
| PM10, NOx, SO4, O3        | Annual mean value from satellite measurements                             | Annual average in μg/m³                                                    | L1–L3 | Dalhousie University [71–73]                    |
| Food environment          | Large food stores with availability of processed foods, frozen foods and fresh produce | Number of supermarkets /area                                               | L1–L3 | Online searches of chain company websites       |
| Density of chain supermarkets | Large food stores with availability of processed foods, frozen foods and fresh produce | Number of supermarkets /area                                               | L1–L3 | Online searches of chain company websites       |
| Convenience stores        | Stores with long opening hours and high availability of ultra-processed foods | Number of convenience stores /area                                         | L1–L3 | Online searches of chain company websites       |

a Population for the urban extent (L1UrbExt) was estimated based on the ratio of built area in the urban extent to the total built area in each L2 unit. Estimated populations for each built-up L2 unit were then aggregated up to the L1UrbEx.
b Although we found that WorldPop’s downscaled data performed poorly in a few cases, we assumed that WorldPop’s relative concentration of population within a given unit would be representative of the actual population concentration. A measure of disagreement between WorldPop and Census data is included in our data to describe uncertainty in the Gini coefficient resulting from WorldPop population data.
c A patch is defined as a homogeneous region of a specific land cover type that differs from its surrounding.
d These air pollution measures are from air quality monitors maintained by local governments.

Spatial Resolution The informativeness of health data is maximized if the data can be georeferenced. Currently, most SALURBAL data are available at L1Admin and L2, though each country team is advancing efforts to geocode mortality, live births, and health data to at least L3. The challenges of georeferencing have included coming to agreement with appropriate government institutions, selecting a method for georeferencing and a high-quality source of geocoding while maintaining confidentiality, and obtaining the appropriate geodatabases of the geographic boundaries of the L3 or smaller units.

Longitudinal Data A goal of the SALURBAL project is to be able to measure changes in the physical and social environment over time and their effect on health outcomes. Some countries will have more data going further back in time than others. While some data may be available going back 20 or 30 years or more, the quality of older data may not be suitable for the project or may not be available at the city or smaller spatial resolution levels; thus, some longitudinal analyses may not include all countries or all cities. Accommodating differences in spatial definitions of L1Admins and other units over time will also present important challenges.
Conclusion

The creation of this unique data platform presents enormous opportunities for research, capacity building, and policy impact and positions SALURBAL as an example of an integrated comprehensive approach to characterizing and studying the drivers of urban health in low and middle-income countries. The flexible, multilevel data structure allows for heterogeneity in space and time at various scales and can accommodate data available with varying degrees of space and time resolution. Various geographic definitions of cities allow for flexibility in analyses depending on research questions and data availability. Additional health data spanning multiple types of health outcomes across multiple ages can be easily incorporated. The data resource will allow a number of analyses to identify factors related to health, health equity, and environmental sustainability of cities. In addition, it is a rich resource for capacity building in the region. The use and presentation of these data (with all its limitations) will necessarily spur improvements to the regional data systems. In addition, continuous updates to the data resources, including addition of other health outcomes across the life course and the incorporation of data on the timing and characteristics of various policies implemented, will provide

Table 7 A typology of selected urban health questions that can be investigated with the SALURBAL data platform

| Question | Analytical approach and unit of analysis | Example |
|----------|----------------------------------------|---------|
| Between-city differences | Multilevel analysis of city-level outcomes nested within countries (including variables at L1 and at the country level) | Does life expectancy vary across cities? Are these differences associated with city size and recent growth? |
| How much do summary health indicators vary across cities (within and between countries) and what factors are associated with this variability? | Multilevel analysis of individual-level survey outcomes nested within cities and countries (including variables at the individual level, at L1, and at the country level) | Does the probability of having diabetes vary across cities? How do individual-level factors, city, and country characteristics contribute to these differences? |
| How much does individual-level health vary across cities and what factors are related to this variability? |  |  |
| Within-city differences | Small area estimation methods for mortality or survey estimates and their association with neighborhood (L3) characteristics | How much does life expectancy vary within a city? Is this related to area-level poverty? |
| Description of small area variations in summary health within large cities and factors associated with this variability | Multilevel analysis of individual-level survey outcomes nested within neighborhoods (L3) and cities (L2 or L1), including variables at the individual-level, and at L3, L2, and L1 as appropriate | How do neighborhood features of the built environment associate with differences in physical activity levels? Do city-level factors (such as street connectivity) modify these associations? |
| How much does individual-level health vary across neighborhoods within cities and what factors are related to this variability? | Multilevel analysis of city-level outcomes stratified by education nested within countries (including variables at L1 and at the country level) or multilevel models for aggregate data | Do mortality differences by education vary across cities? What city-level factors are associated with greater or smaller inequities? |
| Impact of city context on inequities | Multilevel analysis of survey respondents nested within cities, including variables at the individual level, city level, and country level | Do educational differences in diabetes prevalence vary across cities? Are city-level factors associated with smaller or larger inequities? |
| Changes over time | Longitudinal analyses of summary city-level health outcomes and their association with time invariant and time-varying city and country characteristics | How has life expectancy changed over time in cities? Are city growth and air pollution levels related to these trends? |
| What longitudinal trends in summary health indicators are observed and to what extent do city or country characteristics modify these trends? | Longitudinal analyses of individual-level survey responses nested within neighborhoods and cities and their relation to L1, L2, or L3 time-varying characteristics | Do changes in a city’s urban landscape and in neighborhood crime levels affect changes in BMI? |
| Are changes over time in city or neighborhood characteristics related to changes in individual-level health outcomes? |  |  |
opportunities for continuous policy impact evaluation into the future.

Acknowledgements

The SALURBAL Group includes: Marcio Alazraqui, Hugo Spinelli, Carlos Guevel, Vanessa Di Cecco, Adela Tisné, Carlos Leveau, Adrián Santoro, and Damián Herkovits: National University of Lanus, Buenos Aires, Argentina; Nelson Gouveia: Universidade de São Paulo, São Paulo, Brazil; Mauricio Barreto and Gervásio Santos: Oswaldo Cruz Foundation, Salvador Bahia, Brazil; Leticia Cardoso, Mariana Cardoso de Menezes, and Maria de Fatima de Pina: Oswaldo Cruz Foundation, Rio de Janeiro, Brazil; Walskea Teixeira Caiaffa, Amélia Auguste de Lima Friché, and Amanda Cristina de Souza Andrade: Universidade Federal de Minas Gerais, Belo Horizonte, Brazil; Patricia Frenz, Tania Alfaro, Cynthia Córdova, Pablo Ruiz, and Mauricio Fuentes: School of Public Health, University of Chile, Santiago, Chile; Almendra Vives Vergara, Alejandro Salazar, Andrea Cortinez-O’Ryan, Cristián Schmitt, Francisca Gonzalez, Fernando Baeza, and Flavia Angelini: Department of Public Health, Pontificia Universidad Católica de Chile, Santiago, Chile; Olga Lucia Sarmiento Dueñas, Diana Higuera, and Catarina González: School of Medicine, Universidad de los Andes, Bogotá, Colombia; Felipe Montes, Andres F. Usecbe, Oscar Guaje, Ana Maria Jaramillo, and Luis Angel Guzman: School of Engineering, Universidad de los Andes, Bogotá, Colombia; Philipp Hessel and Diego Lucumi: School of Government, Universidad de los Andes, Bogotá, Colombia; Jose David Meisel: Universidad de Ibagué, Ibagué, Colombia; Eliana Martinez: Universidad de Antioquia, Medellín, Colombia; Maria F. Kroker-Lobos, Manuel Ramirez-Zea, and Kevin Martinez Folger: INCAP Research Center for the Prevention of Chronic Diseases (CIIEPC), Institute of Nutrition of Central America and Panama (INCAP). Guatemala City, Guatemala; Tonatiuh Barrientos-Gutierrez, Carolina Perez-Ferrer, Javier Prado-Galbarro, Filipa de Castro, and Rosalba Rojas-Martinez: Instituto Nacional de Salud Pública, Mexico City, Mexico; J. Jaime Miranda, Akram Hernández Vásquez, and Francisco Díez-Canseco: School of Medicine, Universidad Peruana Cayetano Heredia, Lima, Peru; Ross Hammond: Brookings Institute, Washington, D.C., USA; Daniel Rodriguez and Iryna Dronova: Department of City and Regional Planning, the University of California Berkeley, USA; Brisa N. Sanchez: University of Michigan School of Public Health, Ann Arbor, Michigan, USA; Peter Hovmand: Washington University in St. Louis, St. Louis, Missouri, USA; Ricardo Jordán Fuchs and Juliet Braslow: Economic Commission for Latin America and the Caribbean (ECLAC); Jose Siri: United Nations University International Institute for Global Health (UNU-IIGH); Ana Diez Roux, Amy Auchincloss, Brent Langellier, Gina Lovasi, Leslie McClure, Yvonne Michael, Harrison Quick, D. Alex Quistberg, Jose Tapia Granados, Kari Moore, Felipe Garcia-España, Usama Bilal, and Ivana Stankov: Dornsife School of Public Health, Drexel University, Philadelphia, Pennsylvania, USA; Salud Urbana en América Latina (SALURBAL), Urban Health in Latin America, is a 5-year project that studies how urban environments and urban policies impact the health of city residents throughout Latin America. SALURBAL's findings inform policies and interventions to create healthier, more equitable, and more sustainable cities worldwide. SALURBAL is funded by the Wellcome Trust [205177/Z/16/Z]. More information about the project can be found at www.lacurbanhealth.org.

Research Support

This project was supported by the Wellcome Trust initiative, “Our Planet, Our Health” (Grant 205177/Z/16/Z).

Appendix

Table 8 Name, definition, and size of SALURBAL level 3 units by country

| Country         | Level 3 (Urban)          | L3 (Rural)          | Level 3 definition                                                                 | Approximate median number of households |
|-----------------|--------------------------|---------------------|------------------------------------------------------------------------------------|----------------------------------------|
| Argentina       | Radio Censal             |                     | Geographically delimited units used for census data collection.                    | ~300                                   |
| Brazil          | Setor Censitário         |                     | Continuous area in a single urban/rural municipality equal to the workload of a census worker | ~250                                   |
| Chile           | Zona Censal              | Not defined         | Set of blocks dividing distritos censales in urban areas                            | ~700                                   |
| Colombia        | Sector Urbano            | Not defined         | Neighborhoods made up of 1 to 9 secciones urbanas                                    | ~350                                   |
| Costa Rica      | UGEF (Unidad Geostadistica Basica) |                 | Polygon created to help with census data collection. Can be a block or other area with natural boundaries | ~600                                   |
| El Salvador     | Sector Censal            |                     | Group of segmentos censales                                                        | ~300                                   |
| Guatemala       | Sector Censal            |                     | Workload of a single census worker                                                  | ~200                                   |
| Mexico          | AGEB                     |                     | Group of blocks (manzanas)                                                          | ~1000                                  |
| Nicaragua       | Sector Censal            |                     | Group of segmentos censales                                                         | ~250                                   |
Table 8 (continued)

| Country   | Urban level | Rural level | L3 definition | Median number of households |
|-----------|-------------|-------------|---------------|----------------------------|
| Panama    | Barrio      | Not defined | Sub-divisions of urban localities | ~360                       |
| Peru      | Zona Censal | Not defined | Group of adjacent blocks with physical or cultural boundaries | ~1500                      |

* Urban and rural as defined by country. In Argentina, Brazil, Costa Rica (pending confirmation), El Salvador, Guatemala, and Nicaragua (pending confirmation), the administrative units selected as L3 units cover the whole country. In Mexico, the administrative units selected as L3 units are defined to cover the whole country, but geographic files for rural areas were not available for calendar times of interest. In Chile, Colombia, Panama, and Peru, the administrative units selected as L3 units only exist in country-defined urban areas. When administrative L3 units were not defined for the whole country SALURBAL created a special SALURBAL defined L3 (a SALURBAL proxy L3). This was defined as the L2 unit minus any area covered by administrative L3 units (in the case of Mexico, Panama, and Peru). In other cases (Chile and Colombia), a smaller intermediate unit between L2 and L3 (referred to as level 2.5) was available across the country including non-urban areas. In these cases, a proxy level 3 was created by using the level 2.5 in its entirety or (in cases where the level 2.5 included areas with L3s defined) by defining the L3 proxy as the L2.5 units minus any area covered by the L3s. (Note that in Colombia, a “sector rural” is available in non-urban areas but it sometimes includes sectores urbanos, which is why the approach of treating the sector rural as a L2.5 and subtracting L3s when appropriate to create an L3 proxy had to be used.)

Table 9 Definition of L1Metros and component subunits for each country. Component unit (L2 unit when possible or other) is italicized in each definition. Definitions and number of units are based on census data closest to 2010

| Country   | Metropolitan area local name or equivalent | Local definition |
|-----------|---------------------------------------------|------------------|
| Argentina | Aglomerado (also known as Localidad Compuesta) | Agglomerations comprise one or more localities (localidad)—territorial divisions whose boundaries are defined by geographic characteristics or modifications of the land (i.e., buildings and streets). While agglomerations generally comprise adjacent localities, in a few cases, agglomerations include localities that are not contiguous geographically. These units are used as the sampling frame in national household surveys. |
| Brazil    | Região Metropolitanas | Municipalities (municípios) grouped together for purposes of planning and executing public actions as determined by each state. |
|           | Região Integrada de Desenvolvimento Econômico (RIDE) | RIDE—Municípios that have economic ties that transcend state boundaries approved by federal legislation. |
| Chile     | Area Metropolitana | Two or more comunas (administrative divisions of Chile similar to counties or municipalities) characterized by contiguous urban built-up areas with over 500,000 inhabitants. |
| Colombia  | Area Metropolitana | Two or more municipalities (municipios) with strong social or economic ties. The AMs have some political and administrative jurisdiction. |
| Costa Rica| Gran Area Metropolitana (GAM) | Legally created to manage urban development around San Jose. Composed of cantons (cantones). Some cantones in the GAM only include specific districts (distritos) within them. |
| El Salvador| Area Metropolitana | Legally created area post-1986 earthquake to better coordinate development across municipalities (municipios) of San Salvador. |
| Guatemala | Area Metropolitana | Urban agglomeration around Guatemala City that absorbs nearby populations defined by municipalities (municipios). |
| Mexico    | Zona Metropolitana (ZM) | Two or more municipalities (municipios) with strong social or economic ties with a combined population of > 50,000 people, or those within the limits of one municipality with a population of > 1 million people, or those in conurbation with a US city, with a population of > 250,000 people. |
| Nicaragua | Region Metropolitana | Area of 30 municipalities (municipios) that are part of Managua. |
| Panama    | Area Metropolitana | Created after the construction of the Panama Canal. It integrates the two main cities of the country (Panama and Colon). Composed of corregimientos. |
Table 10 Missing data and ill-defined deaths for mortality data in SALURBAL cities in 10 countries. Data corresponds to the latest available year for every country

| Country     | Latest year | Proportion of missing values | Ill-defined deaths |
|-------------|-------------|-----------------------------|-------------------|
|             |             | Age | Sex | Location | Cause of death |
| Argentina   | 2015        | 0.5% | 0.0% | 0.0%     | 0.0%  | 5.7% |
| Brazil      | 2016        | 0.1% | 0.0% | 0.3%     | 0.0%  | 5.2% |
| Chile       | 2016        | 0.0% | 0.0% | 0.0%     | 0.0%  | 2.5% |
| Colombia    | 2015        | 0.0% | 0.0% | 0.3%     | 0.0%  | 2.0% |
| Costa Rica  | 2016        | 0.1% | 0.0% | 0.0%     | 0.0%  | 3.6% |
| El Salvador | 2014        | 0.1% | 0.0% | 0.0%     | 0.1%  | 19.4% |
| Guatemala   | 2016        | 0.7% | 0.0% | 0.0%     | 0.1%  | 8.4% |
| Mexico      | 2016        | 0.6% | 0.1% | 0.3%     | 0.1%  | 1.5% |
| Panama      | 2016        | 0.2% | 0.0% | 0.0%     | 0.1%  | 3.5% |
| Peru        | 2015        | 0.0% | 0.0% | 0.1%     | 0.0%  | 0.7% |

Nicaragua mortality data is not currently available at the necessary geographic level to the SALURBAL study currently.

Table 11 Undercounting estimates and specificity of correction approaches for mortality data by country

| Country     | Year | National % Undercounting | Correction                          | Source                                |
|-------------|------|--------------------------|-------------------------------------|---------------------------------------|
| Argentina   | 2013 | 1.3%                     | Blanket correction                  | UNDP                                  |
| Brazil      | 2013 | 0%                       | L2 and sex-specific correction      | Campos de Lima and Queiroz           |
| Chile       | 2013 | 0%                       | Blanket correction                  | UNDP                                  |
| Colombia    | 2012 | 23.8%                    | Department, age, and sex-specific correction | DANE                                  |
| Costa Rica  | 2013 | 12.8%                    | Blanket correction                  | UNDP                                  |
| El Salvador | 2012 | 16.4%                    | Blanket correction                  | UNDP                                  |
| Guatemala   | 2013 | 8%                       | Blanket correction                  | UNDP                                  |
| Mexico      | 2013 | −0.8%                    | Blanket correction                  | UNDP                                  |
| Panama      | 2013 | 6.8%                     | Blanket correction                  | UNDP                                  |
| Peru        | 2013 | 38.3%                    | Department, age, and sex-specific correction | MINSA                                |

Note: Nicaragua mortality data at the necessary geographic level are not currently available to the SALURBAL study.

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a These two types of entities for Brazil encompass different sets of non-overlapping cities.
b This includes legally organized metropolitan areas with political administrative structure (N = 6) and officially recognized metropolitan areas without legally organized political administrative structures (N = 9, referred to as both “areas metropolitanas” and “aglomeraciones urbanas.” Population, economic, and other statistics are calculated for both types of areas by government organizations [27].

c Departamento Administrativo Nacional de Estadística, Colombia.
d Ministry of Health of Peru [http://bvs.minsa.gob.pe/local/minsa/2722.pdf](http://bvs.minsa.gob.pe/local/minsa/2722.pdf)

Note: Nicaragua mortality data at the necessary geographic level are not currently available to the SALURBAL study.
Table 12 Population projections data sources and characteristics for use as denominators with mortality data.

| Country | Projections years | SALURBAL level | Projections by age available | Projections age maximum | Projections by sex available | Projections by age and sex available | Projections source | Note |
|---------|-------------------|----------------|-----------------------------|-------------------------|-----------------------------|-------------------------------------|-------------------|------|
| Argentina | 2010–2015 | L2 | Yes | 80 | Yes | Yes | Local team<sup>a</sup> |
| Brazil | 2000–2015 | L2 | Yes | 80 | Yes | Yes | Local team<sup>a</sup> |
| Chile | 2002–2017 | L2 | Yes | 80 | Yes | Yes | INE<sup>b</sup> |
| Colombia | 1985-2017 | L2 | Yes | 80 | Yes | Yes | DANE<sup>c</sup> |
| Costa Rica | 2010–2017 | L2 | Yes | 75 | Yes | Yes | INEC<sup>d</sup> |
| Guatemala | 2013-2017 | L2 | Yes | 65 | Sex | Yes | MSPAS<sup>e</sup> |
| 2008–2020 | L2 | No | N/A | No | No | OJ<sup>f</sup> |
| El Salvador | 2005–2017 | L2 | No | N/A | Yes | No | DIGESTYC<sup>g</sup> |
| 2015–2017 | L2 | Yes | 80 | Yes | Yes | Local team<sup>a</sup> |
| Mexico | 2005, 2010, 2015 | L2 | Yes | 100 | Yes | Yes | Census<sup>h</sup> |
| Panama | 2010–2017 | L2 | Yes | 80 | Yes | No | INEC<sup>i</sup> |
| Peru | 2005-2017 | L2 | Yes | 80 | Yes | No | INEI<sup>j</sup> |
| 2005-2017 | Province | Yes | 80 | Yes | Yes | INEI<sup>k</sup> |

Nicaragua population projection data are not currently available at the geographic level needed by SALURBAL.

<sup>a</sup>Records obtained from the local team are not publicly available.

<sup>b</sup>Instituto Nacional de Estadística, República de Chile. http://ine.cl/estadisticas/demograficas-y-vitales

<sup>c</sup>Departamento Administrativo Nacional de Estadística, República de Colombia. http://www.dane.gov.co/index.php/estadisticas-por-tema/demografia-y-poblacion/proyecciones-de-poblacion

<sup>d</sup>Instituto Nacional de Estadística y Censos, República de Costa Rica. http://www.inec.go.cr/proyeccionpoblacion/frmproyec.aspx

<sup>e</sup>Departamento de Epidemiología, Ministerio de Salud Pública, República de Guatemala. http://epidemiologia.mspas.gob.gt/index.php/dos/estadisticas-vitales/poblacion-y-proyeccion

<sup>f</sup>Organismo Judicial, República de Guatemala. http://www.oj.gob.gt/estadisticas/reportes/poblacion-total-por-municipio(1).pdf

<sup>g</sup>Dirección General de Estadística y Censos, República de El Salvador. http://www.digestyec.gob.sv/index.php/temas/des/ehpm/publicaciones-ehpm.html?download=517%3Aestimaciones-y-proyecciones-de-poblacion-municipal-2005-2025

<sup>h</sup>Instituto Nacional de Estadística y Geografía, Estados Unidos Mexicanos. http://www.beta.inegi.org.mx/default.html

<sup>i</sup>Contraloría General, República de Panamá. https://www.contraloria.gob.pa/inec/Publicaciones/Publicaciones.aspx?ID_SUBCATEGORIA=10&ID_PUBLICACION=556&ID_IDIOMA=1&ID_CATEGORIA=3

<sup>j</sup>Instituto Nacional de Estadística e Informática, República de Perú. http://proyectos.inei.gob.pe/web/biblioinformpub/bancopub/Est/Lib0842/index.htm

<sup>k</sup>Instituto Nacional de Estadística e Informática, República de Perú. http://proyectos.inei.gob.pe/web/biblioinformpub/bancopub/Est/Lib1010/index.htm
| Country, survey | Sample characteristics | SALURBAL L1Admins with survey participants | Sampling strategy | Geographic coverage | Oversampling | Representation |
|----------------|------------------------|--------------------------------------------|-------------------|---------------------|--------------|----------------|
| Country: Argentina  | Age: > 18 years | L1Admin: 33 Sample size: 511 (417–693) | Multistage [aglomerado censo; área (groups of radio censales); household; person 18 years or older] Stratified [population size; education level of head of household] | Localidades with over 5000 population | None | National, four localidad groups based on size, 6 regions, 23 provinces, Ciudad Autonoma de Buenos Aires, and 8 metropolitan areas > 500,000 population |
| Survey: Encuesta Nacional de Factores de Riesgo, ENFR (National Risk Factors Survey) | Age: > 18 years N (2013): 32,365 Years: 2005, 2009, 2013 | | | | | |
| | Sample size: 511 (417–693) | | | | | |
| Country: Brazil  | Age: All ages | L1Admin: 27 Sample size: 927 (834–1179) | Multistage [census tracts or groups of census tracts; households; person 18 years or older] Stratified [capital city, metropolitan region, or integrated economic development region, then rest of municipalities; urban/rural; total household income] | Regions (5), states or federation units (27), state capitals (27) | None | Regions (5), states or federation units (27), state capitals (27), urban and rural, metropolitan areas, and development integrated areas |
| Survey: Pesquisa Nacional de Saúde, PNS (National Health Survey) | Age: All ages N (2013): 62,986 Years: 2013 | | | | | |
| | Sample size: 927 (834–1179) | | | | | |
| Country: Chile  | Age: ≥15 years | L1Admin: 19 Sample size: 85 (34–175) | Multistage [comunas; segments within comunas; household; person 15 years or older] Stratified [urban/rural with three groups of population sizes] | National | Adults ≥65, regions distinct to metropolitan region, rural areas | National, Regions (15), urban/rural |
| Survey: Encuesta Nacional de Salud, ENS (National Health Survey) | Age: ≥15 years N (2010): 5434 Years: 2003, 2010 | | | | | |
| | Sample size: 85 (34–175) | | | | | |
| Country: Colombia  | Age: 0–69 years | L1Admin: 33 Sample size: 271 (133–420) | Multistage [municipalities or combination of municipalities if small; manzanas; household; person adults 18–69 and all children 17 and under] Stratified [region; urbanization of municipal seats; urban/rural municipal population; unsatisfied basic needs] | National | None | Region, department, subregion, urban area of municipal capitals, urban/rural, by poverty level |
| Survey: Encuesta Nacional de Salud, ENS (National Health Survey) | Age: 0–69 years N: 166,474 (41,543 adults 18–29 years) Years: 2007 | | | | | |
| | Sample size: 271 (133–420) | | | | | |
| Country: Costa Rica  | Age: ≥20 years | L1Admin: 1 Sample size: 1427 | Multistage [census segments; groups of households] | Metropolitan San Jose | Age ≥65 | Metropolitan San Jose |
| | Age: ≥20 years N: 1427 | | | | | |
| Country, survey | Sample characteristics | SALURBAL L1Admins with survey participants | Sampling strategy | Geographic coverage | Oversampling | Representation |
|----------------|------------------------|--------------------------------------------|-------------------|---------------------|--------------|----------------|
| Survey: Encuesta Multinacional de Diabetes mellitus y Factores de Riesgo, CAMDI (Multinational Survey of Diabetes Mellitus & Risk Factors, Central American Diabetes Initiative) | Year: 2005 | Median (25th—75th percentile) Sample size per L1 Admin | (compactos); persons within three age groups (1 selected from 20 to 39 years, 1 selected from 40 to 64 years, all selected from ≥65 years) | | | |
| Country: El Salvador Survey: CAMDI (see Costa Rica) | Age: ≥20 years N: 1872 | L1 Admin: 1 Sample size: 1872 | Multistage [segmento censal, groups of dwellings (compacto); all household members 20 years and older] | Municipio of Santa Tecla | | Municipio of Santa Tecla |
| Country: Guatemala Survey: CAMDI (see Costa Rica) | Age: ≥20 years N: 1397 | L1 Admin: 1 Sample size: 1397 | Multistage [segmento censal, groups of dwellings (compacto); all household members 20 years and older] | Villa Nueva Municipio, a part of metropolitan Guatemala City | None | Villa Nueva Municipio |
| Country: Nicaragua Survey: CAMDI (see Costa Rica) | Age: ≥20 years N: 1993 | L1 Admin: 1 Sample size: 1993 | Multistage [urban districts divided into 50 strata, groups of households (compacto); all family members living together 20 years and older] | Municipality of Managua | None | Municipality of Managua |
| Country: Mexico Survey: Encuesta Nacional de Salud y Nutricion, ENSANUT (National Survey for Health and Nutrition) | Age: all ages N: 96,031 (2012), 29,795 (2016) | 2012 L1 Admin: 91 Sample size: 190 (89–388) 2016 L1 Admin: 59 Sample size: 39 (25–67) | Multistage [AGEB; manzana (urban) or pseudo-manzanas within localidades (rural); households; 1 person within each of the groups (0–4 years, 5–9 years, 10–19 years, 20 years and older, recent medical service user)] Stratified [socioeconomic status of AGEB at the state level] | National | AGEB with the highest index of poor socioeconomic conditions | National, state, metropolitan areas, urban/rural, high/low SES |
| Country, survey | Sample characteristics | SALURBAL L1Admins with survey participants | Sampling strategy | Geographic coverage | Oversampling | Representation |
|----------------|------------------------|--------------------------------------------|-------------------|--------------------|--------------|----------------|
| Country: Panama Survey: Encuesta Nacional de Salud y Calidad de Vida ENSCAVI (National Survey of Health and Quality of Life) | Age: ≥ 18 years N: 25,748 Years: 2007 L1Admin: 3 Sample size: 1773 (1738-7883) | National | None | National, district |
| Country: Peru Years: Survey: Encuesta Nacional de Demografía y Salud, ENDES (National Survey of Demographics and Health) | Age: All ages N: 122,368 Years: 2008–2016 L1Admin: 23 Sample Size: 356 (164–629) | Multistage [conglomerado (set of census blocks –urban) or empadronamiento (set of households–rural); households; one person within each of the groups (> 15 years, females 15–49 years, children < 5 years, children < 12 years)] Stratified [department; urban/rural] | National | None | National, urban national, rural national, natural region: Lima metropolitan area, coast/mountain/jungle |

*a Documentation for El Salvador’s survey design is based on the design of other countries in the CAMDI project

*b In Mexico, the households with the greatest deficiencies were identified through the construction of a defined social lag (rezago) index for the AGEBs; the index that was built is similar to the social lag (rezago) index built by the National Evaluation Council of the Social Development Policy for localities in 2005. [https://www.coneval.org.mx/rw/resource/coneval/med_pobreza/1024.pdf](https://www.coneval.org.mx/rw/resource/coneval/med_pobreza/1024.pdf)
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