Concept and Methods in Urban Public Health

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1. Preliminary Remarks: Urban Public Health as a Research Subject

The description of (urban) public health is normative, and although public health in its literal meaning as health of the population appears to be a stable construct, it is a moving target shaped by a range of influences, systems, and ideas (Mold et al. 2019). Yet, four key elements can be emphasized:

1. According to the UN Declaration of Human Rights (UN General Assembly 1948) and the WHO Jakarta Declaration on Health Promotion (WHO 1997), health is one of the fundamental human rights and essential for the social, economic and sustainable development of societies.
2. Health is different from the mere absence of ill-health (Moebus/Bödeker 2000).
3. Public health is concerned with the health status of the population.
4. Public health includes the practice of interventions aimed at populations to lower the risk of disease and mortality by reducing the burden of health as well as strengthening health resources through nonmedical interventions (Mold et al. 2019, Rosenbrock 2001).

Health itself unfolds in places and settings of daily lives. It is almost a truism to say that the urban environment has a strong leverage on health and on the distribution of health promoting resources – already known and written down in the *corpus hippocraticum* around the 5th century BC (Capelle 1991). However, population health in the urban context is still far from being mainstreamed. For this reason, urban public health was initiated to fill this gap by expanding the field of public health through spatial approaches from disciplines like spatial planning, geography, biology/ecology, engineering, logistics, social and political science.

In view of global urbanization trends and climate change, the question how to shape and design urban environments therefore must be closely related to the promotion and maintenance of the health of their inhabitants – each with respect to different population groups. This requires a much better and evidence-based understanding of how cities both create and undermine health chances. Understanding cities as complex systems, characterized by an entire ecology of innumerable interlinked structures, functions, networks, concepts and (non)knowledge, it becomes immediately clear that evidence-based knowledge can only be achieved through broad interdisciplinary joint efforts – of both research and practice. This is one of the reasons why the toolbox of scientific methods used by urban public health is typically characterized by its recourse to a multitude of methods from different disciplines.

Nonetheless, prevailing methods in public health are based on epidemiological concepts which focus on the population and use a quantitative approach (Beaglehole/Bonita 2004). For urban public health, the empirical methods of epidemiology are still a major approach. However, issues of problem-solving or evidence-based implementation are not necessarily addressed using the quantitative approaches of epidemiology. An important consequence is the need for quantitative methodological approaches, which makes urban public health an almost bewildering research field with a multitude of methods available. The inter- and transdisciplinary approach of urban public health cannot (so far) rely on methods specifically tailored to or developed for this particular research field. However, the complexity of urban public health research questions deserves a wealth of methodological approaches and accordingly a wealth of analytical methods – and skills. For this reason, research in urban public health relies on a broad interdisciplinary spectrum of methods derived mainly from planning, epidemiology, biometry, geography, urban, social, and political sciences including both qualitative and quantitative methods.

2. Theoretical Framework

To that end – and because urban public health is just an emerging branch of public health – this chapter addresses conceptual approaches rather than describing one specific urban public health method in detail. Accordingly, the aim here is to give initial insights into methods and instruments of urban public health with a focus on basic concepts and applications of urban public health. Still, a brief outline of main epidemiological concepts are given to illustrate the important opportunities for urban public health research.

2.1 The Plurality of Health

Human health is commonly thought of as the absence of disease. Consequently, with regard to health research, the focus is mainly on the study of disease origins and causes, often called pathogenic approach. However, the reverse conclusion from knowledge of diseases to knowledge of health and health causes works quite rarely. Health is not merely the opposite of disease, and impossible to determine with certainty: it is difficult to describe; it is perceived differently, and yet it is intuitively familiar. Health usually only comes to people's mind in case of ill-health – the SARS-CoV-2 pandemic has blatantly brought this phenomenon to the world's attention. In this sense, there is a "hiddenness" of health (Gadamer 1994) that does not stop short of science. A central health model trying to address the pitfalls of the pathogenic approach is the salutogenic concept, which explores health in terms of a "health and disease continuum" (Antonovsky 1987). Importantly, due to the constant interaction of humans with their physical, social and psychological environments, health is not dichotomous. Rather it is a dynamic process affecting the closely related individual, social and ecological levels. What is decisive in all these approaches is that the individual is not regarded as a sum of arbitrarily and individually modifiable characteristics, habits and vices, as is the case in the predominantly behaviourist oriented "lifestyle" prevention approach (Rosenbrock 2001). Rather, in addition to its intrinsic value, health is a means of personal and community development.

Moreover, many diseases are known, but only one health, just as the knowledge of a great number of risk factors, but only a few indicators of health. As a result, the opportunities for individuals to actively maintain their own health are very limited – in contrast to what is still widely believed. Even more, the same groups and social classes of the population that are most at risk of disease, disability, or premature death are also the least able to control their lives and self-help economically, socially, and culturally (Rosenbrock 2001). In this sense, the old paternalistic focus on individual prevention, care and health education needs to be replaced – wherever possible – by strategies of target group mobilisation, and a more specific approach that is more concerned with the everyday life and conditions of the target groups. Overall, the study of the risks to and the promotion of health are therefore complex processes relevant at all levels of society and in a broad range of contexts (Barton/Grant 2006).

2.2 Health and Urban Environments

The urban environment, through its physical design and functionality, daily affects the health and well-being of the population – be it a strong or weak effect, a health-promoting or a harmful health effect. Cities, or in a more general sense, urban environments, are not self-contained, homogenous entities, but complex systems characterized by a number of different urban fields and structures (e.g., education, economy, mobility, politics, buildings) interacting with each other in a complex urban grid. Improving health and preventing disease in urban environments requires evidence based knowledge taking into account this urban grid. The complexity of interactions between urban environments and human health is already conceptualised in several models and frameworks from different disciplines. The most widely recognized are probably the

- joint urban planning and public health framework (Northridge et al. 2003),
- framework for urban health (Galea et al. 2005),
- health map for human settlements (Barton/Grant 2006),
- urban health niche model of multi-level risk clustering and risk pathways (Sarkar/Webster 2017),
- framework to study built environment and health (Gullón/Lovasi 2018),
- model of resources and pressures of urban health including urban governance (WBGU 2016).

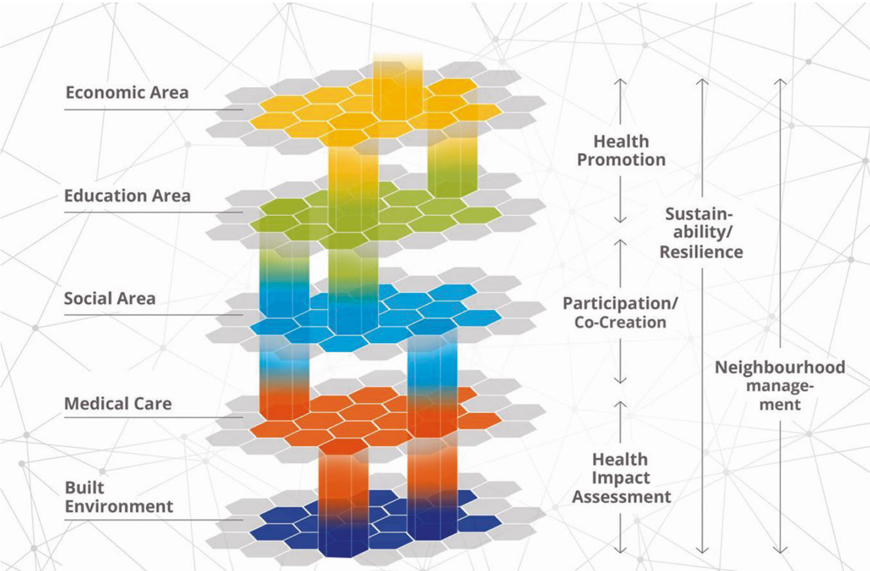
As cities form an entire ecology of infrastructures, institutions, services, and built structures, each of these, and in combination, affects health. It is for this reason that social, economic, cultural and (urban) spatial living conditions have a strong influence on health. Even more, it is internationally undisputed that these structural effects are even stronger than the effects of any kind of lifestyle (Holifield et al. 2018). People who face poverty, unemployment, environmental pollution, poor housing conditions, crime and/or lack of social networks thus experience great difficulty in successfully implementing behaviourally targeted prevention interventions (Vlahov et al. 2007). The challenge for communities is therefore to create and maintain such living conditions that enable health chances for all. For a successful implementation of urban health promotion and urban prevention measures, such an understanding of health is a basic prerequisite.

2.3. "A Place for Place in Public Health": Urban Public Health

As Frumkin pointed out, there is a need for "[a] place for place in public health." (2003, 1452) Thus urban public health is a conceptual and methodological complement to the research and practice field public health relying on the basic approaches and models of public health. One of the most well-known definitions describes public health as the science and practice of preventing disease, prolonging life, and promoting health through the organized efforts of society (Acheson, 1988), which means that public health addresses the entire population or population groups exclusively. However, what is often most difficult to understand about public health is that it is often confused with the objective of clinical medicine, which addresses the health problems of individuals only (Beaglehole/Bonita 2004).

Despite the old-as-the-hills knowledge that urban environments affect urban populations, not all public health is urban public health. For instance, urban public health explicitly addresses a spatial perspective. Two of the fundamental issues of urban public health in designing cities or urban environments as a health resource for all, are to consider (i) the concurrent variability and malleability of urban life's impact on health and the longevity of the built environment; and (ii) the complexity of urban systems. Generally speaking, urban public health complements the public health approach by acknowledging the primacy of sustainability, emphasizing environmental health inequalities and explicitly integrating a spatial dimension – all in the context of the specific characteristics of urban systems. The corollary of the above is mutuality of the relationship between multiple populations in urban areas and the urban environment itself. Indeed, the urban features can affect the health of the urban population, but of course it is the urban population that shapes its environment. In fact, this has crucial implications for the way we analyze the multidimensional and multilevel relationship between cities and their role in population health, taking into account the often neglected close link to governance as well as political and social action and vice versa. Fig. 1 attempts to illustrate these links by referring to the overlay analysis widely used in geographic information systems (see section 3.3). The manifold structural and functional layers or areas of a city, such as built, environmental, economic, transport, social, cultural, educational domains or also healthcare, are stacked and analysed as layers of the same region.

Fig. 1: Layers of public health in urban regions.
The figure illustrates on the one hand the interrelationships between functional and structural layers of a city, and on the other hand indicates the manifold thematic topics within a level by means of the tile. The slender connecting lines in the background are intended to indicate the (future) digital connectivity between all layers and functions.



Urban public health is particularly responsive to the specifically urban characteristics of (1) density and diversity, (2) social and human resources; (3) built structures; (4) large health disparities within the city due to environmental and socio-spatial inequalities; and (5) contextual complexity, as systems of the physical, social, economic, and political environment interact with each other. That is why urban public health closely links to resilience, sustainability, and governance, influenced by political and social action and vice versa. In this respect, urban public health needs to bring together many disciplines, ways of thinking, and methods. However, the interaction between structural urban intervention measures and health has hardly been considered so far. Viewing urban health through a structural lens places more emphasis on health conditions than on individual health behaviours, also avoiding the perils of *blaming the victim*.

As public health is an inter- and transdisciplinary field of research and action, this is inherently true for urban public health. The inter- and transdisciplinary approach of urban public health cannot (so far) rely on methods specifically tailored to or developed for this particular research field. As discussed above, the complexity of urban public health research questions deserves a wealth of methodological approaches and accordingly a wealth of analytical methods – and skills. For this reason, research in urban public health relies on a broad interdisciplinary spectrum of methods already derived mainly from traditional public health disciplines like epidemiology/biometry, sociology, anthropology, health economics, health services research and health policy analyses. However, for urban public health, the interdisciplinary cooperation with spatial and urban planning, geography, architecture, ecology/environmental research, logistics, engineering, as well as urban studies, social, and political sciences is imperative.

3. Empirical Approaches: Data Acquisition and Common Sources

3.1 Starting Points

The advantage of using highly sophisticated interdisciplinary methods in urban public health is simultaneously a challenge, as the large number limits their straightforwardness, comprehension, and accessibility. Further challenges are that a high level of experience and methodological expertise is required for the application and in-depth understanding of this broad interdisciplinary spectrum. Furthermore, their relevance for urban public health issues has by no means been specified in detail so far.

Therefore, in order to launch empirical approaches from urban public health, the following sections can only outline a tiny fraction of the existing plethora of methods, models, instruments, their areas of application, along with their strengths and limitations. The following sections thus limit themselves to presenting examples of opportunities for data acquisition and data analyses with a focus on urban epidemiology.

For reasons of space, in the following only an empirical perspective is presented, which of course is a serious limitation as the highly relevant research issues, findings, instruments, and approaches in qualitative research on urban public health as well as the emerging field of mixed-method approaches are not included. These would be methods such as systematic reviews, critical-constructive analyses or comparative case methods, communication and analysis methods such as process tracing, co-creation, and impact chain analysis.

Sound urban public health research requires a comprehensive understanding of research approaches and a methods-literate access to urban public health problems. Like in all research areas, a clear and competent understanding of research design, sampling or case selection, data collection, and data analysis is required. Since the choice of empirical research design depends on the nature of the intervention, knowledge of randomized and nonrandomized approaches, prospective and retrospective study designs, clinical trials and observational studies is useful. However, the aim here is not to present in detail cutting-edge techniques for evaluating interventions. Furthermore, not all kinds of regression analyses, instrumental variable, interrupted time series and sensitivity analysis are introduced. In this regard, useful basic information is provided in relevant academic literature.

Empirical studies of public health research often use different terms for central concepts like health factors, health traits or outcomes for health issues or risk factors, determinants or exposures that potentially influence health. In the following, these terms are used synonymously.

3.2 Primary Data – Surveys

Information or data for research can be collected in a number of ways. Primary data are newly collected data that are best suited for a given research purpose. Since urban public health is about population health, data from people are essential. Primary data in health research are collected mainly through surveys, for which numerous research designs have been developed. Manifold are the distinctive features that more or less apply to specific research questions and specific ways of conducting a survey. There are also many ways to categorize the distinctive features to facilitate their basic understanding. For example, the temporal perspective refers to prospective, retrospective, and cross-sectional studies; practical procedures refer to experimental and observational approaches; types of analyses refer to description and association studies.

Prospective or retrospective designs include a wide array of study types, including the classical cohort and case-control studies, but also specific ones like case-cohort, nested case-control, case-crossover, case-time-control, case-specular or genetic-epidemiology-case-only approaches (e.g., Gordis 2008).

The sample size differs markedly between study types. For example, a case-control study may include fewer than one hundred participants, while nowadays international longitudinal cohort studies follow thousands to hundreds of thousands of participants over several decades, with the epidemiological Framingham Cohort Study one of the oldest and most famous ones. Sources of exposure and outcome data vary between study types, but typically encompass, e.g., medical and employment records, interviews, questionnaires, medical examinations, environmental measurements. Data from medical records, death certificates, physical examinations, and/or questionnaires, for instance, are often used to verify or specify the reported outcome. For instance, in case a study participant in a medical interview or self-administered questionnaire reports having had a myocardial infarction, diabetes mellitus or cancer, these reports are validated through medical records. Also, in case a participant of a longitudinal study dies during follow up, death certificates are useful to determine the cause of death more accurately. As an example, say, the main objective of the study is to analyze the effect of traffic-related noise (exposure) on myocardial infarction (outcome). To estimate a possible effect, it is necessary to determine the outcome exactly. This means that not only the exact number of participants with a first myocardial infarction must be known, but also the number of participants who died of myocardial infarction during the follow-up.

Longitudinal Cohort Study Design

Longitudinal cohort studies are challenging among other factors with regard to duration and organization of the fieldwork as well as data analysis. The effort is worthwhile as temporal aspects allow for analyzing causal relationships or improving knowledge about long-term developments and longevity. The concept of a longitudinal study, simply put, is that participants without the disease of interest are followed over a given period of time to observe which of the participants develop the disease. Appropriate statistical analyses can then be used to investigate whether and to what extent the exposures of interest (often risk factors) differ between participants with and without the disease. In this way, and bearing in mind many of epidemiologists' most often discussed obstacles like confounding and bias issues (s. below), causes for the development of the disease can be identified. Longitudinal studies allow researchers to follow their participants during a part of their lives. The approach also allows for repeated observations as well as implementation of new study objectives over time – valuable for many research questions. The measurement of health outcomes and exposures (risk factors) can be collected with a high degree of reliability, and modelling cause-and-effect relationships is possible. For instance, exposure measurements should be as free as possible from recall bias, i.e. the issue that participants do not remember past events or their experiences precisely, or leave out details (s. section 4.3). Recall bias is particularly important in environment-related studies, as the extent of inaccurate recall is associated with characteristics of the exposure of interest (Coughlin 1990). One example of a long-lasting established German cohort study is the Heinz Nixdorf Recall Cohort Study. A short overview of the design, study location, assessment methods and main assessed variables is given in the following.

The Heinz Nixdorf Recall Study is an ongoing population-based, prospective cohort study initiated in 2000. It is based on a random sample of the general population of the metropolitan Ruhr area, aged 45–74 years. The former primary study objective was to determine if imaging techniques can be used to improve the risk prediction of myocardial infarction. Overall, 4,814 participants were recruited for baseline examination (participation rate: 55.8%). Extensive follow-ups were conducted in 2006–2008 (response 91%) and 2011–2015 (response 86%). On-site examinations at the study centre, lasting about five hours, included a self-administered questionnaire and a personal interview regarding socio-demographic characteristics, lifestyle factors, and assessment of the medical history, e.g., heart diseases, cancer, allergies, mental health. Additionally, recordings of medications and in-depth risk factor assessment, physical examinations including anthropometric and blood pressure measurements, and comprehensive laboratory tests as well as genetic analyses were performed. Also, mailed questionnaire-based surveys have been conducted annually for 23 years to assess the health status and specific health outcomes of the participants. Thus, relocations, deaths, and causes of death are systematically recorded.

According to environmental/urban public health research, extensive and detailed recording of participants' environmental exposures was performed, including chemical-physical environment (e.g., traffic, air quality, noise, acoustic environment, green spaces), socio-economic environment (indicators of socio-economic status of urban districts), as well as occupational and personal stressors. Environmental factors are assigned to subjects via geocoded residential addresses.

For the coverage of particulate and gaseous air pollutants, an area-wide daily modelling was performed in the entire study area using the dispersion and chemical transport model EURAD (European Dispersion and Deposition Model). This model is particularly suitable to represent urban background pollution and its short- as well as longer-term temporal changes. In addition, source-specific pollution (e.g., pollution from traffic and/or industrial emissions) was modelled. Exposures to fine particulate matters (e.g., PM10, PM2.5, PM2.5abs to measure the proportion of soot in fine dust, or the concentration of nitrogen oxide) are also available and allow in particular the recording of traffic-related particulate matter and the exposure to nitrogen oxides with a very high spatial and temporal resolution.

Chronic traffic pollution is recorded by using the residential address and distance and traffic density indicators. Chronic exposure to traffic noise was assigned as another physical environmental factor according to EU Directive 2002/49/EC. To derive the exposure to traffic noise present indoors, data were collected on both the sound insulation of the apartment and the ventilation behaviour of the participants. Green areas are, e.g., calculated via satellite-based data (Landsat 5 for 2003, 2006, 2009, Landsat 8 for 2013, 2015) as Normalized Difference Vegetation Index (NDVI) for the whole study area. This measure quantifies the presence of green vegetation based on reflected light in the visible and near-infrared bands (s. below). Neighbourhood social status was surveyed on a small scale using the proportion of unemployed, social assistance recipients, and median income in district, as well as the number of relocations.

A hexagonal sampling grid created a walkability measure across each study region covering the municipal boundary of participants' home address and a buffer of one kilometre beyond. Sampling hexagons with sides of 1000 m were used. The granularity of measurement with computational complexity had to be balanced; a larger hexagon would have led to more potential error in interpolation, but a smaller one would have been more intensive to calculate. By selecting the 1000 m hexagons and using the centroid of each hexagon as a sample point as well as the six vertices, a distance of 500 m between each point was used. This interpolation estimation appeared to be scaled appropriately, as a short walk was determined as little over 500 m.

Due to its fine-grained and detailed description of exposure to different environmental and social factors in the study area, the Heinz Nixdorf Recall study offers excellent opportunities to investigate associations with diverse health outcomes, mental and general health as well as risk factors. The variety and depth of both the recording of environmental factors and the pheno- and genotypic characterization of the subjects allow further investigation of important questions beyond the existing study results. Furthermore, through the use of highly standardized assessment and database tools, data of this study is still used in big national (e.g., Kieback et al. 2019; Bächle et al. 2018; De Las Heras Gala 2016) and international research cooperations (e.g., Locke et al. 2015; McClelland et al. 2015). Overall, many important results regarding environmental issues could be achieved (e.g., Lucht et al. 2020; Kartschmit et al. 2020; Orban et al 2017; Fuks et al. 2016; Hoffmann et al. 2015; Hertel et al. 2010).

Case-control Study Design

A substantial trade-off of longitudinal studies is that they are often not suitable for studying the causes of rare diseases, as this requires very large sample sizes and long durations to achieve sufficient statistical power. In this case, case-control studies are often very useful alternatives. Put simply, patients with the disease of interest are identified and their history of exposure to suspected etiologic factors is compared with that of control subjects who do not have the disease. Case-control studies are particularly suitable for investigating outbreaks, as they are fast, inexpensive and comparatively simple, e.g., generally requiring a small sample size. As with all study designs, this approach has several constraints. "Although easier to do, they are also easier to do wrong" (Schulz/Grimes 2002, 431). To mention only a few, case-control designs are prone to biases, e.g., anamnestic information has limited reliability due to long exposure history. Most importantly, a case-control study is not able to detect very small risks, which is an important issue especially in environmental epidemiology studying, e.g., hazardous exposures and cancer outcomes.

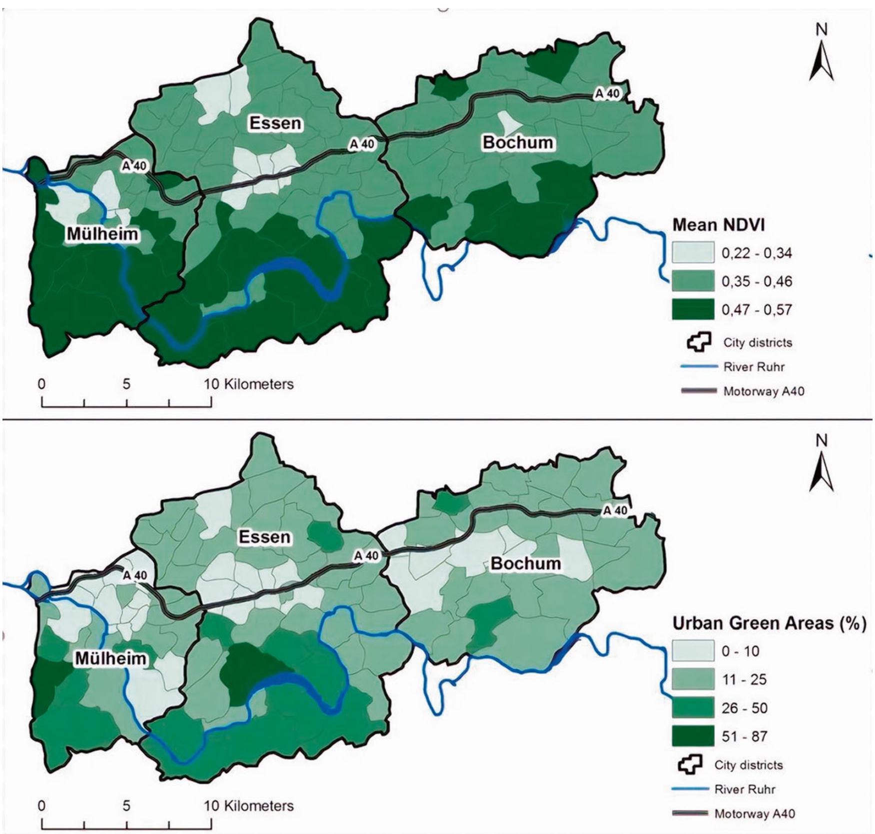
3.3 Secondary Data Sources

Secondary or second-hand data is data often routinely collected for a different purpose than the research question at hand. Secondary data commonly used in epidemiologic health studies include death registers, health- and environmental reports, census data, official statistics, administrative records, medical records or health insurance data. Secondary data analyses are widely used in healthcare system studies or pharmacological studies, to name only two. For urban public health, information on the quality and quantity of features of the built environment are of course crucial. So far, mainly used secondary data in urban public health are those about green and blue areas like parks or lakeside swimming pools for recreation. Many studies investigated pathways linking green space with environmental justice, health outcomes, physical activity, or social interaction.

Urban planning already uses well-known data sources like densities (population, buildings, traffic, …), development structure, street design and open space network, number and types of land uses, plot ratios, ground conditions or redevelopment, public transport, and many more. However, these data sources so far have rarely been linked to urban public health research objectives. One reason for this seems that conceptual approaches in public health incorporating explicit spatial perspectives from scientific disciplines such as spatial planning are still in their infancy.

Similarly, the tremendous potential of satellite remote sensing data has not yet been sufficiently appreciated in urban public health research. As a first satellite data application, the use of the *Normalized Difference Vegetation Index* (NDVI) was recommended as a standardized measure of green to investigate association with human health (Gascon et al. 2015). Several satellites, such as Landsat 5 to 9 are available as data sources for the calculation of the NDVI, providing a 30 m^2 resolution. The NDVI is calculated according to the level of reflectance of near-infrared and visible red wavelength spectra followed by the calculation of the distribution of NDVI (like mean, standard deviation) within buffers of interest using a geographical information system (GIS). However, although easy to access and convenient to work with, the conceptual implication needs critical appraisal. For example, objective exposure to green space is commonly measured either as surrounding greenness or access to green space (e.g., distance to nearest park), which are two different concepts. Applying the concept of surrounding greenness, the exposition can be measured within a certain area, often with a buffer around a residence or on district level using either land-cover data to calculate the percentage of green space or satellite imagery to compute the NDVI. Figure 2 illustrates the differences of the distribution of green space when applying the indicators of NDVI or proportion of urban green space. These differences require a thorough interpretation of their impact in terms of exposure markers as (positive) health factors.

Fig. 2: Distribution of the Normalized Difference Vegetation Index (NDVI) from 2015 and proportion of urban grean areas (2012) in 108 districts in Bochum, Essen and Mülheim/R, Germany. The figures depict the different results of the distribution of green when applying the indicators of NDVI and proportion of urban green areas. However, main hotspots of urban areas with less green are identifiable



The inclusion of secondary data in qualitative research has also been proposed for grounded theory approaches. An advantage identified is that these data sets might be helpful to build a theoretical understanding of complex social processes (Whiteside et al. 2012).

When using secondary data, it is necessary to find the most useful data set given the research question. Further, one needs to make sure the retrieval is feasible and the quality of the data sets is sufficient, e.g., with regard to missing data or methods of their collection. Lack of timeliness, or lack of sufficient detail to address the problem under surveillance are further challenges when using secondary data, as well as possibilities of record linkage with other data sources.

The following example from urban public health research describes a study that uses a set of secondary data sources. The *Acoustic Quality and Health in Urban Environments* (SALVE) project aims to measure spatial-temporal differences of the urban acoustic environment, taking into account the built environment, defined as land use types, and temporal changes. Sounds of urban regions have been a concern of architecture and construction engineering for years. In the context of health research, however, sound has been restricted to the risk factor 'noise', thus reduced to sound decibel levels. Accordingly, noise mitigation measures aim exclusively at the reduction of the noise level below a certain threshold. Soundscapes on the other hand, comprise all acoustic events of the natural and physical environment, which are determined by sound level, frequency, time and space. Soundscape ecology, which includes the study of spatio-temporal heterogeneity of sounds in different landscapes, provides a suitable methodical approach to analyse the relationships between soundscapes, the built environment and human health.

The projects started in 2018 as an interdisciplinary pilot project in the frame of the University Alliance Ruhr (UAR), involving researchers from public health and spatial planning. By taking year-long direct and automated auditory measurements of a robust land-use sample in the city of Bochum, located in the highly urbanized Ruhr Area of Germany, one of the largest multi-seasonal urban soundscape datasets has been established including more than 1.5 Mio minutes of sound recordings. The sound data is categorized into various soundscape metrics as well and is combined with comprehensive spatial data from various data sources of environmental agencies. Lastly, health and social data from the georeferenced longitudinal Heinz Nixdorf Recall (HNR) study (see above) will be used.

A random stratified sample that prioritizes polygons with participants of the Heinz Nixdorf Recall study locations was applied to locate all measurement field points. The target population for field recordings was chosen to maximize the spatial proximity of health reporting with field sound recordings so as to capture the soundscape of participant locations. Using 24 automated recording devices placed stationary in the field, the surrounding sound was recorded for five minutes each hour for 365 days.

Spatial parameters such as proximity of recording points to different features such as highways, city centers, and airports, availability of surrounding green areas and land-use mix were incorporated into the data set. In addition, other spatial datasets may include built area index (NDBI), park and recreation areas, road and rail corridors, urban density gradients (Corine Urban Atlas), natural ecoregion units, soil and geological units, elevation, physiographic regions and sub-regions, demographic and economic data of the general population, open water and streams, and bus and mass transit stations.

The novelty of this study derives from the idea of treating urban land use as a so-called "human habitat", and attempting to use sound as an indicator of habitat quality, similar to the use of bio-acoustic indices as a measure of the quality of non-human habitats. Furthermore, a temporally longitudinal set of recordings will be systematically gathered from the urban environment with both automated and direct recordings, which will ultimately become one of the largest soundscape datasets ever recorded in Europe, and can be used for a wide array of follow-up studies (Haselhoff et al. 2022;

Hornberg et al. 2021). Overall, the application of soundscape metrics in urban environments and their association with health information of the population will provide a deeper understanding of sound than tradition decibel-focused metrics used in noise-related studies.

3.4 Specific Tools for Urban Public Health Research

The following section briefly outlines specific tools for urban public health research that cannot be clearly assigned to one of the above specific categories.

Assessment Checklists and Surveillance Instruments

Overall, checklists are often designed as step in processes to identify health issues in urban environments and to determine if further assessment is needed (Pope et al. 2016). One of the most powerful tools, but also a challenging one, is the *Health Impact Assessment* approach using several different assessment checklists (Kemm et al. 2004) or the less voluminous *Healthy Urban Development* checklist (New South Wales Department of Health 2009). The checklist includes the systematic assessment and description of the urban environment as well as the resources and risks of the population, in some cases even the health status of the population group of interest.

A reporting or assessment level on the smallest possible monitoring/spatial scale should be aimed for, e.g., to be able to identify intra-urban characteristics of environment-related inequalities. In this regard, a newly emerged instrument seems promising: The *Healthy Streets* approach tries to cover what is almost the smallest urban entity, the street, and aims at a "human-centred framework for embedding public health in transport, public realm and planning" (healthystreets.com/what-is-healthy-streets 2021). The concept is based on ten evidence-based indicators representing the human experience with streets in different aspects (Saunders 2021). Besides directly addressing residents, the approach is helpful for designers and engineers to assess their work. *Healthy Streets* provides several publicly available resources like the *healthy street design check, healthy street index, how healthy is my street* and *qualitative street assessment*.

Often these instruments rely on using tailored comprehensive indicator sets, which are briefly depicted in the following.

Health Indicators, Health Indicator Indices

In urban public health research, classical topics include the analysis of spatial and geographic distributions and variations in health and environmental exposures. However, explicit small-scale intra-urban differences are rarely examined. The question of which small-scale urban health indicators or even indicator indices are best suited for systematically capturing the – especially small-scale – spatial distribution of urban health risks and health opportunities is currently under debate. The basic idea behind an index of urban health indicators is to bring together metrics from different disciplines to describe health and multiple contextual variables influencing health in an urban context. Choosing an indicator needs knowledge about its role and link to health.

Indicator frameworks can help to systematically structure the complexity of environmental health. For example, emissions of fine particular matter as part of air pollution is associated with multiple health outcomes. These emissions not only distribute unevenly geographically, but can also originate from traffic, agriculture or industry. This indicates different air pollution sources, which also necessitate different targeted measures. Moreover, in the case of traffic-related air pollution, traffic noise is an important concurrent risk factor for health.

As an example, known theoretical frameworks about environmental health indicator development and monitoring health vulnerability are the *Driving Forces, Pressure, State, Exposure, Effect and Action* (DPSEEA) with its extension *Multiple Exposures-Multiple Effects* (MEME) frameworks (Corvalán et al. 2000).

Exposure and Disease Mapping

Maps are an essential feature in the spatial depiction of specific health outcomes, diseases, and health related indicators, or exposures. The modern advanced possibilities of mapping, however, have only recently found their way into the field of public health. An important application field is health reporting on national and community levels. Here, maps are potent tools in documenting, understanding and advocating the health of the population and population groups. By mapping the distribution of health on a small-scale, e.g., inequalities can be visualised (as an example, see fig. 3). This information source is not only relevant for health reporting and (urban) planning but also for health policy measures in all policy areas according to the "Health in All Policies" framework of the WHO (2014).

Geographic information systems (GIS) are a well-known tool for merging, visualizing and analysing spatially heterogeneous data sources. A fairly new feature of GIS is the so-called "SoftGIS" approach, which combines quantitative and qualitative data assessment, allowing users to annotate positions on a map based on their own spatial perceptions and preferences, e.g., in their neighbourhoods (preferred paths, avoided or favourite places) and also to comment on them. Additionally, questionnaires included in the system allow users to collect additional non-geographical individual characteristics, such as health status, satisfaction, demographic information, or socio-economic status. In Helsinki, for example, the development of a master plan showed the potential of using SoftGIS for promoting participation (Kahila-Tani et al. 2019).

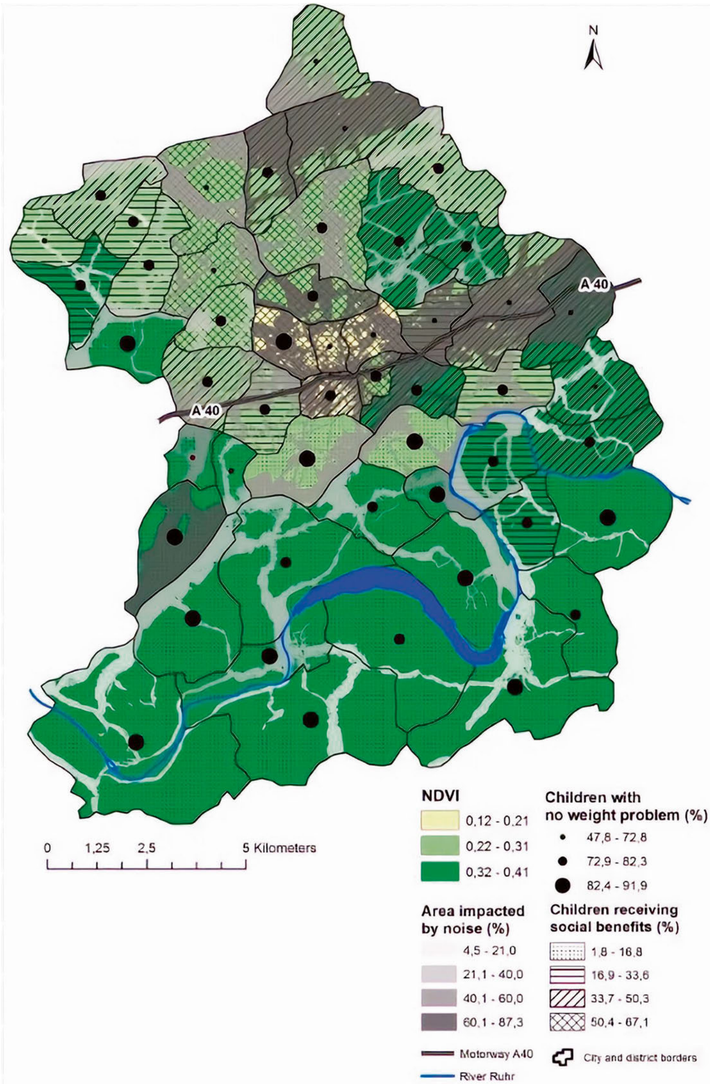
4. Empirical Approaches: Data Analyses

4.1 Measures and Rates

In very simple terms, epidemiology counts cases or health events, describes them in terms of time, place, and person, divides the number of cases by an appropriate denominator to calculate rates, and compares these rates over time or for different groups of people (CDC 2012). The basic aim of epidemiological studies is the analysis of the distribution and determinants of health and disease. Typically, main questions refer to one or all of the five "Ws": Which, Who, Where, When, Why – and how to change.

In principle, studies aim at a comparison either between subjects with and without disease (when interested in how subjects differ with respect to determinants) or

Fig. 3: Multi-layer map using the indicators 'greenness' (NDVI), 'noise' (>55 dB (A)), 'unemployment' and 'children's health'. Sources: Geodata and noise map, socio economic and children's health from City of Essen (2013–2017), NDVI (2015): U.S. Geological Survey (//earthexplorer.usgs.gov/). Cartography: Sutcliffe (Sutcliffe 2018)



between subjects with and without an exposure (when interested in how subjects differ with respect to diseases). To do so, subjects can be enrolled in a variety of study designs aimed at capturing diseases present (prevalence) or emerging (incidence) in a given time period. Prevalence measures the occurrence of a disease without regard to when the disease developed. The time period used varies and often even a day or other short period is the reference, the so-called point prevalence. Incidence in contrast is focused on newly developed disease cases in a given sufficiently long time period. Thus, e.g., subjects already diseased at the beginning of the study will not inform the incidence but will be counted as prevalent cases. Incidence therefore plays a crucial role in attributing a disease to a determinant, since a causal association implies the cause to happen before the outcome.

For quantitative analysis, disease occurrence is related to the study population. When the size of the study population is used as denominator, then the disease rates are termed “risk” and proportions are reported, e.g. 10 % of population is diseased. When the denominator is chosen as the time subjects were at risk of developing a disease, then rates or densities are reported, e.g., 10 cases per 100 person years.

$$\text{Prevalence} = \frac{\text{No of subjects with a disease in a given period}}{\text{No of subjects in the study population during the same period}}$$

$$\text{Incidence} = \frac{\text{No of newly diseased subjects in a given period}}{\text{No of subjects at risk of developing the disease during the same period}}$$

To cope with the principal aim of comparing disease occurrence across populations, the risks or rates will be calculated for each population separately and then combined in disease measures. Table 1 gives the three most important disease measures in epidemiological studies. The risk difference compares populations on an absolute scale, can be negative when diseases occurrence is higher in the unexposed population and is thought to highlight the public health impact of an exposure. In contrast, the risk ratio, often also called the relative risk, can never be negative. It is especially suitable for estimating the strength of a relationship between an exposure and a disease outcome. Risk differences and risk ratios do not necessarily lead to the same conclusion. For instance, the risk difference between exposed and unexposed subjects can be the same for two populations, but the risk ratios may differ vastly. Odds ratios finally differ from the other disease measures as the number of diseased subjects is not related to the total population (giving the risk), but to the number of subjects not diseased (giving the odds). Odds ratios in general overestimate the risk ratio but are a good approximation when the prevalence of the disease in question is small (e.g. 10%).

Tab. 1: Measures for population comparison

Subjects	***Diseased***	***not diseased***
exposed	a	b
not exposed	c	d

$$\text{Risk difference} = \text{disease rate exposed} - \text{disease rate not exposed} = \frac{a}{a+b} - \frac{c}{c+d}$$

$$\text{Risk ratio} = \frac{\text{disease rate exposed}}{\text{diesease rate not exposed}} = \frac{\frac{a}{a+b}}{\frac{c}{c+d}}$$

$$\text{Odds ratio} = \frac{\text{odds exposed}}{\text{odds not exposed}} = \frac{\frac{a}{b}}{\frac{c}{d}} = \frac{ad}{bc}$$

In environmental health research, effect sizes of a risk factor on a health outcome are often very small, implying little importance of the risk factor. However, since environmental exposures, like environmental toxins, air pollution or noise, often affect very large proportions of the population, even small risks can be of great health relevance. The SARS-CoV-2 pandemic drastically demonstrated this effect: Although hospitalization rates due to Covid-19 infection were relatively low, the sheer number of people 'exposed' to the SARS virus caused, e.g., the health care system to partially collapse, which in turn led to drastic measures being taken. Although prone to conceptual problems in its definition and interpretation, the *population attributable risk fraction* (PAF) is a widely used measure in epidemiology to assess the public health impact of exposures in populations. It can be interpreted as the proportion of disease cases that would be prevented following elimination of the exposures (Greenland/Robins 1988). The PAF thus relates the observed number of cases to the expected number of cases under no exposure.

$$\text{PAF} = \frac{\text{Incidence in the whole population} - \text{Incidence in unexposed population}}{\text{Incidence in the whole population}}$$

4.2 Statistical Approaches

Given the multidisciplinary approach of urban public health, the full spectrum of statistical tools is utilized. However, regression analysis has become the most important and variable approach to data analysis. Regression analysis aims specifically at the quantification of the association between diseases and their determinants. In addition to the simple linear regression model, more complex associations are usually modelled within the framework of Generalized Linear Models, which offers a great variety of functions. Disease measures like risk and odds ratios can easily be estimated, e.g., by logistic regression or Poisson regression. Specific research questions can require more specific approaches like hierarchical or spatial regression models. However, finding the most appropriate model and statistical tool can be challenging, but can be guided by flowcharts directing users through stormy waters. For example, decision trees are currently provided to select the best multilevel modeling approach for longitudinal (and cross-sectional) spatial data based on changes in characteristics of the contexts. The best approach is decided on by asking questions about evidence of spatial confounding and changes in the characteristics of areas over time. The decision tree is helpful in navigating diverse statistical models when participants are nested within geographical areas or for which all variables are initially measured at an areal level or aggregated to a common spatial resolution that might be of interest to health research. The methods are based on a tradeoff between accuracy to retrieve regression coefficients, a model's goodness of fit, and time needed to complete the fit. These tools are accompanied by information to help applicants to choose the appropriate software packages when analysing data using regression analysis, particularly when a spatial effect is possibly present (Djeudeu et al. 2022).

4.3 Bias

The validity of empirical studies rests on many assumptions. Study results can deviate systematically from the 'true' results for various reasons. This bias leads to either an overestimation or underestimation of the 'true' exposure-disease relationship. Three types of bias are of general importance: selection bias, information bias, confounding. Selection bias is said to occur when the study population is different ('not representative') from a population originally targeted, e.g., subjects eligible for inclusion in a study might have refused to participate. Information bias is the general term for many bias sources like, for instance, a differential remembering of exposures between diseased and not diseased subjects (recall bias) or the inexact identification of diseases (misclassification). Confounding is a bias occurring when an association between exposure and disease is distorted by another known or unknown variable. A confounder therefore is a factor that partly accounts for the observed effect of a risk factor. Avoiding confounding is a central topic widely discussed in empirical studies and is addressed by a great number of methods in all phases of the study course. A helpful tool, especially for the analysis of causal effects, are directed acyclic graphs (DAG). These support epidemiologists in selecting *a priori* relevant confounders for their association models, avoiding both overfitting and potential unintended consequences of commonly used methods such as conditioning on mediators (simplified examples for using DAGs to gain important insights in neighbourhood health effects research are given in Fleischer/Diez Roux 2009).

Further methods and instruments are methods for modelling complex systems, e.g., agent-based modelling, optimizing stochastic techniques (based on the use of random numbers and probability statistics to investigate problems) and verbal models (cf. the chapters by Rienow; Westerholt; Weyer et al.; Gönsch/Gurr in this volume).

5. Remaining Issues and Perspectives for Further Research

Overall, how to identify which characteristics of the urban context are modifiable, and under which circumstances, is an important theoretical and empirical (urban) public health question. Often, more content-related topics relate to the impact of spatial context and neighbourhoods on resident's health. These concerns have developed into a major research focus in recent years (Diex Roux et al. 2010) with research on physical activity, green space, and various health outcomes coming to the fore. Thus, research on the processes through which the urban context may affect health and on further elucidation of these processes still remains a major issue (Galea/Vlahov 2005). Likewise, the best measures to assess the physical environment relevant to health need investigation, accompanied by the research question how these measures relate to health in urban and suburban environments.

One focus of urban public health research is to deepen knowledge of how urban social characteristics, structures, migration flows, and interaction patterns affect health. There is already an enormous amount of knowledge about how poverty affects health. However, information on the association of economically deprived urban populations is still missing (O'Campo/Yonas 2005). For instance, although concerns regarding the impacts of gentrification are increasing, few studies to date have analysed gentrification effects on health. First studies show that gentrification is associated with worse self-rated health and higher risk for preterm birth for Black residents, but not for all residents (Diez Roux 2021, 97). Similar to this is the issue of environmental justice with its human health implications relating, for instance, to degraded urban landscapes and environmental quality.

An emerging concept relates to the urban microbiome, a complex ecosystem including a myriad of microorganisms – from sewers to roof (gardens) – that interact with the environment as well as with humans. In combination with the roles of, e.g., the immune system and the growing understanding of epigenetics (meaning the study of heritable phenotype changes that do not involve alterations in the DNA sequence, Bird 2007) and environment-gene-interactions, an intriguing research field arises. For instance, gaining an overview of the situation of the local antibiotic resistance situation by sampling and analysing wastewater is a promising approach providing complementary health data at lower costs compared to testing an equal number of individuals living in the same area (Schmiege et al. 2021). Using the example of antibiotic resistance, identified by the WHO as the greatest challenge to global health, urban wastewater epidemiological methods are developing to analyse the spatio-temporal variation of the resistome in urban wastewater (which means the collection of antimicrobial resistance genes in the wastewater), taking into account small-scale socio- and environmental diversity. The innovative approach of wastewater-based screening creates an evidence base through short and long-term monitoring and mapping of temporally and spatially varying health-related conditions – at neighbourhood, community and regional levels. This is of great interest especially from the perspective of planning and public health (cf. also the essay by Hupało et al. in this volume).

Common epidemiological methods so far have failed to address the complexity and dynamism of urban systems due to their narrow problem definitions and mainly reductionist, often linear analytical representations. Systems thinking in general and systems dynamics in particular are relatively new approaches in public health. These methods for modelling and analysing the complexity underlying urban processes seem promising for effectively designing urban public health interventions (Tozan/Ompad 2015). This concept has not yet been linked to one of the most challenging new research concepts, which aims at analysing the so-called exposome. The exposome is supposed to address the complexity, dynamics, and contextuality of environmental and societal influences as a whole from a life course perspective. In that, this approach aims to overcomes the traditional epidemiological approach of one exposure-one outcome at a given time period (Haddad et al. 2019). Furthermore, novel methodologies and tools are currently considered for better assessment of the human exposome, including approaches using –omics technologies (genomics, proteomics, transcriptomics, and metabolomics), personal samplers and wearable sensors. As a result, new biometrical and computational methods have emerged, such as the environment/metabolome-wide association study approaches. The metabolome refers to a whole set of chemical compounds found within a biological sample (like nucleotides, aminoacids, lipids). However, their applications and interpretation are still in their infancy and need careful and thoughtful refinement. By targeting urban areas, the exposome framework could lift urban public health studies to a new, more complex level. First large EU research collaborations use diverse data sources (including data from participatory processes), apply statistical methods according to the complex data structure (e.g., machine learning), pursue both a pathogenetic and a salutogenetic view (health-promoting environmental resources), and systematically integrate aspects of social inequality. Their results will show whether the expectations of modelling complex and dynamic exposure patterns is feasible, and it remains to be seen if the challenging concept will establish new methods of data collection and analysis.

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