Advances in Geographical and Environmental Sciences

R. B. Singh
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# Urban Health Risk and Resilience in Asian Cities

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# Preface

Presently, world is facing crucial and grave danger as Coronavirus disease (COVID-19). This is the kind of crisis on human existence and can not be eliminated without understanding the environment, urban development process and health degradation. Different models of cities have been found in the past decades; today, we are more concerned about healthy, sustainable and future cities. Urban areas are often most vulnerable to hazards and disasters. The global urban sustainability and sustainable development goals requires cities to be sustainable by ensuring that they are healthy places to live in and providing opportunities to improve the wellbeing of its inhabitants. Cities are the dominant human habitat, where environmental, social, cultural and economic factors have impacts on human health and wellbeing. The world is becoming more urban day by day. In 2050, the world population will reach about 9.5 billion with around 66% living in cities. The urban population in Asia has increased from 32% in 1990 to 47% in 2019 and years are not very far when Asia will be more than half urbanized.

Global sustainable development challenges concentrate in cities and are closely tied to human health and wellbeing. On 25 September 2015, global community adopted United Nations 17 Sustainable Development Goals (SDGs); out of these, two Sustainable Development Goals address these concerns: Goal 3 is related to "Ensure healthy live and promote wellbeing for all" and Goal 11 discusses to "Make cities inclusive, safe, resilient and sustainable". Highest scientific bodies like International Council for Science (ICSU) started new initiatives: Health and Wellbeing in Changing Urban Environments—A System Analysis Approach. Global sustainability cannot be achieved without local sustainability. Urban health and wellbeing is central to the mission of the International Council for Science (ICS), which is to strengthen international science for the benefit of the society. ICSU's strategic programme: Health and Wellbeing in Changing Urban Environment—A System Analysis Approach was initiated in the above context. The programme recognizes the constraints due to geographical diversity in social status, income level, culture, governance, capacity and most importantly availability of data for implementing systems analysis approach in health management in the region.

Environment, climate and health degradation are big threats to the sustainability of the future earth, particularly in Asia. The factors which influence urban health include urban governance; demographic characteristics; natural and built environment; social and economic conditions; services and health emergency management; and food security. Now, focus is being shifted from Illness to Wellness. The Asia Health and Wellbeing Initiative (AHWIN) promotes vibrant and healthy societies where people can enjoy long and productive lives, and to contribute to the region's sustainable and equitable development and economic growth, it fosters sustainable and self-reliant healthcare system in Asia. By looking at the health problems and issues, an idea came in mind that there should be research volume to provide the analytical overview of health conditions and wellbeing in Asian cities. Interdisciplinary research with biophysical and human geosciences should be promoted and the roles of geographers are crucial to providing the necessary sociocultural linkages by connecting social sciences, humanities and science and technology for the sustainable cities. It is now realized that future research initiatives for sustainability need to be appropriate, indigenous, smart and solution-orientated.

In this volume, conceptual framework of health applied as a natural integrator cutting across different urban sectors attempts to describe the health problems and solutions having case studies. The knowledge gained through the case studies will be very crucial in developing local, regional and global sustainable planning for sustainable health. It provides an overview of environmental, geographical and cultural urban development and related health challenges and explains how good health can be achieved in Asian cities. This volume is an outcome of the valuable contributions made by eminent scientists and academicians who have been striving to develop alternative strategies, solutions and modes for urban sustainability through supplying the conceptual tools as well as evidence-based suggestions to planners. This volume will be useful for academicians, scientists, policymakers, decision makers and various related stakeholders. We are highly thankful to all the contributors for their significant research papers and thoughts.

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August 2019

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# Part I
# Urban Process, Vulnerability and Risk: Methods and Techniques

# Chapter 1
# Systems Approach for Climate Change Impacts on Urban Health: Conceptual Framework, Modelling and Practice

**Yinpeng Li, Peter Urich and Chonghua Yin**

**Abstract** Climate change has direct and indirect impacts on urban human health and well-being at multiple scales and levels. WHO and other international and national organisations have exerted great effort in understanding and adapting to the add-on or new challenges from climate change. A systems approach is an ideal tool for managing the analysis of such complicated systemic challenges. Systems approaches are accepted in health sector projects and research work in past decades from conceptual frameworks to practical applications. The socio-ecological system (SES) framework is an appropriate approach for such a complex system. Applying SES frameworks starts with the scoping and conceptualisation of risk identification; then forms system dynamics models, or hybrid models, and ends with scenario analysis. This approach can provide different types of support for organisational thinking and decision-making. A system approach software platform UrbanCLIM/RIDS—an integrated decision support system—is briefly described in this chapter. The tool includes mapping, modelling, data and knowledge management functionalities for addressing the integrated challenges of climate change, urban health and well-being. There are many opportunities to push forward in applications of system sciences to analyse climate change and health SES issues. Given the nature of a complex system, there is no simple pathway to get people to understand, and communicate between different sub-systems. However, barriers could be breached with systems approaches, data technologies and economic innovations.

**Keywords** System approach · Mapping · Modelling · Health · Climate change

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## 1.1 Introduction

Nowadays, cities are the dominant human habitat, where a large number of environmental, social, cultural and economic factors have impacts on human health and well-being. This is a kind of typical complex system (Batty 2013). In addition, climate change has posed extra risks for urban population health and well-being, through the direct impacts on food, nutrition, waste, air quality, transport, infrastructure, housing and indirectly on energy, safety and access to health care, and other urban public services. Currently, there is a limited understanding of the complex processes that shape urban population health and well-being. On the other hand, systems approaches are increasingly being recognised as appropriate tools for examining complex socio-ecological system (SES) issues (ICSU 2011).

Climate change positioned as discrete to the environment and disconnected from health systems is an ineffective approach. A holistic SES perspective that integrates a range of climate change and sustainability-related initiatives and focused on actions (i.e., implementation of solutions) is considered a better pathway. Such an approach typically, explicitly and iteratively connects climate mitigation with cultural attitudes, social and intergenerational justice, human rights, economic transitions and efforts to minimise degradation of human and environment systems (Hall et al. 2017).

SESs are often large complex systems, which contain a significant number of attributes such as nonlinearity, uncertainty, emergence, scale and self-organisation as defined by Bar-Yam (2002). Gunderson et al. (2002) and Ostrom (2009) considered SES systems theory as the amalgamation of natural and social science approaches.

SES analysis frameworks have been developed and applied for different sectors over several decades (Binder et al. 2013; Schlüter et al. 2014).The development of sustainable management strategies and better understanding are new methods based on social and ecological interaction. However, SES frameworks have not been adopted as mainstream tools in population health planning and policymaking (Bai et al. 2012; Maglio et al. 2014). There are several issues hampering its applications, which consist of (a) ranges of uncertainty derived from the use of statistical approaches based on confidence intervals and estimate (b) the difficulty of multidisciplinary collaboration for modelling and simulation, and (c) systems scientists' inability to communicate effectively about the added value of specific tools, as well as (d) limited financial support for population health systems science.

Some of the transdisciplinary potentials of the systems approach has been realised (e.g., Castella et al. 2005). The systems approach has also made headway in organisational development and the analysis of learning organisations. Senge (1990) and a number of other scholars regard systems thinking as key to the understanding of complexity and options for change in organisations and as a mental model to facilitate strategy development. As anthropogenic activities endanger sustainability, research needs to address whether and how systems thinking on human/nature connections can increase the learning capacity of society at large-scale (Clark et al. 2016).

System dynamic models and other new modelling technology can serve as a set of systems science tools to explore social-ecological interactions to examine behaviours and outcomes resulting from these interactions over time (Page et al. 2017; Atkinson et al. 2015). Studied systems are typically very complex. It is, therefore, challenging to take different disciplinary theories and knowledge bases and integrate them. This chapter proposes a systems approach based on a SES framework, and furthermore describes a decision support platform based on the proposed approach, where a set of useful tools are provided to bridge the gaps of research and practice between climate change and human health.

## 1.2 Human Health and Well-Being

Climate change incessantly impacts human health and well-being by interfering with the environment, social conditions and infrastructure. It is important to understand these interactions so as to better integrate climate change and other drivers of global environmental change like social and economic conditions, habitat loss, land degradation and ecosystem disruptions to address the impact of climate change on human health (UNFCCC 2017). In general, climate change needs to be considered in terms of impact, vulnerability and adaptation in a SES framework (Berry et al. 2017).

We define SES as a composition of four subsystems: institutional, economic, social, and ecological (bio-physical). The key elements, functions and their interdependencies with climate change are briefly described as follows: Figure 1.1 maps out the analysis structure.

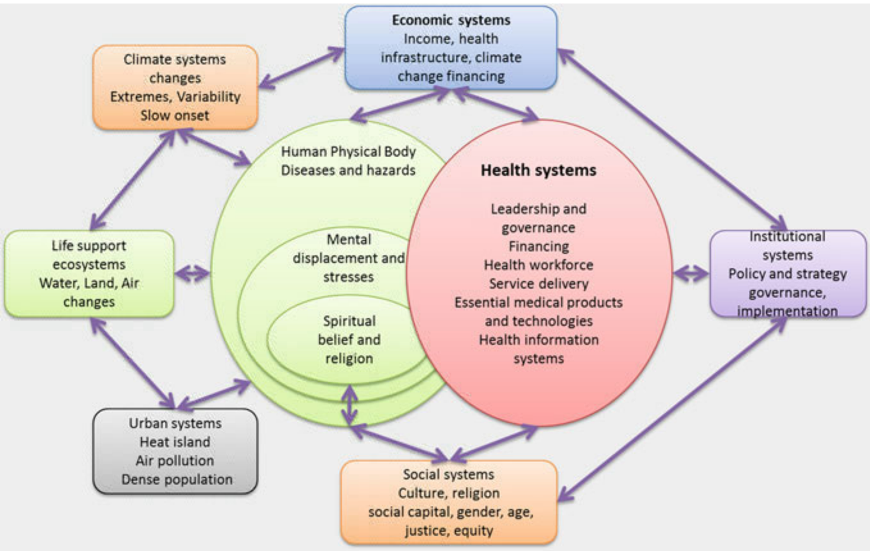


**Fig. 1.1** A high-level systemic framework for climate change impacts on urban public health. This framework needs to be further explored for the next level of detail for each system in special case studies *Source* Author created

### 1.2.1 Physical Body—Diseases

Studies have shown that airborne, vectorborne and waterborne diseases are all sensitive to climate change (Patz et al. 2005; Greer et al. 2008), among which the incidence of mosquito-borne diseases (such as malaria, dengue and viral encephalitis) are most sensitive to climate change (Patz et al. 1996). Brenner et al. (2017) found that airborne infectious diseases spreading dynamics are strongly dependent on the climatic environment of the epidemic outbreak location, and the season during the year when the outbreak is happening. Curriero et al. (2001) found fifty-one percent of waterborne disease outbreaks were preceded by extreme precipitation events that resulted in surface water contamination entering surface and groundwater sources. Forzieri et al. (2017) indicated that two-thirds of the European population will be exposed to climate change related weather distasters. By 2100, and disaster-attributable deaths are expected to increase by roughly 50 times, mainly from heatwaves.

Other categories of human disease related to climate change include asthma, respiratory allergies, airway diseases, cancer, cardiovascular disease and stroke, neurological diseases and disorders (Patz et al. 2005).

### 1.2.2 Mental Health

The affective dimensions of climate change and changes in the land directly impact emotional health and well-being (Fritze et al. 2008; Shukla 2016). While numerous studies examine the physical health impacts of climate change, few consider the affective implications of these changes (Gifford and Gifford 2016). A multi-year, community-driven project in Canada showed that the emotional consequences of climate change are extremely important to residents (Willox et al. 2013).

Human mental health is impacted by climate change-induced extreme weather, changing weather patterns, damaged food and water resources and polluted air. Stress and distress rise as do social relationships that all impinge on physical health, memory loss, sleep patterns, immune suppression and changes in digestion. Major chronic mental health impacts can include aggression and violence, more mental health emergencies, helplessness, hopelessness, or fatalism and intense feelings of loss. Life-affirming emotions, a sense of meaning and purpose, and strong social connections are all used to define psychological well-being. Conversely, the feeling of loss may be due to profound changes in a personally important place (such as one's home or land) and/or a sense that one has lost control over events in one's life that are climate-related. Personal or occupational identity can arise when belongings are either lost or damaged by a disaster or jobs and livelihoods are disrupted by climatic events (Clayton et al. 2017).

Personal relationships and community interactions can be affected by shifts in climate. Compounded stress from a changing environment, eco-migration, and/or eco-anxiety can affect an entire community's sense of mental well-being. A loss of social identity and cohesion followed by hostility, violence, and interpersonal and intergroup aggression can result.

Climate change can threaten one's ability to process information and make decisions without being disabled by extreme emotional responses. Extreme weather increasingly can be a source of trauma. Such an experience can trigger disabling emotions. More subtle and indirect effects of climate change can add stress to people's lives in varying degrees. Most people are able to cope with a certain amount of stress. However, the accumulated effects can overwhelm a person and flip them from a mentally healthy to a mentally ill condition. Uncertainty can be stressful and a risk factor for psychological problems (Swim et al. 2009). People can become distraught by the news of other's negative experiences, and by fears—founded or unfounded—about their own vulnerability.

### *1.2.3 Spiritual Well-Being*

Spirituality is recognised as a real phenomenon and not merely a "mental illusion" (Rose 2001; Koenig 2015). More detailed assessments to extend our understanding of spiritual wellness are needed, to help diagnose spiritual disease, so well designed spiritual care might be provided to recover spiritual health (Bergmann 2009; Zwingmann et al. 2011). Gomez and Fisher (2003) defined four facets of spiritual well-being: personal; communal; environmental and transcendental spiritual. Rowold (2011) applied a Spiritual Well-Being Questionnaire (SWBQ-G). The SWBQ-G was found to be valid and that each of the four SWBQ-G scales discriminated between mental, physical and emotional well-being. The SWBQ-G also predicted levels of future happiness, psychological well-being (positive relationship) and stress (negative relationship). Such results affirm the validity of the construct of spiritual well-being.

Although religions have considerable reach and act as major social actors and institutions relatively little social science research has addressed the interaction of religious bodies and human-induced climate change (Gerten 2010; Haluza-DeLay 2014). Murphy et al. (2016) found that religious beliefs can have tangible influences on the lived practices of individuals and communities, and vice versa. They can be a critical determinant of the adaptive capacity of a community to climate change (Posas 2007).

### *1.2.4 Community Health*

Besides residents' mental and physical health affecting communities, the impacts of climate on community health can have a particularly strong effect on community fabric and interpersonal relationships (Berry et al. 2008). The fabric of social interaction can be shifted by climate-related events. Relationships between the natural world and individual and the larger society can also change (Black et al. 2011).

## 1.3 Elements and Structures of SES Subsystems in the Context of Human Health and Climate Changed World

A socio-ecological systems framework emphasises the integrated concept of human beings in a natural environment. The delineation between social systems and ecological (or bio-physical) systems is stressed as being artificial and arbitrary. Social and ecological systems are linked within the SES approach through feedback mechanisms as both display complexity and resilience.

In this section, we describe with regard to SES, the key elements and structures of the subsystems within human health and well-being systems in the context of a climate-changed world.

### *1.3.1 Ecological (Bio-Physical) Systems*

#### 1.3.1.1 Climate System: Climate Variability, Extremes and Slow Onset Changes

Climate change presents, in terms of variability, two broad categories of interpretation: extremes and slow onset. Climate variability includes the seasonality and annual variations. For example, rainfall and temperature vary in patterns year by year. Climate extremes include extreme heat, heat waves, cold, extreme precipitation, drought cyclone (hurricane) and storm surge events. They will definitely change as global mean temperatures increase (Meehl et al. 2000; Stott 2016). Climate extremes have clear impacts on human health (Hashim and Hashim 2016). Slow onset changes include mean temperature change, warm nights, sea ice melting, mean sea level rise and those impacting societies in a slow way (Stocker 2014). Whatever these key elements or variables impact human health directly or indirectly, they need to be considered in a defensible and actionable manner with local historical and projected future climate change data when impacts assessment are carried out.

#### 1.3.1.2 Human Life Support Ecosystem

Although human life is limited, it is a long-term task to protect our earth systems (Cash et al. 2003) as this involves intergenerational equity. The earth system includes all the elements of land, soil, water, food and air each of which is life-supporting element that links directly to human health. They have been studied over history, such as land and soil water degradation (Rosenzweig et al. 2001; Huang et al. 2016), desertification (Xu et al. 2014; Li et al. 2016), soil erosion (Nearing et al. 2004; Panagos et al. 2017), water scarcity (Gosling and Arnell 2016), food production (Deryng et al. 2014; Lesk et al. 2016; Cheeseman 2016) and air pollution (D'Amato et al. 2013). However, the understanding and awareness of protecting this system are still in a developing stage with new evidence being found with time.

**Food**

In a climate changed world, elevated carbon dioxide stimulates the yields of wheat and other grains; however, it reduces their protein/nitrogen (N) concentration in turn. Other essential nutrients are also subject to change (Broberg et al. 2017). It was found that the staple foods of rice, wheat, barley and potato protein contents decreased by more than 6% with the increase of carbon dioxide. As a consequence, by 2050, assuming today's diets and levels of income inequality stay static, an additional 1.6% or 148.4 million of the world's population may be placed at risk of protein deficiency because of elevated $CO_2$ (Medek et al. 2017).

**Water quality and supply**

Climate changes include slow onset changes such as mean temperature increase, and extreme events including, heavy rainfall, cyclones, floods, heatwaves, droughts, extreme cold and wildfires. Changes in water catchments, storage reservoirs, the capacity of water treatment processes or the viability of distribution systems can have far-reaching and potentially harmful impacts on the quality fo drinking water (Khan et al. 2015; Urich et al. 2017). The provision of safe drinking water could be exposed to new risks. This may require the integration of the knowledge gained from examination and recognition of systemic risk relations, in combination with more inclusive collaboration across the water and related sectors (Boholm and Prutzer 2017).

**Air quality**

The source of emissions, transport process, dilution, chemical transformation and the eventual deposition of air pollutants can be directly impacted by air temperature, humidity, wind speed and direction, and atmospheric mixing layer. Concentrations of other human health-related air contaminants, such as smoke from wildfires, airborne pollens and molds could be exacerbated by climate change. Growing studies focusing on impacts of climate change on air quality show these impacts and the implications for human health may manifest in the near future (Kinney 2008; Hsu et al. 2017; Ebi et al. 2017).

#### 1.3.1.3 Urban System

Urban built-up areas are largely a huge and relative standing out system, which represents support complex and dynamic interactions between societies and natural ecosystems. As the world's population migrates to urban centres, cities will increasingly concentrate and potentially attract greater populations for working opportunities and unbalanced development. Urban populations are characterised by their high population densities and thus can become more vulnerable to climatic change and bacterial and viral disease threats from heat waves, wildfire particulates ($PM_{10}$ and $PM_{2.5}$), air pollution, and for coastal cities the impacts from sea-level sea level rise and extreme still high water events and the impacts stemming from the concatenation of land-based and sea-based flooding (Campbell-Lendrum and Corvalán 2007; Slovic et al. 2016).

Meanwhile, urban areas are consumers of resources and contributors to GHG emissions. This may lead to changes in socio-economic development paths that exacerbate global climate change. The interaction between urban-related energy and transportation and climate change policies, and in relation to health and well-being creates both a need and an opportunity for new understanding and methods to assess complex risks and to support urban planning and development decisions (Hughes et al. 2018).

### *1.3.2 Social Systems*

#### 1.3.2.1 Social Capital

Social capital is defined as "the degree of social cohesion which exists in communities. It refers to the processes between people which establish networks, norms and social trust, and facilitate coordination and co-operation for mutual benefit". With the gradual in depth understanding of the social determinants of health, social capital is increasingly becoming an important component of health research (Kunitz 2004; Harpham 2008; Kim et al. 2008).

Beyond impacts on physical infrastructure, some studies have indicated "Climate change adaptation is a social process inherently" (e.g., Wolf 2011). The strengthening of individuals and communities affected by climate change needs to be on the agenda of adaptation (Adger et al. 2005; Aldrich et al. 2016). Therefore, social capital naturally needs to be addressed in the social system.

#### 1.3.2.2 Justice and Equity

When considering SDG's justice and equity issues are increasingly on the international community's agenda. This is actioned locally through their incorporation in climate risk assessments and concomitant adaptation planning and project implementation. Increasingly climate change and its role in equity and justice amongst the poorest and vulnerable groups are gaining attention at local and sub-national and international levels (Thomas and Twyman 2005).

Guerra et al. (2016) found that health inequalities are linked to social inequities. Imbalances in the distribution of power, prestige and resources can have either a direct or indirect role in determining the health status of population groups. Linking with climate change, Boeckmann and Zeeb (2016) proposed a theoretical perspective focusing on proxy indicators, by measuring the effects of adaptation on determinants of health. This framework was aimed at the measurement of health related inequities, so as to improve climate justice and climate change adaptation evaluation standards.

#### 1.3.2.3 Gender

There are complex and dynamic links between gender and climate change, and they exist at all the dimensions from vulnerability to adaptative capacity and mitigation measures, and at different spatial scales (Terry 2009). Manata and Papazu (2009) described that due to the division of labour between the sexes, which places the primary burden of natural environmental systems, mainly agricultural related work on the women, making women more vulnerable than men to the consequences of climate change, as well as making great demands on women's adaptive capabilities, especially in developing countries (Andersen et al. 2016; Chauhan and Kumar 2016). Studies from Sub-Saharan Africa consistently exhibit high-levels of gender engagement (Bunce and Ford 2015). Natalia (2011) and Bunce (2015) found that women may be affected differently according to their status in physical health, education and agricultural production activities. Other vulnerabilities and adaptive capacities of women were, however, found to be consistent with women in Arctic regions where hunting and collection of marine resources can be important sources of sustenance.

#### 1.3.2.4 Health Literacy and Culture

Inclusive with functional literacy is the notion that increasingly more sophisticated literacy skills are needed to continue to fully participate in society. Therefore, low literacy may have an effect on health and health care (Berkman et al. 2010). Health literacy reflects the knowledge and abilities of persons to reach the demands of health in modern society. Sørensen et al. (2012) developed an integrative conceptual model that focused on four-dimensional matrices of health literacy. These were applied to several health domains: knowledge and motivation; competencies of accessing and understanding; and finally, appraising health care information, disease prevention and health promotion settings.

Regarding climate change related health literacy, interventions and knowledge translation and guidelines for projecting health impacts are lacking (Hess et al. 2014), capacity building is part of the climate change adaptation process (Marinucci et al. 2014; Araos et al. 2016).

#### 1.3.2.5 Belief and Religion

Quality of life and spirituality research is a growing area of interest in the health professions (Panzini et al. 2017). Li et al. (2016) found that frequent attendance at religious services was associated with a significantly lower risk of all-cause, cardiovascular, and cancer mortality among women. When appropriate, physicians have been advised to consider the discussion of religion and spirituality with their patients to gain a more holistic understanding of well-being in relation to their presented health status. Moore (2017) demonstrated that when spirituality, demographic factors, social support and spiritual coping usage were all examined as predictors of mental health, religious and secular forms of spirituality were the only variables that maintained a large predictive strength. The results indicated that living in accordance with one's spiritual values, even when defined in a variety of ways, is characteristic of greater mental health.

The encyclical on Climate Change and Inequality: On Care for Our Common Home (Pope Francis 2015) has had far-reaching influence. The encyclical suggests that sustained exposure to compelling climate messages from trusted sources can increase the performance of activism and ultimately modify human behaviour (Myers et al. 2017).

### *1.3.3 Economic Systems*

#### 1.3.3.1 Economic Development

Many epidemiological transitions are propelled by economic development. For example, differences in GDP per capita explain almost two-thirds of the differences in female obesity among 37 developing countries (Monteiro et al. 2004). Within countries, cardiovascular disease (CVD) is also related to income level. CVD and its risks are concentrated among the lowest socio-economic groups of the more developed (upper-middle and high-income) countries, and among middle and high-income populations of low-middle income countries (Monteiro et al. 2004; Kelly and Fuster 2010).

Health can affect income, work productivity, children's education, savings and investment and demographic structure (Chisholm et al. 2010). Current illness may impact on lifespans and life cycle behaviour. Some studies link health and nutrition in utero, with that of the first few years of life, on adult physical and cognitive development and economic success (World Health Organization 2009; Bloom and Canning 2009). Some health interventions that are relatively inexpensive can have large-scale effects on population health. Such investments are a promising policy tool for growth in developing countries (Deogaonkar et al. 2012).

Climate change has largely been driven by fossil fuel-dependent economic development stemming from the consequences of the industrial revolution and corollary changes in institutional, socio, earth, economic, and technical systems (Fouquet 2016). Eventually, the impacts of climate change on human health became noticeable and costly. To solve problems stemming from climate change, they need to be mainstreamed into economic development processes (Fouquet 2016; Qi et al. 2016), and need to be evaluated and monitored (Peters et al. 2017).

#### 1.3.3.2 Individual Income and Health Expenditure

Individual income inequality has adverse impacts on health and this is manifested by a myriad of differences from the individual to population groups (Lynch et al. 2000; Deaton 2008). Poor households can pay a substantial share of their income for health services and this can push up poverty (World Health Organization 2004). Many households borrow, sell their assets or forgo needed health services and are either incapacitated or are underproductive in the labour market. Households may not be able to escape the trap of ill-health and poverty once they enter it.

Many governments have cut the real per capita budget for health owing to poor overall national economic performance. To keep a resemblance of a public health system operating policymakers have resorted to cost containment and cost recovery strategies and user fees. Households are increasingly paying for necessary health services and often under duress. Public and private resources need to be more equitably allocated to address health related issues (Lynch et al. 2004).

Climate change could bring more problems on income equality in low-income countries (Hanna and Oliva 2016). Normally they are the most vulnerable population to climate change (Lloyd et al. 2016). In low-developing countries, children also encounter air and water pollution, infectious and parasitic diseases and can suffer climate-induced displacement, migration and violence (Hanna and Oliva 2016).

#### 1.3.3.3 Health Infrastructure

The malfunctioning of health care facilities can ensue during and immediately following extreme weather events. This can be devastating for communities during disaster events and hamper sustained recovery efforts (Balbus et al. 2016). Climate change related hazard can have an impact on infrastructure location (service locations, stormwater, site and transportation access issues); infrastructure structure (fixed structural elements, such as roofs and walls); non-structural (utilities, electromechanical systems, communications systems); organisational (supply chain and staff accommodation). The function and accessibility of the infrastructure like the hospital and critical healthcare provision system should be climate resilient (Guenther and Balbus 2014).

To produce more resilient hospital infrastructure, there needs to be better resourced and integrated/collaborative approaches applied to disaster management planning (Chand and Loosemore 2015). Disaster planning decisions would benefit from the more active participation of health facilities managers. Better systems, training, technology and information about health infrastructure performance before, during and after extreme climatic events would strengthen resilience.

## *1.3.4 Institutional System*

### 1.3.4.1 Governance

Steering and rule-making related functions define governance in the health sector. Governance requires the balancing of competing influences and demands from the different components of the institutions. It can include: defining the strategic direction of policy development and implementation; remapping poorly performing trends; spelling out how health fits with national development priorities; regulation of a complex myriad of actors and agents; and creating and implementing appropriate monitoring and evaluation mechanisms. These are carried out to meet a set of governmental health objectives that are designed to broaden access and improve the overall individual health of the population (Kickbusch and Gleicher 2012). The governance challenges in the health sector are by no means unique (Frenk and Moon 2013), especially linking with climate change governance and city issues (Gupta 2016; Hughes et al. 2018). Systems approaches are needed to solve interdependent complex governance issues.

### 1.3.4.2 Institutional Arrangement and Capacity

Management of the health effects of climate change and strengthening health systems will require inputs from all sectors of government, civil society, local communities and academic institutes. This is the new way of institutional arrangement and certain capacities to carry out new activities (Costello et al. 2009; Bloland et al. 2012). An integrated and multidisciplinary approach requires multiple levels of action to reduce the adverse health effects of climate change. Institutional capacity building is critical for the implementation of some regions (Furgal and Seguin 2006; McIver et al. 2016).

### 1.3.4.3 Policy and Strategy

More proactive policy and strategy are required to ensure that development decisions serve the ultimate goal of improving human health (Campbell-Lendrum et al. 2007; World Health Organization 2015). In 2015 the Lancet Commission on Health and

Climate Change mapped out the impacts of climate change, and the necessary policy responses, to attain the standards of health for population worldwide (Watts et al. 2015). Climate change could become a great opportunity for global health (Wang and Horton 2015). Adaptation policy and actions for climate-related health hazards can be both proactive and reactive and they occur at the population, community and individual levels (McMichael 2003).

#### 1.3.4.4 Implementation Capacity

Common barriers to implementation can include: opposition from key stakeholders; a lack of resources (human and financial); poorly defined implementation guidelines, roles and responsibilities; institutional and existing policy conflicts; and, poor coordination and lack of political will to see changes through to fruition (WHO 2017).

Many innovations in the health sector are complex, requiring coordinated use by multiple organisational members to achieve benefits. Often, complex innovations are adopted with great anticipation only to fail during implementation (Haines et al. 2004; Helfrich et al. 2007). This reflects the gap that can often exist between theory and practice. Interventions designed in a research environment fail to achieve the desired end result and desired patient care outcomes when introduced into a diverse array of real world settings. (Damschroder et al. 2009).

#### 1.3.4.5 Healthcare Sector as Systems

Climate change is creating an opening for the health sector, whereby population health can be a foil for improving our ways of living to become more environmentally sensitive and equitable (McMichael et al. 2009). There could be substantial health dividends achieved through restructuring our social practices, technologies, for example in energy production and commercial practices. The current health care system characterised by fragmentation and lack of coherence seems to be limiting interventions and quality health reform outcomes.

A reorientation of goals with an increasing emphasis on patient functioning, social participation and the addition of clinical measures as core outcomes of effective care may be required (World Health Organization 2012). Policies for climate change mitigation and adaptation offer different opportunities for healthcare sector development, especially climate financing mechanisms for innovative solutions (World Health Organization 2017; Junghans et al. 2017).

## 1.4 Systems Thinking and Modelling for Human Health and Climate Change

Systems thinking requires that one views systems and their sub-components as intimately interrelated and connected to each other. Ultimately, there needs to be the belief that truly understanding how things work requires the interpretation of interactions and relationships within and between systems (Adam and de Savigny 2012; Adam et al. 2012). Such a perspective goes beyond specific events, to recognise behaviour and the underlying systemic interrelationships that define the patterns and their related events (Leischow et al. 2008). When the systems are open they can be complex and adaptive, constantly changing, sometimes resistant, counter-intuitive, non-linear, often the whole is greater than the sum of the parts (Best et al. 2007).

System thinking in health care systems has been reported from South Africa (Gilson et al. 2014), India (Varghese et al. 2014) and China (Zhang et al. 2014). Varghese et al. (2014) guided by a complex of interactive and adaptive systems when they explored changes in vaccination coverage in India. Paxton and Frost (2017) developed a multidisciplinary curriculum that utilised systems thinking to frame and analyse global health policies and practice so as to train future leaders in global health. Caffrey and Munro (2017) applied a systems approach to evaluate health policy.

### *1.4.1 Existing System Approaches for Health and Well-Being*

At their core, systems science methodologies are designed to generate models, or simplified versions of reality. They do this by attempting to capture the real world in important ways while simplifying where ever possible but maintaining the critical aspects relevant to the studied problem. We can, therefore, better understand the structural complexity of real world problems that results from the interaction of specific phenomena and their environments.

System dynamics addresses the dynamic complexity that characterises public health issues (Homer and Hirsch 2006). The approach involves computer simulations that digitise processes of accumulation and feedback. They can be tested systematically to help uncover policies for overcoming policy resistance. Interdisciplinary partnerships have opened up and become stronger linking behavioural–social–ecologic models at various levels with new understanding achieved that all invigorate the debates around public health (Mabry et al. 2008, 2010).

Much like what-if climate change science, Semwanga et al. (2016) presented a system dynamics model of a neonatal health system. The resulting deeper understanding of constraints and opportunities and, the identification of barriers to change led to more inclusive and better adoption of required interventions in the overall system of care. Using ‘what-if’ scenarios, health practitioners could more easily discuss the consequences and effects of various decisions. Proposed interventions and their impact could be tested through simulation experiments and the results could be fed into policies and interventions with the highest impact for improved healthcare delivery. O'Donnell et al. (2017) and Pitt et al. (2016) found similar results that challenged the traditional use of hierarchies of evidence to support decisions on complex dynamic problems.

### *1.4.2 Mapping of the Structure and Function of the System*

In the system mapping phase, conceptual models of a problem are created, known as causal loop diagrams (CLDs). This is a major component of the systems thinking and modelling approach. The following steps are normally used in causal loop mapping:

(1) Identify main (key) variables (elements).
(2) Draw behaviour charts that include a time element (or reference modes) for the main variables.
(3) Develop causal loop diagrams to show the relationships among the variables.
(4) Discuss the implications of changes in behaviour over time that are implied by the causal loop diagrams.
(5) Identify archetypes that would describe high-level causal patterns.
(6) Identify key leverage points.
(7) Develop intervention strategies.

Although these steps are part of an overarching process, they need to be carefully customised when a specific SES issue is to be investigated. Figure 1.2 is an illustration of what can be considered, but may not be exhaustive when building an SES-based system dynamics model.

**Step 1: Risk identification**

This step is taken to create a broad list of climate change risks that might affect health in different scales. It is the process that generates a broad list of reasonably foreseeable ways that climate change stressors could hamper an individual or organisation in relation to health. All potential risks should be considered. This is because if risks are not identified in the early stage, they will not be analysed and evaluated in subsequent steps.

Risk identification is often carried out either through survey questionnaires, expert group discussions, brainstorming and literature reviews or the collective application of all of these methods. Expert groups are composed of experienced researchers, managers and officers from different sectors. Their expertise should cover social, economic, ecological, climatological and institutional aspects. Identifying risks is the first step, perhaps the most important step, in health risk management. When risks are not adequately identified other steps in risk management cannot be implemented.

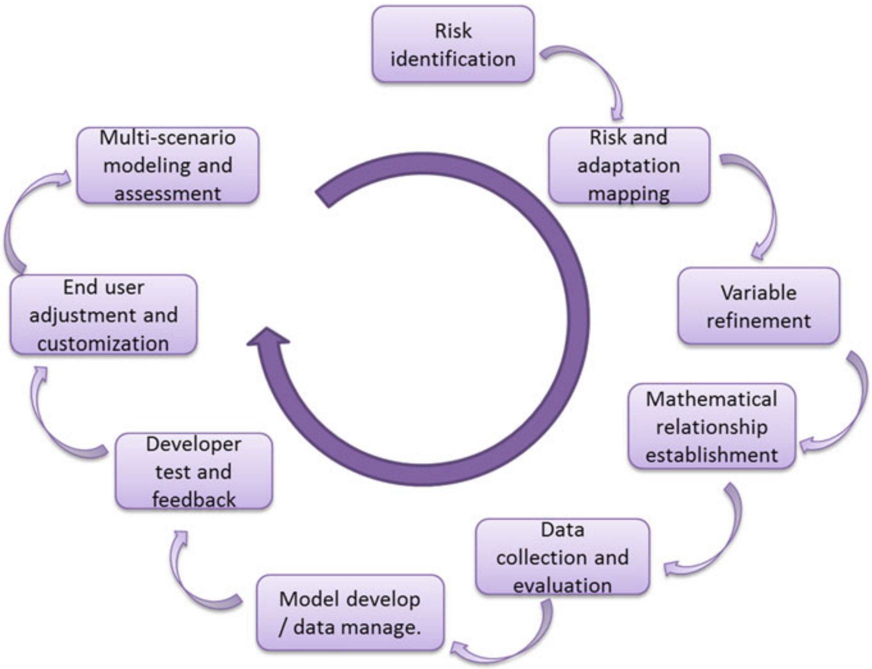


**Fig. 1.2** Steps for building system dynamics model in UrbanCLIM/RIDS platform *Source* Reprinted from Li et al. (2016). Copyright Asia-Pacific Network for Global Change Research 2016

It is important to realise that an individual or organisation's exposure to risks may change over time and new and previously unexperienced risks could emerge.

**Step 2: Risk and adaptation mapping**

The linkages and relationships among the risk (and potential options) factors are mapped to expose the structure of the socio-ecological system. The SES framework is applied at this point. Risks are defined in a SES context, to consider the interdependency of the four subsystems.

**Step 3: Variable refinement**

Variable refinement is the selection of variables in other words, which depend on data availability. Moreover, only key variables should be selected and utilised in the model building; otherwise, the model may become very complicated and bloat. The key parameter is also selected in this step.

**Step 4: Mathematical relationship establishment**

The procurement or development of mathematical equations between variables could stem from either a comprehensive review and critical assessment of the literature, or through independent development and the application of existing data. No doubt, mathematical capacity is critical for building a system dynamics model.

**Step 5: Data collection and evaluation**

According to selected variables and equations, corresponding data need to be collected, wrangled and evaluated. Data can derive from various methods and formats such as statistical or time series, raster or vector in the GIS (Geographical Information System) realm or, from categorical ranking systems.

**Step 6: Model development in relation to data management**

Available mathematical equations and data are used to build the model. Much thinking is needed. The model should be simple and logical but robust. It involves a designing and programming process. Software manuals can inform the process, however, often the most efficient way is to work with software and programmers familiar with the modeller's needs.

**Step 7: Developer test and feedback to designers**

This step involves the running of the model and testing its performance. It is an iterative process to tune model parameters in order to get the expected outcome. It is imperative that developers demonstrate the model to their end-user community, and seek their opinions and then modify and improve the model accordingly.

**Step 8: End-user adjustment and customization**

After the model ran smoothly, end users can start to adjust its parameters in order to acquire better understanding of its functions. The model can also be configured with specific skin colour, graph type, logo, etc. according to user preferences.

**Step 9: Multi-scenario simulation applied in assessments**

The last step is the creation of real simulations applying scenarios to related stakeholders who could be policymakers or peer-researchers.

As a whole, model building is a loop process of capacity building on risk assessment, risk management, integrated risk governance, evaluation and feedback.

### 1.4.3 Indicators and Variables in System Modelling

In earlier sections, potential modelling areas were described in the SES elements and structures. In fact, it is only a start for the system modelling indicator and variable identification process. There are many ways to look at indicators of system elements and functions. Moser & Ekstrom (2010) highlighted that in the management of climate change the diagnostic framework's structural elements such as actors and agents, the governance and wider socio-economic context, and the system of concern needed to be carefully considered. In the climate change adaptation process, including understanding, planning and managing (or implementing), each stage has its own working process and barriers. For successful assessment and action to be achieved it needs to be informed by the elements and the structure of the systems.

In modelling practice, the following points could be considered when indicators need to be selected:

- Accessibility and feasibility of each indicator consistently and accurately over time.
- Choosing indicators that help make the case for particular actions or strategies.
- Maintaining flexibility with the results framework, allowing users to add or adjust indicators later for projects and programmes.
- Less is more and a small set of well-tracked indicators are better than several at multiple levels. The complex process could be embedded in the modelling process as intermediate variables.
- Indicators that provide relative data (proportion, percent, ratio) ease tracking of overall progress in the larger context.
- Indicators should be chosen based on information already available or could be derived using data technology.

### 1.4.4 UrbanCLIM/RIDS Decision Support System

The UrbanCLIM system's architecture was designed to provide robust support for three classes of users—developers, modellers, analysts and policymakers (Li et al. 2016). UrbanCLIM was extended to a Risk Informed Decision Support (RIDS) platform for other sectors and broader applications (International Global Change Institute, New Zealand: www.igci.org.nz/RIDS).

By applying UrbanCLIM/RIDS, it is easy for developers to reach into the deepest software layers to extend existing and/or build a new simulation, modelling and interactive capabilities that integrate seamlessly with other applications. Modellers are able to use a variety of blocks and connectors, user interaction and model aggregation capabilities to create robust models. Analysts and policymakers like to apply simple and powerful analytical tools that smoothly integrate models and other decision-making methods into a support engine for formulating practical approaches to real world challenges. Therefore, its open framework can act as a generic platform for many other areas other than climate change issues by adding outer components.

The UrbanCLIM/RIDS platform was designed to support multi-tiered applications. The interactive layers allow efficient and effective interaction between the model developers and end users. The policy-making tier supports the policy-making processes through the provision of graphs, maps, and technical information. It supports a participatory assessment approach through users' dialogue with urban policymakers and planners from targeted cities.

**The features of the UrbanCLIM/RIDS platform include**

- Apply a modular design approach including standardised technologies to either reduce or eliminate barriers to the linking of existing and potential future models and related applications;
- An open framework, allowing for multi-scale impact assessments, that can be customised case-by-case for each studied area;
- Integrated analysis tools that enable testing of adaptation and mitigation options against socio-economic drivers, likely impacts and current sustainable development goals (SDGs);
- Climate change uncertainty analysis based on GCM and RCM ensemble approaches and the latest IPCC climate change scenarios;
- GIS compatibility;
- Visualisation and enhanced analysis options for the assessment of results;
- Integration with the Socio-Ecological-System framework.

### *1.4.5 Model Library Strategies*

To realise a publicly accessible and broadly useful library, UrbanCLIM/RIDS has an urban climate change decision support model library that includes impact and risk assessments for major analytical sectors: climate-related hazards such as water, transport and health. Targeted urban policymakers and planners should be part of an integrated approach. Through the UrbanCLIM/RIDS Community of Practice, various tools, data and models can be enhanced and integrated into the platform thus enabling a robust knowledge, technology sharing, transfer and, communication system.

### *1.4.6 Knowledge Management Tool*

The risk-informed decision support system provides a navigator that can act as either a knowledge or project management tool. It can also be used to store and index existing studies, data, models and literature. Each model and study is presented alongside