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Urban adaptation to climate change: geographers and wicked problems

La adaptación urbana al cambio climático: los geógrafos y algunos problemas perversos

Andrew Kirby
andrew.kirby@asu.edu
School of Social and Behavioral Sciences
Arizona State University (United States)

Abstract

This paper explores the importance of adaptation to climate change impacts in urban areas. The complexity of existing and likely impacts poses unique challenges to all aspects of society, from state to polity and economy. These in turn pose methodological challenges to academic practice, demanding the integration of macro and micro perspectives and pure and applied research. The paper argues that geographers can make significant contributions to this scholarship.

Key words: climate change; cities; adaptation; transdisciplinarity; geographers.

Resumen

Este artículo explora la importancia de la adaptación a los impactos del cambio climático en zonas urbanas. La complejidad de los impactos existentes y potenciales plantea retos singulares a la sociedad, desde el Estado hasta las formas de gobierno y la economía. Y estos, a su vez, plantean retos a la academia, exigiendo la integración de las perspectivas micro y macro, así como de la investigación teórica y aplicada. El artículo defiende que las/os geógrafas/os pueden contribuir de manera significativa a esta cuestión.

Palabras clave: cambio climático; ciudades; adaptación; transdisciplinariedad; geógrafos/as.

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1 Introduction: wicked problems demand different approaches

Climate change constitutes an exemplar of a wicked problem, which can be characterized as a serious challenge to existing social, political and economic life (Head, 2008). Wicked problems are marked by their scale and intractability, both of which limit our ability to comprehend both the extent of the problem, and the manner in which we can generate policy responses (Zellner & Campbell, 2015).

The low probability of successfully mitigating climate change in the immediate future suggests that both science and policy practitioners should also consider alternative avenues of applied research, notably a focus upon adaptation to the likely future, in contexts ranging from agriculture to urban design. As will be discussed in greater detail below, the challenge to established practice in any such context will depend upon analysis which involves an integration of macro and micro conditions. It will also necessarily involve the interplay of the social and the natural sciences.

For clarification, Figure 1 suggests illustrative examples of what can be considered to be macro or global research, and micro or local research; these can be further broken down into work focused on nature or society. Examples include the global dimensions of climate change [A]; this is well-established research, recently being complemented by work done by social scientists on global issues such as slums or gentrification [B]. Physical scientists are also known for empirical work at the local scale [C] (e.g. watersheds, deltas or biomes), although these units are infrequently used in social science, where for instance 'the city' is invoked as an ideal type rather than a common form of case study [D].

Figure 1 also includes examples of research undertaken by geographers, whose commitment to an understanding of processes operating at different spatial scales is well established. In addition, we can state that while many geographers have moved to the margins (of spatial science and the humanities), some do still recognize the possibility of integration. We will return to this in Sections 4 and 5.

Figure 1. Illustrative examples of research undertaken at different scales by social scientists and physical scientists [A–D] and by geographers [1–4]

	Global	Local	Global Geographic Research	Local Geographic Research
Physical	[A] Clayton, S., Devine-Wright, P., Stern, P.C., Whitmarsh, L., Carrico, A., Steg, L., Swim, J., &Bonnes, M., (2015). Psychological research and global climate change. *Nature Climate Change, 5(*7), 640.	[C] Llubes, M., Florsch, N., Hinderer, J., Longuevergne, L., & Amalvict, M. (2004). Local hydrology, the Global Geodynamics Project and CHAMP/GRACE perspective: some case studies. *Journal of Geodynamics, 38*(3–5), 355–374.	[1] Summerfield, M.A. (2014). *Global geomorphology*. Routledge.	[2] Whitman, G.P., Pain, R., & Milledge, D.G. (2015). Going with the flow? Using participatory action research in physical geography. *Progress in physical geography, 39*(5), 622–639.
Social/Human	[B] Lees, L., Shin, H.B., & López-Morales, E. (2016). *Planetary Gentrification*. John Wiley & Sons	[D] Hambleton, R. (2014). *Leading the inclusive city: Place-based innovation for a bounded planet*. Policy Press.	[3] Vasudevan, A. (2015). The makeshift city: Towards a global geography of squatting. *Progress in Human Geography, 39(*3), 338–359.	[4] Dolan, A.H., & Walker, I.J. (2006). Understanding vulnerability of coastal communities to climate change related risks. *Journal of Coastal Research*, 1316–1323.

Source: own elaboration

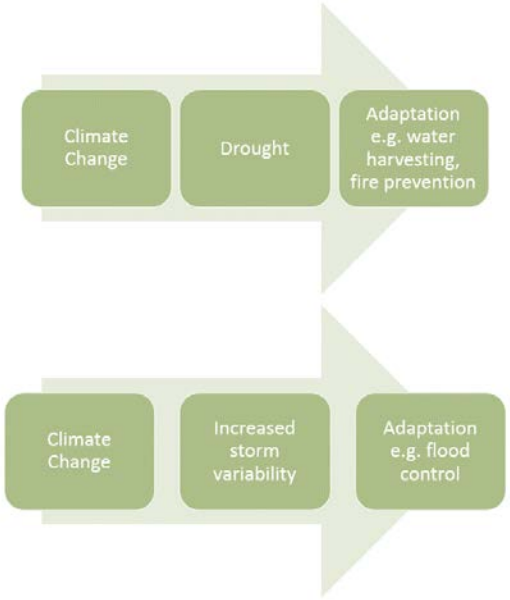
2 Climate change impacts

In this paper, it is taken for granted, from even the admittedly brief data record, that unusual weather events pose significant challenges to human societies at this moment: as Adger et al. put it bluntly [and a decade ago]—"climate change is a reality" (2004, p. 77). As there is little evidence that these challenges are being successfully met at the regional or global scale, it is a question of social justice that we address the outcomes of these extreme events, and do so by producing adaptive policy for communities under threat (Pielke et al., 2007; Saraswat & Kumar, 2016).

This is easier suggested than accomplished. Even similar process changes can result in very different outcomes in different locations, and they demand, in consequence, different policy responses. In the hypothetical situations demonstrated in Figure 2, changing climate might lead in one location to prolonged conditions of drought, but in a second location to a higher probability of intense rainfall

and consequent flooding. The adaptive demands placed upon public policy and civil society will thus be quite different, and this could occur in locations which are relatively close to each other. In the first context, adaptation will involve a range of social interventions such as education to reduce water consumption through to the creation of new technologies to maintain agricultural yields despite reduced rainfall (Varela-Ortega, 2016). In contrast, in a second location, adaptation will demand attention be paid to infrastructure placed under threat from extreme weather events, and changes to urban design to cope with flood impacts.

Figure 2. Similar climate change processes producing examples of different outcomes



Source: own elaboration

2.1 Climate change and urban impacts

While extreme natural events (earthquake, landslide, or storm) can cause severe devastation in rural areas—which often lack advance warning systems and are hard for rescuers to reach subsequently—urban areas face particular challenges in this era. This is especially apparent in the context of larger and more frequent storms, be they tornadoes, typhoons, or hurricanes.

Precipitation that falls in natural settings is destined to become groundwater or to evaporate, with quite small percentages becoming runoff; this can be as little as 5% of total precipitation in a forest setting (Saraswat et al., 2018). This is very different than what occurs in urban areas, where limited amounts of vegetation and large impervious surfaces can rapidly lead to over half of total precipitation becoming runoff and producing an 'urban stream syndrome' (Askarizadeh et al., 2015). It is suggested that in a typical urban environment (with roads, parking lots and other concreted areas, only 0.25" of rain may be contained in retention ponds, and all more intense storms are likely to produce runoff that generates flooding (Wilson, 2016, chapter 2).

While these differences between rural and urban areas are well known, current research on climate change also suggests the following. First, while rainfall may in the future become more variable, the possibility of unusually large rainfall events also increases (Knight, 2017). Second, as already noted, 500 and 1000-year events will certainly trigger flooding (even in rural areas). In urban areas, such flooding increases the possibility of infrastructural failure, as runoff becomes channeled into creeks, and then roadways, freeways and so on (Kim et al., 2016).

A third dimension to urban flooding is that traditional problems of pollutant transfer is exacerbated, with chemicals and pharmaceuticals being transported to distant surface locations. Heightened amounts of mercury and benzine are found routinely in most cities, while the excess nitrogen employed in many gardens is also transported away from source. While chemical and solid materials eventually find their way into groundwater, this too is problematic; for example, nitrogen can participate in chemical reactions which can eventually produce elevated levels of arsenic in aquifers (Wilson, 2016).

2.2 New adaptive planning demands

Empirical studies suggest that physical damage and injury are rising in step with increased urban development and climate change impacts, although the calculations are complex in the extreme (Tol, 2009). Even in situations where planners and policy makers fully understand the challenges that they face, extreme weather events demand a new approach to adaptation. A compelling example of the complexities of adaptive planning is contained in a study of infrastructure provision in Phoenix, Az (Kim, et al., 2017). This case study is based upon a 1000-year storm that occurred in 2014, depositing one third of a usual year's rainfall in a single 24-hour period. The failure of a pumping station, designed to keep the city's major freeway open, points to the dangers of 'fail-safe' planning—that is, the assumption that threats can be managed by the design of technical systems that can handle low-probability events. Naturally, many events do fall within the limits of engineering tolerance; but other examples are now well known in the aftermath of cascading failure—the flooding of New Orleans following Hurricane Katrina in 2005, and the failure of the Fukushima nuclear power plant following the 2011 tsunami are paradigmatic cases (Yarnal, 2007; Park et al., 2013).

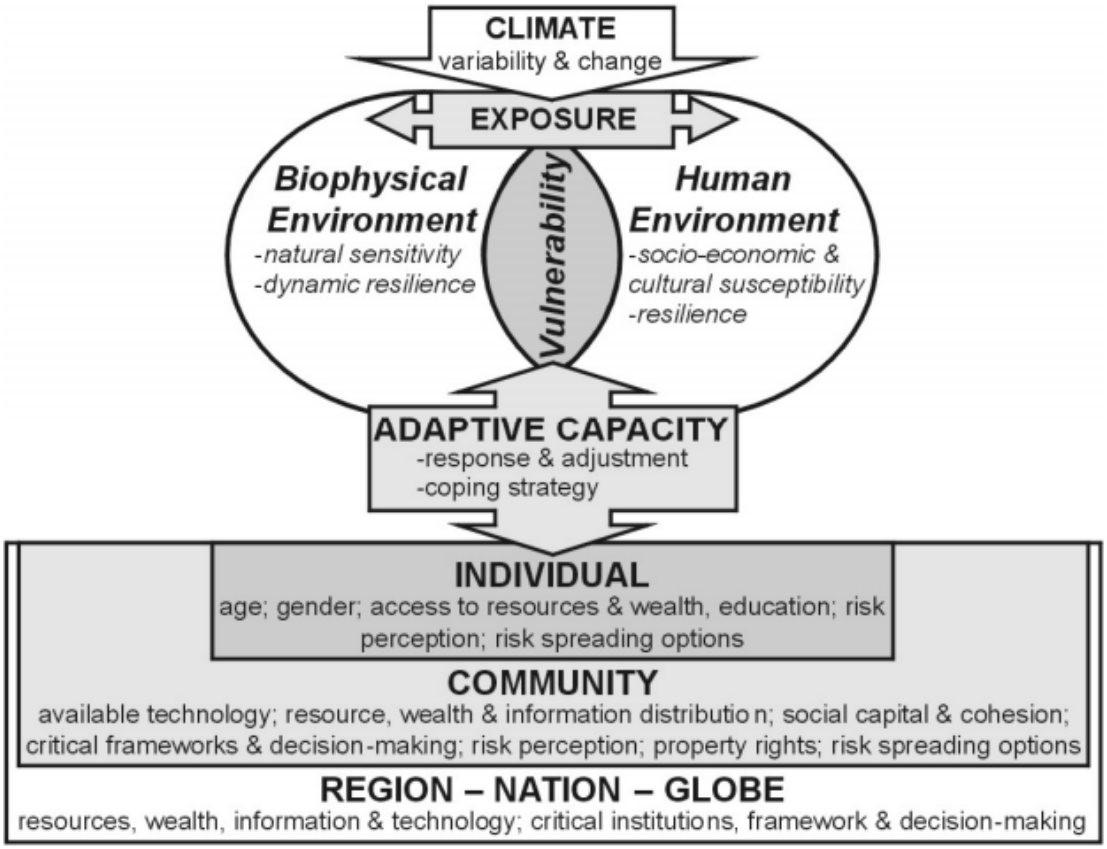
Kim et al. argue that in an era of climate change which is taking us into unknown probabilities, we should move away from fail-safe planning towards an alternative—which is termed 'safe to fail' (Ahern, 2011). In such situations, it is assumed that infrastructural failure is more likely to occur because of changing environmental conditions; the goal of the planner is thus to ensure that the repercussions are kept within regulatory limits. It is important to note that this approach demands that residents and businesses impacted by controlled failure are consulted within the policy process, so

that evacuation plans and other forms of adaptation can be explored. This innovation will be explored further below.

2.3 Adaptive heuristics

The complexities of adapting to climate change in urban areas can be summarized as an integration of the elements shown in Figure 1—global/local/natural/societal. An interesting example of this integrated thinking is provided by Dolan and Walker, who explore the concept of vulnerability as a heuristic which connects climate change to adaptation (2006). Their study is focused on Canadian coastal communities, but their heuristic could be applied to many different studies.

Figure 3. Human and physical elements at the core of the adaptive process



Source: Dolan and Walker (2006)

The complexities implied by this integration are evident, in terms of the science and the large numbers of stakeholders involved. The latter will be picked up again below.

3 Practical challenges posed by adaptation

The demands placed upon the planning process by the creation of adaptive responses to climate change are multiple. While the broad outlines of European or national policy may be relatively straightforward—as with the case of Water Directives (España Villanueva, 2016)—the creation of local plans involves analysis of the specific conditions of each community, which involves

components of both the physical and human geography. Safe-to-fail plans of the sort discussed above must inevitably depend upon the knowledge of residents and other stakeholders in a locality. In part, this is a function of the importance of resident participation in any legitimate planning process, as has been advocated for a half century. More recently, it is now strongly promoted by transdisciplinarity advocates (Sakao & Brambilla-Macias, 2018) and is seen as reflecting the importance of local knowledge in adaptive plans.

3.1 Stakeholders

An example of the fine-grained nature of local planning is provided by Chiang (2018). This case study focuses on a neighborhood in Taipei which has historically been subject to flooding. The flood risk has increased in some locations in recent years since control measures were introduced, which have had a range of positive and negative impacts. In the study, residents were asked to give their views on flood risks and possible solutions, and the results show how detailed local plans depend upon these differing experiences for success. Planned interventions create feedback loops, which can sometimes be negative, necessitating further data collection. Obtaining high quality quantitative and qualitative data from stakeholders (amongst other sources) is therefore important, although recent technological developments make this a much simpler task. A resident's smart phones can be employed for crowdsourcing data (Zevenbergen, Fu, & Pathirana, 2018), and these fragmented technologies are consistent with the safe-to-fail concepts already discussed and as such can also be used for emergency warning messages, placing the information literally in the hands of those at risk.

The identification of residents as participants or even policy initiators in adaptive planning is part of a complex reappraisal of how research and public policy happens. This is occurring on several different but related levels. These include a. the existence of wicked problems; b. the consequent need for multidisciplinary research teams; c. the increased visibility of transdisciplinary research (Td) with its emphasis upon the participation of stakeholders of different types; and d. the recognition of 'holders of varied types—in the Taipei case for instance, participants in the policy process might exist as resident stakeholders, and/or knowledge-holders with experience of floods over many seasons, and/or property holders with a financial stake in the neighborhood.

This incorporation of stakeholders in research and policy (and re-appraisal of how scholarship is funded and evaluated) come as retractions and manifestations of research deception undermine policy development (on issues such as obesity, which demand greater integrity in the research process—see Sarewitz, 2016). One safeguard is to open up the process of scholarship by creating multiple member research teams. This shift to multi-and inter-disciplinary research has been broadened by the proponents of Td scholarship, who advocate for taking research outside the academy by involving citizen scientists and all types of stakeholders (termed T2 research by Sakao & Brambilla-Macias, 2018).

T2 research offers an attractive alternative to traditional forms of scholarship, which is essentially defined within the academy and is hostage to academic standards of funding and publication, and is constrained by academic criteria of promotion and other rewards. The induction of stakeholders of varied types is an attempt to break the remoteness of academic research and to make related policy outcomes more relevant to residents and citizen scientists (Saltelli & Funtowicz, 2017). Nonetheless, while T2 research appears attractive, it is also often problematic on several levels. It is very difficult to sustain the level of complexity that is common in many examples of urban research. While Collier et al. have argued that cities constitute exciting laboratories in which residents can add to the processes of research and policy formulation, this optimism may be misplaced. Decades of attempts to incorporate resident views and experiences show only mixed success. In the contexts under scrutiny here, it is often the case that planning agencies are deeply entrenched arms of the state and their slow and secretive deliberations about expensive projects are commonly kept from public scrutiny. For instance, a case study of river basin management in Ebro and Tucson, which touches on adaptation strategies, reveals that consultation with residents is intermittent and viewed by planners as an indulgence rather than offering meaningful advantages (Ballaster & Lacroix, 2016). Perhaps the most egregious example is that of New Orleans post-Katrina. Numerous strategic plans were generated to bring the city towards a more sustainable future, ranging from the dismantling of at-risk neighborhoods to the creation of new infrastructure. However, none of these involved significant resident input, with the result that opposition to each proposal was vocal and intense (Ford, 2010).

Racialized attitudes leading to socially-unjust policies are today a common theme in urban planning; beyond the example of New Orleans we can also turn to adaptation studies in Boston which have shown that minority communities are not centrally placed in mainstream planning efforts (Douglas et al. 2012). Due in part to historical attitudes, it is a challenge to incorporate stakeholder views from minority neighborhoods, where language barriers and immigration status can be impediments (Paolisso et al., 2012). This is of course a serious issue as low-income minority communities are frequently in at-risk locations.

These complexities can cause research to drift in directions that are inconsistent with the needs of stakeholders. Zellner and Campbell (2015) discuss the problems inherent in planning for complex problems with residents whose needs and commitment cannot be shoehorned into projects which last for at least two to five years. In consequence, while T2 scholarship is highly desirable, it may be best sought in specific types of context, where smaller and quicker projects are realistic. By definition, these are unlikely to extend to policy development related to climate change.

4 Transdisciplinarity and Geography

Transdisciplinarity has revealed an avenue towards a revised form of scholarship, paying particular attention to social outcomes and citizen participation. However, as has been argued here, the

emphasis upon incorporating stakeholders may place significant restrictions on the process. The limits to Td include the complexity of the topics and the need to incorporate different forms of scalar thinking—analytical [broad] and knowledge-based [narrow/local]. The challenge posed by adaptation can be seen consequently as consistently complex. It involves a global problem which is manifested in local contexts. It is also of course a wicked problem that is rooted in the physical environment, regardless of the role that human actions play in its trajectory.

A significant challenge to the creation of effective teams in this research setting is that the analytical components are highly fragmented. The science focused upon the natural world is often unconnected to the scholarship produced by social scientists and policy makers. The difficulties are compounded by the way in which conceptual and empirical work is fragmented into global or local foci. While Td research is promoted as a new orthodoxy, it is possible to see the emphasis upon transcending disciplines (and indeed the academy) as limits rather than as opportunities. For this reason, it is appropriate to ask if representatives of a single discipline—geography—may be better placed to contribute to teams to tackle research and policy formulation in contexts such as urban adaptation. As Figure 2 indicates, the key needs can be fulfilled by research teams involving geographers, who are familiar with the goals of integration across scales and across the 'two cultures' of natural and social science.

5 Geography in the time of adaptation

Relations between the physical and human wings of the discipline have been discussed since the creation of the modern university after 1945 (e.g. Goudie, 1986). These discussions have (for the most part) been hortatory and normative observations about professional prospects at the level of the discipline, rather than being focused upon improved research outcomes. They have also tended to involve human geographers 'generously' crafting new directions for their physical colleagues (Massey, 1999; Lave, 2015).

This paper has no aspirations towards adding to these essentially circular discussions, and certainly makes no suggestions about how individuals should do their work or how disciplines should cohere. Indeed, it will be remembered that this discussion has emphasized that the existence of wicked problems demands team research of one form or another. That said, it makes sense that human and physical geographers could—perhaps, should—come together as members of larger research teams, as their shared training can add to the coherence of a multidisciplinary unit, which is often lacking (Ledford, 2015, p. 308). Crucially, this pragmatic insight is supported by more permanent perspectives, which are well expressed by a physical geographer as follows:

> At some scales, and for some societies, it can be relatively straightforward to demonstrate cases where both society and environment are closely related, and where

> destruction of their relatedness constitutes an immoral act damaging to both… The processes of environmental change are in this case global in scale, but we can see that global processes impact on local communities and destroy their evolved relationships on timescales that prevent a measured response and adaptation (Richards in Harrison, 2004).

Richards is basing his integration upon ethical considerations: "this offers geography a chance to respond to the now often expressed need for interdisciplinarity, by promoting its own intra-disciplinary, integrated analysis, and by adopting a stance which is both critical and ethical in relation to debates about sustainability and global change" (2004, pp. 436–437). The introduction of an ethical perspective may appear distracting, although the social justice dimension of adaptation has already been introduced (Saraswat & Kumar, 2016): yet even without that component, the complementarity of team interdisciplinarity on the one hand, and intradisciplinarity within geography, remains compelling.

5.1 What can geographers bring to the table?

As we have already indicated in Figures 2 and 3, adaptation is narrow neither in creation nor response. Adger, Arnell and Tompkins have emphasized that adaptation must emerge in a multi-scalar way and that there can be no 'one size' solutions (2005). They point out that within society, scales are socially defined through experience in managing conflict in environmental contexts. In contrast, in the environmental context, scales reflect unique biological and other physical processes, and these may not easily be mapped one to the other. For instance, in the Ebro/Tucson cases, watershed management produces large and distant management solutions which may be effective but are remote from social constructions (Ballaster & Mott Lacroix, 2016). Overall, Adger et al. argue as follows:

> adaptation operates at different spatial and societal scales and that success or its sustainability needs to be evaluated against different criteria at these different levels. Elements of effectiveness, efficiency, equity and legitimacy are important in judging success, but the relative weight allocated to each criterion is not given but rather emerges from societal processes of consent and action. The degree of success critically depends on the capacity to adapt and the distribution of that capacity. The relative importance of success criteria is contested and will vary over time.

6 Discussion and agenda

This paper has argued that adaptation to climate change presents us with a truly significant challenge to both science and public policy. The examples introduced above underline the importance of

urban adaptation but have not provided the details of how this research and policy material might be pursued.

The challenge is three-fold. First, the continued expansion of urban populations converges with existing natural hazards—such as rising sea levels and more powerful storms—to produce greater numbers of residents living in harm's way. Second, the expansion of built-up areas into locations where development has not previously occurred constitutes a convergence of pressures upon residents living in dense conditions, such that cascading failures may result in large losses of life and prosperity. And third, this convergence in turn throws into relief the social justice dimension, for as Pielke et al. have argued, these changes constitute growing risks for the vulnerable (2007). These will be examined in turn.

First, and most simply, urban development continues as a global phenomenon. In many contexts, urban populations are safer than rural ones, as they can be educated about risks and reached more readily by emergency services (and now via smartphones). However, it is also the case that urban populations are difficult to support in situations where catastrophic failures occur. Hurricane Katrina is clearly the paradigmatic example (Yarnal, 2007).

The list of negative outcomes that can result from climate change impacts is enormous. Gasper et al have presented an overview of the many possible results, which range from a collapse within the supply chain through to the possibility of infectious diseases and even the appearance of dangerous wildlife in residential spaces (2011). This heightened level of risk is further exacerbated in situations where development has taken place in locations which have not previously witnessed roads, homes and infrastructure. Residents may live in ignorance for a long period until circumstances reveal the full extent of the risks they face. This was the case in Houston, Tx where residential sub-divisions had been developed in many locations previously occupied by grazing land or wilderness. An extreme rainfall event in 2017 generated extensive flooding not previously seen in the metropolitan area, although catastrophic flooding had been predicted for several years (Satija, Shaw & Larson, 2016). This is an example that caused billions of dollars of damage in an affluent city; the costs of damage to communities in emerging nations may appear less in total (as insurance is little available), but for the same reason, the impacts on poor households are qualitatively greater (Waters & Adger, 2017).

Third, it is also clear that as cities grow, the operation of land and housing markets will place the poorest households in the most vulnerable locations (Kim et al., 2016). When we take all these factors into account, it is possible to see that urban adaptation is especially challenging. Detailed empirical studies in Boston of communities subjected to coastal flooding point to key issues. On the physical side, there is complex science, which is not fully understood by residents (a situation exacerbated, we can assume, by the existence of climate change denial in the US). On the social

side, there are myriad policies that can be considered, ranging from elevating homes through to exit. Different communities view adaptation in different ways. Older African American communities were concerned for their church and adjacent cemeteries; newer groups of Latina immigrants have different priorities. Furthermore, case studies indicate just how many stakeholder interests may be present in a T2 project (beyond the residents themselves). A study of greening in Brooklyn mentions 14 governmental agencies (including Federal, State and local entities), in addition to the different interests represented within the community (Curran & Hamilton, 2012).

6.1 Possible solutions: what can be done

Responses to frequent flooding will depend upon the context of governance, itself closely connected to the level of affluence of a community. In some cases, adaptation is a personal choice, while in other societies it is a communal decision. The particular solutions considered will of course also reflect the resources available to a community.

A strategic initiative is to increase awareness of the runoff challenge and to attempt to increase levels of permeability within a community. In China, for instance, planners have attempted a re-branding exercise to develop the concept of "Sponge City". In a society with a similar planning system but fewer resources, we can see a lower-profile intervention; in Hanoi, for instance, flood control has been linked to the creation of fish farms (Saraswat et al., 2018).

In situations of affluence, policy makers have opted for more elaborate interventions. In Tokyo for example, all levels of government have collaborated to create enormous overflow pipes which can accommodate millions of gallons of water in situations of excess runoff.[1] A much less costly approach has been taken in the Netherlands, where flood control has been evolving over centuries. There, communities have participated in 'Room for the River' plans, which involve the development of safe-to-fail plans for local spaces. In these instances, emphasis has been placed upon proposals which have originated within the communities, involving participation of urban communities (where flooding occurs) and agricultural communities, to which the overflow is directed (Zevenbergen et al., 2018). When this occurs, mechanisms are in place to recompense farmers and landowners for damage and loss of agricultural revenue.

An additional approach is to widen the way in which adaptation is characterized; if flooding is re-thought as a public health issue, then it becomes possible to assess the risks associated with certain practices. In rural areas, this might involve greater control of effluent from animal rearing; in urban areas it might involve greater control of toxins and chemicals now freely available for home use: the

1 This is of course the opposite of a safe-to-fail system, and reflects the popularity of highly engineered systems within Japanese disaster planning; the Fukushima catastrophe indicates just how dangerous such thinking can be, regardless of the many safeguards built in.

elimination of DDT in the US following the work of Rachel Carson was an important milestone in this context (Carson, 1962).

7 Conclusions

This paper has argued for the importance of cities adapting to climate change, using flooding as a powerful example of the impacts of natural events and the necessity of making changes to social practice.[2] This is a controversial advocacy, as it accepts that there is a low probability of climate change impacts being reversed during this century. However, it is assumed here that local impacts demand research and policy changes in order to minimize loss of life and property.

The example of flood adaptation strategies is important on a number of levels. It links back to the existence of wicked problems and the concept that there are challenges that demand high levels of research and policy development. It connects global processes to very localized outcomes, such that a single driver leads to results that may be different even within neighborhoods. As has been argued through the paper, many European researchers have promoted transdisciplinary research as the way forward in this context, although there are problems inherent to such an approach.

One alternative examined here involves the participation of geographers in the multi-discipline research teams necessary to engage with a wicked problem such as climate change. With their specialties straddling both social and natural realms, and global and local research, they bring particular skills to any multi- or inter-disciplinary scholarship. This is not to argue against the input of citizen scientists and other stakeholders with direct experience of the project in hand, but it is to suggest that geographers should have a special affinity for this kind of scholarship and should be effective participants in adaptive research and policy development.

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2 For clarity, the focus in this relatively short paper has been on a single outcome, flooding. As noted in the outset, adaptation will take many forms as different communities confront fires, more powerful tornadoes, and other hazards, some in turn linked and creating new hazards.

References

Adger, W. N., Arnell, N. W., & Tompkins, E. L. (2005). Successful adaptation to climate change across scales. *Global Environmental Change, 15(*2), 77–86. https://doi.org/10.1016/j.gloenvcha.2004.12.005

Adger, W. N., Butler, C., & Walker-Springett, K. (2017). Moral reasoning in adaptation to climate change. *Environmental Politics, 26*(3), 371–390. https://doi.org/10.1080/09644016.2017.1287624

Ahern, J. (2011). From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. *Landscape and Urban Planning, 100*(4), 341–343. http://dx.doi.org/10.1016/j.landurbplan.2011.02.021

Askarizadeh, A., Rippy, M. A., Fletcher, T. D., Feldman, D. L., Peng, J., Bowler, P., … Jiang, S.C. (2015). From rain tanks to catchments: use of low-impact development to address hydrologic symptoms of the urban stream syndrome. *Environmental Science & Technology, 49*(19), 11264–11280. https://doi.org/10.1021/acs.est.5b01635

Ballester, A., & Mott Lacroix, K. E. (2016). Public participation in water planning in the Ebro River Basin (Spain) and Tucson Basin (US, Arizona): impact on water policy and adaptive capacity building. *Water, 8*(7), 273. https://doi.org/10.3390/w8070273

Carson, R. (1962). *Silent Spring*. Boston: Houghton Mifflin.

Chiang, Y. C. (2018). Exploring community risk perceptions of climate change-a case study of a flood-prone urban area of Taiwan. *Cities, 74,* 42–51. https://doi.org/10.1016/j.cities.2017.11.001

Clayton, S., Devine-Wright, P., Stern, P. C., Whitmarsh, L., Carrico, A., Steg, L., Swim, J., & Bonnes, M. (2015). Psychological research and global climate change. *Nature Climate Change, 5*(7), 640. https://doi.org/10.1038/nclimate2622

Collier, M. J., Connop, S., Foley, K., Nedović-Budić, Z., Newport, D., Corcoran, A., … McQuaid, S. (2016). Urban transformation with TURAS open innovations; opportunities for transitioning through transdisciplinarity. *Current Opinion in Environmental Sustainability, 22,* 57–62. https://doi.org/10.1016/j.cosust.2017.04.005

Curran, W., & Hamilton, T. (2012). Just green enough: Contesting environmental gentrification in Greenpoint, Brooklyn. *Local Environment, 17*(9), 1027–1042. https://doi.org/10.1080/13549839.2012.729569

Dolan, A. H., & Walker, I. J. (2006). Understanding vulnerability of coastal communities to climate change related risks. *Journal of Coastal Research, sp. issue. 39,* 1316–1323.

Douglas, E. M., Kirshen, P. H., Paolisso, M., Watson, C., Wiggin, J., Enrici, A., & Ruth, M. (2012). Coastal flooding, climate change and environmental justice: Identifying obstacles and incentives for adaptation in two metropolitan Boston Massachusetts communities. *Mitigation and Adaptation Strategies for Global Change, 17*(5), 537–562.

España Villanueva, M. R. (2016). Valoración del grado de adaptación de los planes subregionales andaluces a la Directiva Marco de Aguas. *Boletín de la Asociación de Geógrafos Españoles, 71,* 129–150. http://dx.doi.org/10.21138/bage.2277

Gasper, R., Blohm, A., & Ruth, M. (2011). Social and economic impacts of climate change on the urban environment. *Current Opinion in Environmental Sustainability, 3*(3), 150–157.

Goudie, A. S. (1986). The integration of human and physical geography. *Transactions of the Institute of British Geographers, 11*(4), 454–458.

Ford, K. (2010). *The trouble with city planning: What New Orleans can teach us*. Yale University Press.

Gore, A. (2006). *An inconvenient truth: The planetary emergency of global warming and what we can do about it*. Rodale.

Hambleton, R. (2014). *Leading the inclusive city: Place-based innovation for a bounded planet*. Policy Press.

Harrison, S., Massey, D., Richards, K., Magilligan, F. J., Thrift, N., & Bender, B. (2004). Thinking across the divide: perspectives on the conversations between physical and human geography. *Area, 36*(4), 435–442. https://doi.org/10.1111/j.0004-0894.2004.00243.x

Head, B. W. (2008). Wicked problems in public policy. *Public Policy, 3*(2), 101. https://doi.org/10.1177/0095399713481601

Kim, H., Marcouiller, D.W., & Woosnam, K.M. (2018). Rescaling social dynamics in climate change: The implications of cumulative exposure, climate justice, and community resilience. *Geoforum, 96,* 129–140. https://doi.org/10.1016/j.geoforum.2018.08.006

Kim, Y., Eisenberg, D. A., Bondank, E. N., Chester, M. V., Mascaro, G., & Underwood, B.S. (2017). Fail-safe and safe-to-fail adaptation: decision-making for urban flooding under climate change. *Climatic Change, 145*(3–4), 397–412. https://doi.org/10.1007/s10584-017-2090-1

Knight, J. (2017). Issues of water quality in stormwater harvesting: Comments on Fisher-Jeffes et al. (2017). *South African Journal of Science, 113*(5–6), 1–2. http://dx.doi.org/10.17159/sajs.2017/a0207

Lave, R. (2015). Introduction to special issue on critical physical geography. *Progress in Physical Geography, 39*(5), 571–575. https://doi.org/10.1177/0309133315608006

Ledford, H. (2015). Team science. *Nature, 525*, 308–311. https://doi.org/10.1038/525308a

Li, X., Li, J., Fang, X., Gong, Y., & Wang, W. (2016). Case studies of the sponge city program in China. In *World Environmental and Water Resources Congress 2016* (pp. 295–308).

Massey, D. (1999). Space-time, 'science' and the relationship between physical geography and human geography. *Transactions of the Institute of British Geographers, 24*(3), 261–276.

Paolisso, M., Douglas, E., Enrici, A., Kirshen, P., Watson, C., & Ruth, M. (2012). Climate change, justice, and adaptation among African American communities in the Chesapeake Bay region. *Weather, Climate, and Society, 4*(1), 34–47. https://doi.org/10.1175/WCAS-D-11-00039.1

Park, J., Seager, T. P., Rao, P. S. C., Convertino, M., & Linkov, I. (2013). Integrating risk and resilience approaches to catastrophe management in engineering systems. *Risk Analysis, 33(*3), 356–367. https://doi.org/10.1111/j.1539-6924.2012.01885.x

Pielke Jr, R., Prins, G., Rayner, S., & Sarewitz, D. (2007). Lifting the taboo on adaptation. *Nature, 445* (7128), 597–99. https://doi.org/10.1038/445597a

Radhakrishnan, M., Pathirana, A., Ashley, R. M., Gersonius, B., & Zevenbergen, C. (2018). Flexible adaptation planning for water sensitive cities. *Cities, 78*, 87–95. https://doi.org/10.1016/j.cities.2018.01.022

Sakao, T., & Brambila-Macias S. (2018). Do we share an understanding of transdisciplinarity in environmental sustainability research? *Journal of Cleaner Production 170*, 1399–1403.

Saltelli, A., & Funtowicz, S. (2017). What is science's crisis really about? *Futures 91*, 5–11. https://doi.org/10.1016/j.futures.2017.05.010

Saraswat, C., & Kumar, P. (2016). Climate justice in lieu of climate change: a sustainable approach to respond to climate change injustice and an awakening of the environmental movement. *Energy, Ecology and Environment, 1*(2), 67–74. https://doi.org/10.1007/s40974-015-0001-8

Saraswat, C., Kumar, P., & Mishra, B. K. (2016). Assessment of stormwater runoff management practices and governance under climate change and urbanization: An analysis of Bangkok, Hanoi and Tokyo. *Environmental Science & Policy, 64*, 101–117. https://doi.org/10.1016/j.envsci.2016.06.018

Sarewitz, D. (2016). Saving science. *The New Atlantis, 49*, 4–40.

Satija, N., Shaw, A., & Larson, J. (2016). Hell and High Water. In *ProPublica*. Retrieved from https://projects.propublica.org/houston/

Summerfield, M. A. (2014). *Global Geomorphology*. Routledge.

Tol, R. S. (2009). The economic effects of climate change. *Journal of Economic Perspectives, 23*(2), 29–51. https://doi.org/10.1257/jep.23.2.29

Varela-Ortega, C., Blanco-Gutiérrez, I., Esteve, P., Bharwani, S., Fronzek, S., & Downing, T.E. (2016). How can irrigated agriculture adapt to climate change? Insights from the Guadiana Basin in Spain. *Regional Environmental Change, 16*(1), 59–70. https://doi.org/10.1007/s10113-014-0720-y

Vasudevan, A. (2015). The makeshift city: Towards a global geography of squatting. *Progress in Human Geography, 39*(3), 338–359. https://doi.org/10.1177/0309132514531471

Waters, J., & Adger, W. N. (2017). Spatial, network and temporal dimensions of the determinants of adaptive capacity in poor urban areas. *Global Environmental Change, 46,* 42–49. https://doi.org/10.1016/j.gloenvcha.2017.06.011

Whitman, G. P., Pain, R., & Milledge, D .G. (2015). Going with the flow? Using participatory action research in physical geography. *Progress in Physical Geography, 39*(5), 622–639. http://dx.doi.org/10.1177/0309133315589707

Wilson, W.G. (2016). *Stormwater*. University of Chicago Press.

Yarnal, B. (2007). Vulnerability and all that jazz: Addressing vulnerability in New Orleans after Hurricane Katrina. *Technology in Society, 29*(2), 249–255. https://doi.org/10.1016/j.techsoc.2007.01.011

Zellner, M., & Campbell, S. D. (2015). Planning for deep-rooted problems: What can we learn from aligning complex systems and wicked problems? *Planning Theory & Practice, 16*(4), 457–478. https://doi.org/10.1080/14649357.2015.1084360

Zevenbergen, C., Fu, D., & Pathirana, A. (2018). Transitioning to Sponge Cities: Challenges and Opportunities to Address Urban Water Problems in China. *Water, 10*(9), 1230; https://doi.org/10.3390/w10091230