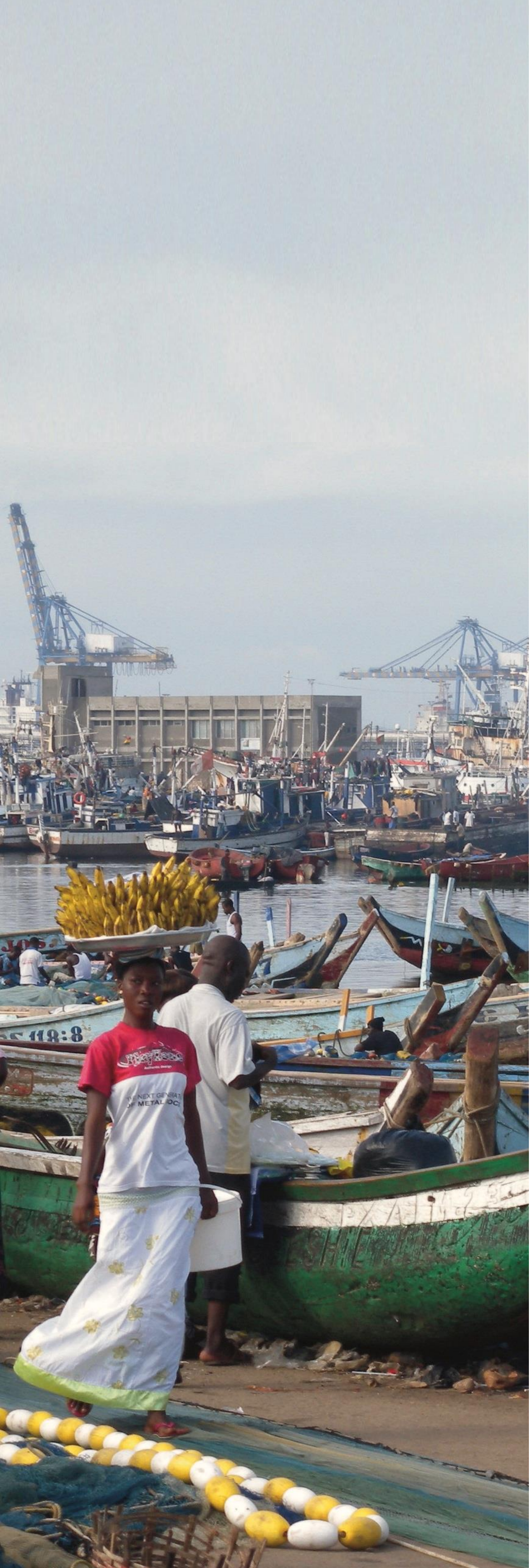

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Toward a Political Ecology of Biosocial Relations

Rethinking the Urban Water Metabolism Beyond the City

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Abstract

This working paper examines the concept of metabolism and its potential as an critical analytical lens to study the contemporary city from a political perspective. The paper illustrates how the metabolism concept has been used historically, both as a metaphor to describe the technological, social, political and economic dimensions of human-environment relations, and as a concrete analytical tool to quantify and better understand how flows of matter and energy shape the territorial and spatial configurations of cityscapes. Drawing on the example of the urban water metabolism of the Greater Accra Metropolitan Area (GAMA), it is argued that contemporary approaches to metabolic analysis should be extended in two ways to increase the integrative potential of the urban water metabolism concept. On the one hand, the paper demonstrates that political ecology approach is particularly well-suited to illuminate the contested production of urban environments and move beyond a narrow technical, managerial and state-centric focus in research on urban metabolic relations. On the other hand, the paper advocates for an approach to metabolic analysis that views the urban environment not simply as a relatively static exteriority that is produced by dynamic flows of matter, energy and information, but rather as a dynamic, nested and co-evolutionary network of complex biosocial and material relations, which in itself shapes how various metabolisms interact across scales. The paper then concludes by briefly discussing how a combination of metabolic analysis and political ecology research can inform urban water governance. In sum, the paper emphasizes the need for metabolic analysis to remain open to a plurality of different knowledge forms and perspectives, and to remain attentive to the inherently political nature of material and technological phenomena in order to allow for mutually beneficial exchanges between various scholarly communities.

Toward a Political Ecology of Biosocial Relations

Rethinking the Urban Water Metabolism Beyond the City

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1 Introduction

The notion of the urban metabolism immediately invokes a variety of metaphorical associations that range from chemical transformations within the human body to imageries of densely populated metropolitan areas, where flows of bodies, information, energy, and resources interconnect to create a vibrant, hybrid environment. Historically, the emergence of the metabolism concept can be traced back to the nineteenth century, for example through the writings of the German agricultural chemist Justus von Liebig (1803-1873), who introduced a novel, co-evolutionary perspective on the biochemical or 'metabolic' exchange between humans and the nonhuman environment. Influenced by the rapid expansion of industrialization, urbanization and international trade flows during the nineteenth century, von Liebig noticed a growing spatio-temporal separation between spaces of production and spaces of consumption as well as between the city and the countryside. Based on his studies of soil nutrient circulation, von Liebig observed how crops produced in the countryside were increasingly consumed in the city or shipped abroad, thereby interrupting the nutrient cycle and contributing to environmental degradation as well as urban pollution. Von Liebig termed this disjunctive socio-spatial development process the "metabolic rift" (Swyngedouw 2006a: 22).

Von Liebig's concept of the metabolic rift also strongly influenced the writings of Karl Marx, who incorporated von Liebig's ideas as well as the works of other natural scientists such as Jacob Moleschott (1822–1893) and Charles Darwin (1809–1892) into his political theory of historical materialism (de Molina and Toledo 2014: 46). In his seminal work *Capital*, Marx used the metabolism concept to describe complex interactions between humans and their environment from a political economy perspective, thus defining biosocial relations as being tightly interwoven with historically situated processes of production, labor relations, capital accumulation, and commodity flows. Drawing on the idea of metabolism, Marx sought to analyze "how each mode of production creates a particular social metabolic order that determines the interchange between society and nature [as well as] the ongoing reproduction of society and ecosystems" (Clark and York 2008: 14). Inspired by the work of von Liebig, Marx also engaged with the concept of the metabolic rift and used it as a metaphor to illustrate the "material estrangement of human beings in capitalist society from the natural conditions of their existence" (Foster 1999: 383).

However, it was not until the 1960s that the metabolism concept came to be applied in the context of urban ecology, planning and design, when Wolman's (1965) understanding of city as an ecosystem initiated a paradigm shift in the field of urban ecology. In other words, "it was no longer the ecology *in* the city that was studied, but the ecology *of* the city […] not to explain how ecological processes in the city differ from those in other environments, but how the city, as a dynamic system, exchanges energy and material with its environment" (WBGU 2016: 67; emphasis in the original).

Against this background, the key goal of metabolic analysis in urban as well as industrial ecology became to quantify the "inputs, outputs and storage of energy, water, nutrients, materials and wastes for an urban region" (Kennedy *et al.* 2011: 1965). This functionalist approach to metabolic analysis mainly relies on practical methods such as Material Flow Analysis (MFA) or Economy-Wide Material Flow Accounting (EW-MFA) to quantify the circulation and flow of resources, energy, or materials on different systemic levels, ranging from urban systems to entire economies (Eisenmenger 2016). Moreover, political ecologists and urban geographers have used the metaphoric notion of the *social metabolism* to describe the politicized production of complex urban environments through socially mediated flows of energy, materials and information that are needed to sustain human activities (de Molina and Toledo 2014). From this analytical perspective, the modern city is seen "as a process of fusing the social and the natural together to produce a distinct 'hybrid' or 'cyborg' urbanization" that transcends the immediate spatial boundaries of the cityscape (Swyngedouw 2006b: 106). These examples illustrate that the concept of the urban metabolism is currently used in a variety of different fields such as industrial ecology, urban ecology, political ecology and ecological economics to describe "the exchange processes that produce the urban environment" (Broto *et al.* 2012: 851).

Nevertheless, the inclusion of water in the study of urban metabolic processes has thus far proven to be problematic. As Madrid-López and Giampietro (2015: 853) remark, "water can be considered the Achilles’ heel of metabolism studies" since water flows have for a long time been excluded from more traditional metabolic analyses and calculations of material balances due to serious difficulties with the conceptualization of the accounting, for example in the context of flow measurements and water use. At the same time, there is the need for a better and more comprehensive integration of social and political dynamics into traditional analyses of the urban water metabolism, mainly because water is not merely a resource but also a "critical dimension to the social production of space" (Gandy 2004: 373; also see Pincetl *et al.* 2012). The concept of the urban water metabolism is therefore closely related to broader questions of urban politics, development, and governance, particularly with regard to the socioecological impacts of accelerating urbanization such as land use competition, environmental degradation and increasing demand for infrastructure, food, energy, water and housing (McPhearson *et al.* 2016).

Thus, considering the complex nature of the urban water sphere and its underlying metabolic relations, the analytical goal of this paper is to examine how the concept of the urban water metabolism can be used as an analytical lens to study the interconnected nature of water in concretely situated urban environments as well as in relation to complex global urbanization processes. Since the human dimension of the urban water metabolism has thus far received considerably less attention than the immediate problems related to the quantification of water flows and relatively narrow, indicator-based environmental impact analyses, it will be necessary to further contextualize the so-called 'natural' functioning of the water cycle to examine how water flows are embedded in, and shaped by, complex sociomaterial relations (Sivapalan 2015; Madrid-López and Giampietro 2015). Consequently, the overarching question that guides this paper is: *"How can urban metabolic processes be conceptually understood and practically analyzed, with a specific focus on the politicized sociomaterial flows of urban water under accelerating urbanization?"* In order to answer this question, the paper outlines an interdisciplinary approach to urban metabolic analysis that aims to combine insights from practical urban metabolism research, political ecology and socio-hydrology to shed light on the nested nature of multiple social and material metabolic processes that shape (and are in turn shaped by) the changing urban environment. In particular, the paper focuses on metabolism approaches that emphasize dynamic interactions between rapid urbanization and the biophysical, technological, political, sociocultural, and economic dimensions of urban water flows.

2 One metabolism or many? The concept of the urban metabolism and its use across disciplines

2.1 Industrial ecology and material flow analysis

In recent years, the study of urban metabolic processes has become increasingly dominated by the field of industrial ecology, which is primarily concerned with the systematic quantification of urban material and energy flows to transform and optimize industrial processes by creating synergies between industries, and by reducing costs as well as unsustainable ecological impacts (Rapoport 2011: 12). In particular, mass-balance accounting methods such as MFA or EW-MFA have been further refined since their development in the 1970s, and are now also applied to cities. The primary goal of these methods is to reduce the functional dependence of cities on areas that lie beyond their immediate spatial confines, for example with regard to resource supply and waste disposal, and to improve urban governance, economic performance and sustainability by measuring the 'stocks' and 'flows' of materials, energy or substances – including waste – that are related to a particular urban space (Brunner 2008; Minx *et al.* 2011; Rapoport 2011). However, debates among industrial ecologists about the methodological challenges of mass-balance accounting continue in a lively manner. There is a considerable strand of research in industrial ecology that discusses methodological and analytical questions of data availability and accuracy, as well as challenges with respect to scale or the definition of systemic boundaries for urban areas (see, for example, Rosado *et al.* 2014; Laner and Rechberger 2016). Indeed, such issues are still pertinent when it comes to the quantification of urban material, resource and energy flows, particularly in cities of the global south, where available statistical data are especially scarce. As the brief case study on the urban water metabolism in the Greater Accra Metropolitan Area (GAMA) of Ghana will illustrate, there are a number of characteristic uncertainties that make the precise calculation of urban water flows a highly complex endeavor. These uncertainties are primarily related to broader questions of data availability and reliability, for example due to the absence or damage of flow meters, the difficulty of measuring urban water use patterns that are not related to the networked water infrastructure, and because of political reforms that led to a change in the administrative boundaries of the GAMA districts, which profoundly complicates the use of official statistical data and limits data comparability over longer periods of time.

In addition, and on a broader analytical level, a number of blind spots have been identified in previous studies that describe the urban metabolism from the perspective of industrial ecology or MFA/EW-MFA. Elisabeth Rapoport (2011: 28), for example, concludes her wide-ranging review of the metabolism literature with the remark that

> *"industrial ecologists continue to use a conceptualisation of urban metabolism from which politics and power relations remain notably absent. This may ultimately limit the viability of their normative recommendations, as the implementation of dematerialization at an urban level may depend as much on political support as on the particulars of material cycles."*

Similarly, Erik Swyngedouw (2006a: 35) emphasizes that analyses of urban metabolic processes

> *"have often uncritically pursued the standard industrial ecology perspective based on some input-output model of the flow of 'things' […] Such analysis merely poses the issue and fails to theorize the making of the urban as a socio-environmental metabolism."*

Consequently, there is a need to widen the methodological and analytical scope of industrial ecology and MFA/EW-MFA research, particularly by including valuable insights and analytical methods from the vibrant fields of political ecology and socio-hydrology to better comprehend how flows of materials, energy or substances are embedded in wider cultural, economic and sociopolitical relations that shape or produce the urban.

2.2 The metabolism metaphor in urban political ecology and socio-hydrology

The subfield of urban political ecology gained prominence during the second half of the 1990s, when the Geographer Erik Swyngedouw (1996) introduced the concept of hybrid 'socionatures' as an attempt to reconcile pervasive dichotomies such as society/nature and materiality/discourse that were extremely influential in shaping the field of political ecology ever since its formative phase in the 1970s. Inspired by the idea of a hybrid socionatural metabolism that reorganizes, transforms, and ultimately 'produces' environments in line with the forces of social power and capital, Swyngedouw recommended a rapprochement between political ecology and urban studies (Swyngedouw 1996). For a long time the urban sphere had been practically ignored by political ecologists whose attention was primarily focused on the preservation and rehabilitation of an allegedly pristine nature and wilderness, whereas the urban environment was implicitly regarded as a space "where nature was understood to be already subjugated to society" (Angelo and Wachsmuth 2014: 17). Given his interest in the politicized production of urban environments, Swyngedouw also saw the medium of water as particularly well suited to study urbanization as "a political-ecological process with water as the entry point; water that embodies, simultaneously and inseparably, bio-chemical and physical properties, cultural and symbolic meanings, and socio-economic characteristics" (Swyngedouw 1996: 76; as cited in Angelo and Wachsmuth 2014: 18). In particular, a number of scholars have pointed to the inherently political materiality of water, and to the mediation of this materiality through technologies such as dams, dikes, infrastructure, pumps and so forth (Kaika 2006; Monstadt 2009). Karen Bakker (2012: 617) describes this sociotechnical aspect of water as "a kind of micro-politics, which excavates the politics of water-related technologies, their uses, and their enrolment in political agendas, all of which are simultaneously and inherently socio-technically (and hence materially) constituted."

Research in urban political ecology is therefore particularly well positioned to study how the politicized production of the urban is shaped by hybrid biosocial metabolisms, and how processes of urbanization in turn influence the functioning and situatedness of these various metabolic relations. If we take 'the' urban water metabolism as an example, it is quite obvious that the various phenomena that are captured by this metaphor can neither be characterized as being entirely urban, nor as being part of a single urban 'mega'-metabolism. Instead, it seems warranted from an analytical perspective to perceive the various metabolic processes of the urban water sphere as being embedded in extensive and networked biosocial relations that include phenomena as diverse as rural water treatment plants, anthropogenic climate change, mobile water tankers in peri-urban areas, water privatization and trade policies, as well as sociopolitical power relations and cultural patterns of meaning-making. Capturing this extreme diversity of urban metabolic relations is arguably not possible by using a single, overarching approach such as political or industrial ecology. In a practical sense, it seems more viable for scholars from different backgrounds to focus on common questions and 'problematizations' of societal challenges such as urbanization to establish an open, inclusive, critical and publicly visible dialogue that respects multiple ways of knowing and being-in-the world.

This being said, it is suggested that research in industrial and urban political ecology with a specific focus on water-centered processes in the urban sphere can also benefit from a thorough engagement with the analytical perspective and interdisciplinary field of socio-hydrology. In a recent article, Sivapalan *et al.* (2014: 226) outline the following three main goals of socio-hydrology, namely to:

> *"(1) analyze multiscale, space-time patterns and dynamics of socio-hydrologic processes, and interpret them in terms of the underlying structural features of biophysical and human systems and their interactions; (2) explain and interpret socio-hydrologic responses in terms*

> *of outcomes relevant to human well-being, and discern possible future scenarios of their evolution; and (3) understand the meaning and value of water as a culturally, politically, and economically embodied resource necessary to human life, and do so in a manner that explicitly accounts for biophysical and human interactions."*

However, socio-hydrology is certainly not a "new" science, despite occasional claims to the contrary (see Sivapalan *et al.* 2012). As Sivakumar (2012: 3788) aptly puts it, the science of water and people, or of human-water interactions, is at least 30 years old, and has initially been referred to as "hydrosociology" in academic discourse. What characterizes this scientific field, beyond minor quibbles over its exact name, is an integrated perspective on the complex interactions between humans, ecosystems, and the hydrological cycle (Bakker 2012: 915). In a nutshell, hydro-sociology adds a more distinct focus on ecological and hydrological phenomena to political ecology perspectives, without completely losing sight of social justice concerns and the cultural, political, and economic aspects of water use and distribution.

It can nevertheless be said that the two interdisciplinary fields of socio-hydrology and urban political ecology are still disadvantaged within the disciplinary structures of contemporary university systems, and relatively small compared to the sizable scientific community that explores the urban metabolism from the systemic, quantitative and managerial perspective of industrial ecology. Yet, there are certainly many opportunities for a mutual exchange between industrial ecology, political ecology and socio-hydrology on matters pertaining to biosocial metabolic relations. Newell and Cousins (2015: 721), for example, propose the development of an *urban political-industrial ecology* that seeks to examine "a global circulatory process of socio-natural relations that transforms and (re)creates urban ecosystems through the exchange of resources, capital, humans, and non-humans into and out of the spaces of global urbanization", whereas Boelens *et al.* (2016: 1) introduce the concept of *hydrosocial territories* to examine "spatial configurations of people, institutions, water flows, hydraulic technology and the biophysical environment that revolve around the control of water." While both of these approaches are in principle complementary in their normative orientation and relative openness, they are nevertheless troubled by common methodological and analytical challenges, for example with regard to the characterization and delineation of urbanization and the urban as such.

2.3 Urban geographies beyond 'methodological cityism'

An important problem for the qualitative and quantitative study of urban metabolic processes that received considerable attention in recent years is the meaningful integration of different scales and descriptive domains. As previously mentioned, there are multiple perspectives that need to be taken into consideration to understand the nature of urban metabolic processes across space and time. Yet, it remains particularly challenging to include various analytical perspectives and their often fundamentally different epistemic, ontological and methodological viewpoints into a productive, dialogical process in order to move from a fragmented mode of knowledge generation that remains firmly situated within disciplinary silos toward a more holistic perspective on metabolic analysis. According to a recent flagship report by the German Advisory Council on Global Change titled *"Humanity on the move: unlocking the transformative power of cities"* (WBGU 2016: 451), it has become evident that the pressing challenges of global urbanization require a new urban research agenda that comprises of *"interdisciplinary basic research spanning the borders between technology and natural sciences on the one hand and the social and cultural sciences on the other."* Thus, even though disciplinary research and traditions are both necessary and valuable, there is the need to arrive at a more holistic understanding of urbanization and urban metabolic processes.

Another crucial methodological and analytical challenge for the study of urban metabolic relations which has attracted scholarly attention across multiple disciplines is to determine the constantly shifting boundaries of 'urban' spaces, assuming that space as such, especially if it is seen as an abstract category, is quite an elusive concept that constantly evades our grasp. At the same time, it is clear that the concrete physical places that we inhabit or may find ourselves in are always comprised of biosocial relations and generative processes that are not immediately visible.

Urban political ecologists, in particular, have thus pointed out that contemporary approaches to the study of urban metabolic processes are still hampered by a "methodological cityism" or, put differently, by a narrow empirical and analytical focus on the traditional city that potentially excludes other interconnected and relational aspects of globalized urbanization (Angelo and Wachsmuth 2014: 16). From the perspective of industrial ecology, it has also been argued that the "first wave" of urban political ecology during the second half of the 1990s has neglected quantitative research and core ecological aspects of metabolic processes in favor of a focus on social dynamics and qualitative research methods, thus limiting the boundaries of analysis largely to the social sphere (Heynen 2014: 600; Newell and Cousins 2015: 704).

In sum, it may therefore be concluded that the choice of scale or methods, and the definition of boundaries for any metabolic system or process under investigation – be it a particular city, ecosystem or the unfolding of urbanization processes on a macro scale – depends first and foremost on the research questions asked and the choice of the investigator(s). Conversely, it also has to be borne in mind that specific research findings may only be valid for the scale of investigation, and do not easily lend themselves to generalization. Yet, if the key goal of an integrative theory of urban metabolic relations is to contribute to a novel theory of urbanization that takes into account how the social, material and ecological production of urban environments unfolds across space and time, and how this 'biosocial' production of urban spaces intersects with the historically situated forces of labor, power and capital, it may be useful to understand the concept of the urban metabolism as a "boundary metaphor" that – at least theoretically – allows for mutually beneficial interactions and fruitful exchanges between various scholarly communities (Newell and Cousins 2015: 704). The concrete application of this metaphor, for example to the study of the urban water sphere, may therefore contribute to joint theory building, and to the advancement of more integrative research on urbanization processes.

3 The Urban Water Metabolism of the Greater Accra Metropolitan Area

In order to explore the multiple biophysical and sociopolitical entanglements between rapid urbanization, environmental change and water flows in the Greater Accra Metropolitan Area (GAMA) of Ghana, it is suggested to study these interrelated processes through the analytical lens of the urban water metabolism (Bruns 2014). The basic rationale behind the concept of the urban water metabolism is to unravel the complexities of 'biosocial' or hybrid nature-society-technology relations by focusing on the dynamic interplay between the social and material production of a particular hydrosocial territory. This means to take into account how water is embedded in the immediate urban environment not only as a natural resource that requires a functioning material and institutional infrastructure to be managed and used by different consumer groups, but also as an ambiguous symbolic and cultural variable that can be discursively framed as more or less politicized according to a variety of vested interests. Accordingly, two particular aspects of hybridized metabolic processes need to be considered: (a) water as a cultural element and politicized socioeconomic resource that is managed institutionally as well as technologically across space and time, and (b) water as a physical element that is embedded in complex ecological relations and flows through the city in a specific quantity and quality.

While it is obvious that these various facets of water are inseparable due to their physical mixing across scales (e.g., social, ecological, temporal, spatial) it is still crucial to ask how the previously mentioned fallacies of methodological cityism may be overcome in practice. Bearing in mind the everyday complexities of inherently 'messy' urban environments, where human activities such as research and decision-making are often constrained by disciplinary and administrative boundaries as well as limited resources or a lack of appropriate expertise in multiple fields, methodological cityism often seems to be a rather pragmatic choice instead of an intellectual vacuity.

However, before engaging with this important question from an empirical perspective, a few preliminary points need to be made about the nature of the urban environment and water management system in the GAMA. Since Ghana’s independence in 1957, water management and governance structures in Accra’s core urban areas have been repeatedly reformed. These governance reforms were largely characterized by the adoption of modernist socioeconomic development strategies such as structural adjustment programmes administered by the World Bank, and Integrated Water Resource

Management (IWRM) policies promoted by Western donor organizations (Bruns and Frick 2014). Simultaneously, as Richard Grant (2009: 2-3) argues in the case of Accra, it has to be borne in mind that

> *"at both extremes of the urban spectrum, from elite gated community residents to the poorest of slum dwellers, city residents now think and act beyond the confines of the city and employ global strategies to mediate their positions in the contemporary city."*

Existing linkages across space and time thus require a reconsideration of simplistic dichotomies between the periphery and the urban core in order to trace dynamics of the 'urban' water metabolism beyond the confines of a particular bounded territory (McHale *et al.* 2013). To this end, it will be necessary to consider how minimally governed (peri-)urbanization contributes to the socially and politically contested governance of water flows in the GAMA, thereby simultaneously affecting the deeper structural layers of the 'urban' water metabolism (Swyngedouw 2009). At the same time, it is necessary to gain a solid understanding of the hydrological processes that shape the urban water sphere. The analysis of the urban water metabolism in the GAMA therefore begins with a more traditional industrial ecology approach, while building on the related quantitative findings to engage with processes of uneven urbanization from a political ecology and socio-hydrological perspective.

3.1 Determining the hydrological balance of the Greater Accra Metropolitan Area

The GAMA is located in the dry coastal savanna zone of southeastern Ghana, with mean annual rainfalls between 635 mm along the coast and 1,140 mm in the northern parts (Ghana Statistical Service 2013: 2). Rainfall in the area occurs within two rainy periods, a major rainy period that lasts from March to July and a minor rainy period from September to October (Adank *et al.* 2011: vii). Administratively, the GAMA is divided into twelve metropolitan, municipal and district assemblies (see Figure 1; also see Alba and Bartels 2016). According to the latest available demographic data provided by the GWCL, the estimated total population of the GAMA is 5,106,969 for the year 2015 (Appiah Otoo *et al.* 2012: 12).

With regard to fresh water supply for potable use, the population of the GAMA is mostly dependent on surface water that is partly imported from sources that lie outside of core urban areas, namely the Weija Lake and dam that is located on the Densu River with an optimal safe yield of 272,765 m^3/day (approximately 0.10 x 10^3 m^3/year) and an impoundment volume of 212,546 m^3, and the Volta Lake with two large dams that is located on the Volta River (Abbey 2013: 58). Given an annual discharge of approximately 43 km^3/year, Adank et al. (2011: vii) conclude that "the potential yield from the Volta is determined by the capacity of the intake and treatment infrastructure, rather than by the availability of water resources, even when considering a potential drop in river flow caused by climate change and increased use of water upstream in the basin." In addition to surface water, the second most important source of potable water in the GAMA is groundwater, with an estimated total recharge of about 0.038 km^3/year, although groundwater in the coastal areas is often too saline for consumption (Adank *et al.* 2011: vii).

The pipe network in the GAMA is operated by the Ghana Water Company Limited (GWCL) and only covers a part of the urban and peri-urban agglomeration in the area. This means that even though Ghana has abundant water resources in principle, only half of the urban population in the GAMA has direct access to piped water (Adank *et al.* 2011). However, having access to the pipe network does not necessarily guarantee regular access to water, since a rationing scheme is currently in place and piped water flows only on certain days per week and certain hours of the day (Stoler *et al.* 2012; Peloso and Morinville 2014). As a result of limited and uneven water supply through the pipe network, multiple water provisioning systems have emerged and households have developed alternative strategies to secure access to water for both domestic and drinking uses (Alba and Bartels 2016). These multiple water provisioning systems include so-called "water kiosks" that are run by NGOs or private companies, small town water supply systems that are managed by local communities (often with the support of local administration and the Community Water and Sanitation Agency), individual water vendors that are managed by private entrepreneurs, as well as mobile water tankers that are either run by individuals or organized in associations and groups (Alba and Bartels 2016).

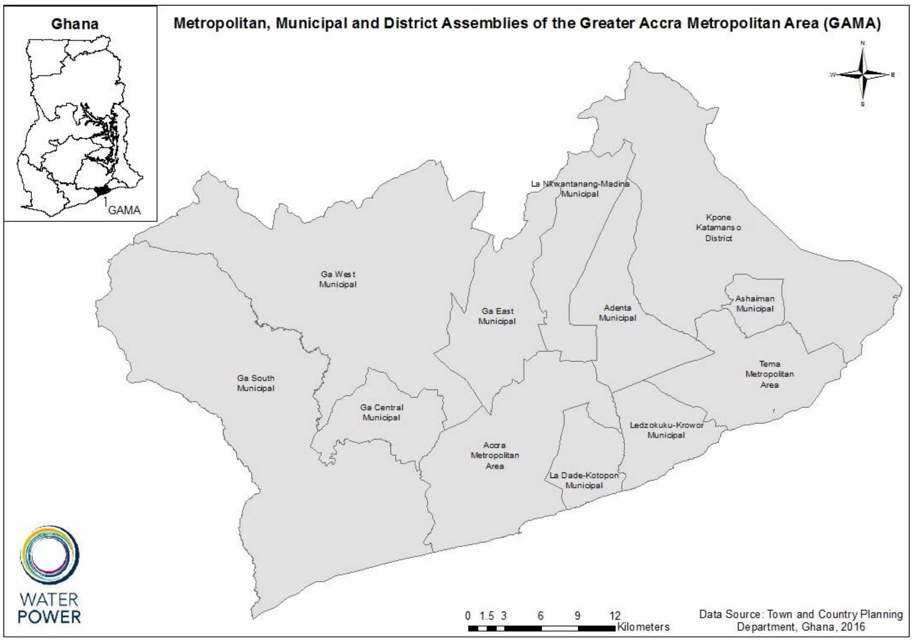

Fig. 1 Administrative Boundaries of the Greater Accra Metropolitan Area (GAMA)

The nested nature of various water metabolisms in the GAMA, which is related to different water sources as well as different water access and use patterns thus makes the precise quantification of water flows a highly complex endeavor. Currently, there are no reliable quantitative data at the level of the GAMA for water sources for drinking and domestic uses and related water use patterns that are not directly related to the GWCL pipe system, such as groundwater abstraction, domestic rainwater harvesting, and the use of surface water, for example from small rivers or streams. Yet, available statistical data provided by the GWCL still allow for a quantification of the actual and projected demand and production of potable water for the period from 2000-2030 (see Figures 2 and 3).[1]

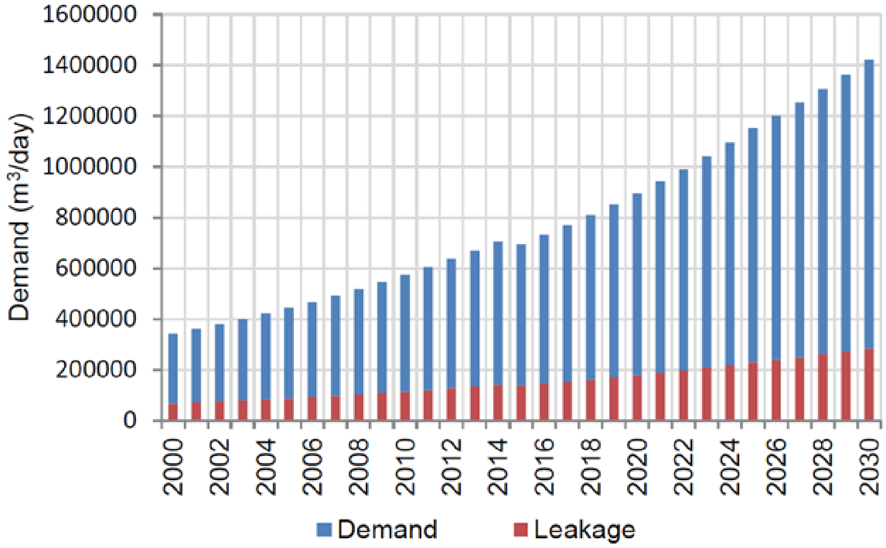

Fig. 2: Administrative Boundaries of the Greater Accra Metropolitan Area (GAMA)

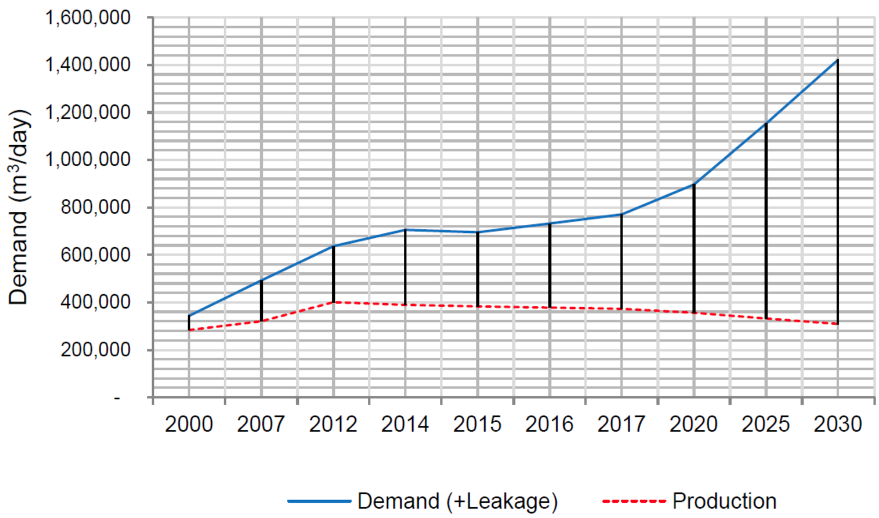

Fig. 3 Administrative Boundaries of the Greater Accra Metropolitan Area (GAMA)

[1] Data source: Appiah Otoo *et al.* (2012). *Study on the drinking water distribution network of the Greater Accra Metropolitan Area* (GAMA). Technical report. Accra: The GIS Company, pp. 14-15. The expected annual population growth rate is 4.3 percent.

In sum, these quantifications can be considered quite comprehensive with regard to the description of the urban water metabolism, since the GWCL utility system covers about 99 percent of all water that is used in the GAMA (Adank *et al.* 2011: vii). The available data also show that the actual demand for potable water in the GAMA is far higher than current production, and that the demand deficit will further increase if population growth continues apace and production levels remain unchanged (Appiah Otoo *et al.* 2012: 14).

Moreover, it is estimated that 350,607 m^3 of wastewater were generated in Accra on a daily basis in 2011, and that the daily amount of wastewater production will rise to 884,477 m^3 in 2030, assuming a medium water use scenario with medium population as well as economic growth (Adank *et al.* 2011: 60). Wastewater includes greywater, storm water runoff and polluted surface water sources. Adank *et al.* (2011: 64) therefore conclude that the "capacity for liquid waste treatment is far below the estimated wastewater production – only about 17 percent of the estimated amount of wastewater produced."

In view of these actual and expected predicaments of rapid urbanization, an "integrated urban water management vision for Accra 2030" has been defined by a stakeholder coalition that was brought together by the Accra Learning Alliance, comprising of government representatives, development partners, local NGOs and CSOs, water user groups, the media, and national as well as international research institutions (Adank *et al.* 2011: v). Two main goals that have been formulated in this context are to guarantee 100 percent access to uninterrupted water supply in the city of Accra, and , thereby implying a large-scale and long-term infrastructural expansion and improvement process.

However, while conventional quantitative approaches to urban metabolic analysis are indeed highly useful for monitoring and planning purposes, they are not sufficient to analyze the politics and socially uneven conditions that are related to such large-scale sociotechnological change processes. Especially when it comes to understanding the social embeddedness of material-technological formations, as well as the power-ridden economic and political processes that influence water access or distribution modalities, it is crucial to include social science perspectives from, for example, political ecology and socio-hydrology.

4 Uneven metabolic relations: a curse and blessing in disguise?

A conventional analysis of the urban water metabolism – understood as the flow of resources through the urban system – points toward the fact that the growth of cities in general, and the modernization of cities in the Global South in particular, coincides with a significant increase in total water demand, wastewater output, water pollution, and water withdrawals from surface and ground water sources. Moreover, approximately 30 percent of the global demand for water currently stems from urban settlements, while roughly 50 percent of all cities worldwide with more than 100,000 inhabitants are located in regions affected by hydrological water scarcity (WBGU 2016: 76).

Hence it must be assumed that the rapid expansion of urban areas will play an increasingly important role in shaping metabolic processes and environmental change on a regional as well as a global level, for example in terms of both population growth and related lifestyle changes, as well as through the expansion of large-scale urban infrastructures and technological networks. Yet, while the reduction of inequalities in water access and improvements in infrastructure coverage have for a long time been declared goals of international development efforts, it has to be borne in mind that the accumulated regional and global effects of envisioned local infrastructural projects are still largely unknown.[2]

Two simple figures may serve to illustrate this fundamental tension between the urgent need for infrastructural development under conditions of increasing water demand and rising social inequalities, and the wider environmental pressures that are potentially caused by such large-scale infrastructural expansions: the average household with access to pipe water in East Legon, which is one of the most developed high-income neighborhoods of Accra, uses more than 400 liters of water per day for drinking and domestic uses, whereas the same figure is considerably lower for Ashale Botwe, one of the less developed areas in the GAMA, where the average household with access to pipe water normally consumes less than 200 liters of water per day (Abbey 2013: 126; also see Ainuson 2010).

This stark difference in household water consumption can arguably be explained by two crucial factors. First, the argument can be made that water supply and access, and consequently urban metabolic processes, are mediated through the various types of infrastructure that coexist and serve domestic as well as industrial demands in ways that often reinforce social inequalities, and may lead to unevenly distributed health risks (Amankwaa *et al.* 2014). This means that social inequalities are not only reflected in the quantity of water that is consumed, but also in the quality of accessible water.

Moreover, the second important argument that has to be considered while analyzing observed differences in household water consumption is that water use patterns are not merely related to infrastructure access, but also to growing social and income disparities. Even in rapidly expanding peri-urban areas where high-income households often have no (reliable) access to the official pipe water infrastructure, water consumption levels are not necessarily lower. Not only can wealthier households generally afford more re-

[2] Examples include Goal 6 of the 2030 Agenda for Sustainable Development, which calls for universal, equitable and affordable access to drinking water, and the now concluded Millennium Development Goals (MDGs), which focused on the number of people with access to water and sanitation.

source intensive household items and luxury facilities such as washing machines, dishwashers, swimming pools, and water fountains, they are also able to purchase large quantities of water from alternative providers such as mobile water tankers (Abbey 2013: 128; also see Bartels 2016).

However, the growing demand for water in the GAMA is not driven by domestic consumption alone, even if domestic water demand due to population growth is expected to be the most important causal factor (Abbey 2013: 77). Increased water demand is also closely related to increasingly globalized economic processes such as industrial production and agriculture that often transcend the boundaries of the city. While comprehensive data on water consumption per sector for the whole of GAMA are presently not existing, the available data illustrate that non-domestic water consumption in 2015 amounts to less than a third of total water consumption in the core districts of the GAMA, including Accra (Figure 4).

Table 1: Water consumption per type of consumer in the Accra, Tema and Ga Districts in millions of m^3 (2015)

Type of consumer	Accra	Tema	Ga	Total (mil. m^3)	Total (m^3 per day)
Domestic	67.8	29.0	13.4	110.2	302,000
Non-domestic	22.6	17.1	4.0	43.7	120,000
TOTAL	**90.4**	**46.1**	**17.4**	**153.9**	**422,000**
Domestic connections	170,393	111,681	56,963	339,037	

Source: Abbey (2013: 77)

In sum, the close entanglement between uneven urbanization and metabolic processes on multiple scales clearly illustrates that the urban environment is not simply a relatively static exteriority that is produced by metabolic flows of matter, energy and information, but rather a dynamic, nested and co-evolutionary network of complex biosocial and biomaterial relations, which in itself shapes how various metabolisms interact across scales. Particularly with regard to the rapidly growing urban centers of the Global South, such as the GAMA, where access to networked water infrastructure is often low, it thus appears to be more precise to speak not of a single urban water metabolism, but of several nested water metabolisms that safeguard urban water supply and mediate flows of water through different material-technological pathways such as the pipe network, bottled and sachet water, or mobile water tankers. Furthermore, it must be taken into account that metabolic relations are not only mediated through material, technological and ecological factors, but also through social, political and economic processes that are in turn shaped by asymmetric power relations. The United Nations World Water Development Report 2015 thus emphasizes the crucial role of equitable water governance by concluding that "comparatively powerless groups tend to be shut out of not just access to water but also the processes whereby allocation decisions are made" (WWAP 2015: 21).

Thus, a question that certainly deserves more attention in the context of improving sustainable, integrated water resource governance for the GAMA is whether more decentralized modes of infrastructural development and water supply are a viable alternatives given the possible negative impacts of large-scale infrastructural expansion on ecological and metabolic processes. This question becomes even more pertinent in view of largely uncontrolled urban expansion, increased population growth, as well as under conditions of actual or expected climate change and increased variability.

The socioecological challenges of uneven urbanization may therefore even be considered a 'blessing in disguise', because they might open up a window of opportunity for exploring alternative forms of urban development that are neither following a path of unregulated service privatization nor a strategy of top-down policy implementation, but rather aim to pursue a more communally embedded mode of decentralized water governance. Exploring further options for more decentralized forms of community-based water management in urban areas may also represent a possible response to the pertinent challenges that are posed by the fragmented, top-down water governance regime in the GAMA that have been identified in previous studies (see, for example, Adank *et al.* 2011: 84ff). Options for community-based water management include the more active involvement of water user communities in decision-making, planning processes and rehabilitation activities, as well as a more inclusive collaboration between existing communal user groups and both public and private service providers to facilitate community ownership of water supply and sanitation services (Osumanu 2010). In view of these possible options for participatory water governance, however, it will be necessary to consider both opportunities and challenges with regard to different modes of engagement (Morinville and Harris 2014).

5 Conclusion

Based on a review of the metabolism literature in the fields of industrial ecology, political ecology and socio-hydrology, this paper sought to examine the question of how urban metabolic processes can be conceptually understood and practically analyzed. It is argued that exploring the politicized socio-material flows of urban water requires a novel theory of socially uneven urbanization that takes into account how the social, material and ecological production of urban environments unfolds across space and time, and how this 'biosocial' production of urban spaces intersects with the historically situated forces of labor, power and capital. While conventional quantitative approaches to urban metabolic analysis are indeed highly useful for monitoring and planning purposes, they are hardly sufficient to analyze the socially uneven conditions that are related to large-scale sociotechnological change processes, especially when it comes to understanding the social embeddedness of material-technological formations, as well as the power-ridden economic and political processes that influence water access and distribution modalities.

Overall, the paper advances the analytical argument that the urban environment is not simply a relatively static exteriority that is produced by dynamic flows of matter, energy and information, but rather a dynamic, nested and co-evolutionary network of power-ridden biosocial relations, which in itself shapes how various metabolisms are situated and interact across scales. The concrete application of the urban metabolism metaphor, for example to the study of the urban water sphere, may therefore contribute to joint theory building, and lead to the advancement of more integrative research on urbanization processes across disciplines. Pertinent questions that occupy researchers from various disciplinary backgrounds revolve around issues of scaling, boundary setting, and of defining urbanization and the urban as such. Here, one of the major practical challenges is to avoid the various pitfalls of a "methodological cityism" (Angelo and Wachsmuth 2014: 16) that fails to account for the inherently political and interconnected nature of water flows across space and time, and still limits the analysis of urban metabolic processes to the confines of the traditional city.

In analyzing the urban water metabolism of the Greater Accra Metropolitan Area (GAMA), the paper then provides a concrete example of how quantitative and qualitative methods of industrial ecology, political ecology and socio-hydrology might be combined to better understand urbanization and urban metabolic processes. The quantification of water demand and water production in the GAMA clearly indicates that the actual demand for potable water is far higher than current production, and that the demand deficit will further increase if population growth continues apace and production levels remain unchanged. The results of the analysis also show that urban metabolic processes are mediated through various types of infrastructure that coexist and serve domestic as well as industrial demands in ways that often reinforce inequalities and may lead to unevenly distributed health risks. This means that social inequalities are not only reflected in the quantity of water that is consumed, but also in the quality of accessible water.

Moreover, it is important to consider that water use patterns are not only related to infrastructure access, but also to growing social and income disparities. High-income households also consume more water in areas where no direct or reliable connection to the pipe network exists. The socioecological challenges of increasing water demand are therefore not only related to infrastructural expansion, population growth and industrialization. They are also the result of increasingly uneven water consumption patterns. Yet, in the best case, these existing challenges might open up a political window of opportunity for exploring alternative modes of urban development that are neither following a path of unregulated service privatization nor a strategy of top-down policy implementation, but rather aim to pursue a more communally embedded and socially balanced form of decentralized water governance.

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