Exploring the Relationship Between Melbourne's Water Metabolism and Urban Characteristics

Aristide Athanassiadis[1;2;3], Robert H. Crawford[2] and Philippe Bouillard[3]
[1] Belgian Fund for Scientific Research (F.R.S.-FNRS), Belgium
[2] Faculty of Architecture, Building and Planning - The University of Melbourne, Australia
[3] Building, Architecture and Town planning – Université Libre de Bruxelles, Belgium

Abstract: Cities can be seen as complex urban systems that mobilise local and global resource flows to meet the needs of their inhabitants and their manufacturing sector. However, the local consumption of resources can be responsible for major local and global environmental changes that impact the human health and wellbeing inside and outside of the boundary of the urban system. With global urban population expected to continue to grow, the mitigation of further future environmental pressures from urban consumption is of critical importance. The complexity of the interrelationships between the local social, political, cultural, economic and environmental facets of a city as well as the interrelationship between these local characteristics and urban consumption, dictate that each city will have a different set of parameters that drive urban consumption.
This research will investigate this issue by exploring the relationship between Melbourne's water metabolism and its urban characteristics. In practice, this study will correlate the spatially disaggregated water use of Melbourne with local factors such as demography, average income, territorial organisation, etc. It will then be possible to identify which urban characteristics have the greatest influence on water use and ultimately help to inform the development and implementation of the most appropriate and best targeted policies for reducing water use across Melbourne Metropolitan Area.

Introduction

It is now widely acknowledged that through their activities and their inhabitants' needs urban areas put a considerable pressure on the environment due to their natural resource use (Corvalan *et al.*, 2005). In fact, urban areas are estimated to use 67-76% of global energy supply and emit 71-76% of global CO_2 emissions coming from energy use (Seto *et al.*, 2014). While current anthropogenic activities already pose serious threats in the sustainable provision of ecosystem services and to human health (McMichael *et al.*, 2008), these threats could worsen in the future as urban population is expected to grow and in particular in developing countries (UN 2014). The incumbent creation and expansion of urban areas due to the increase of urban population will not only increase resource use and environmental effects due to urban activities and their inhabitant's needs but also and most importantly due to the embodied environmental effects of the new built environment (Müller *et al.*, 2013).

Facing these pressing challenges, it becomes necessary to mitigate existing and future environmental effects of cities. To do so, it is however important to better understand "*how much of what input is used where, by whom, and to do what"* (Pincetl *et al*., 2015). A methodological approach that aims to answer these questions, by accounting resource flows and pollution flows entering and exiting urban areas is Urban Metabolism (UM). This method has been used in more than 75 cities to monitor their environmental effect (Kennedy and Hoornweg, 2012). Indeed, UM is now acknowledged by researchers and environmental administrations as a central tool to assess the sustainability of cities (Zhang, 2013).

However, UM still suffers from a number of shortcomings due to its high dependence on data. As each city possesses different data about the resource and pollution flows that interact with their urban system, UM lacks a common and rigorous accounting methodology. However, the limitation that really hinders UM to give context-specific and comprehensive policies to mitigate urban resource use and their associated environmental effect is its "black box' approach. In other words, most UM studies only give an overview of the flows entering and exiting the urban territory without identifying what causes this consumption.

To address this issue, this study proposes to study the disaggregated and spatialised water use of Melbourne and correlate it with some of its urban characteristics. This will enable a more grounded analysis of Melbourne's water use and investigate what are the socioeconomic and territorial organisation indicators that drives this consumption. The results of this study will also open the path toward policies that are more appropriate and relevant for Melbourne. Finally, this study wishes to explore the use of open data in the field of Urban Metabolism and how open data from urban or national administrations could become a most valuable source for future studies and analyses.

The rest of this study will be divided into four parts. The next section will provide a brief state of the art of the UM approach with a particular focus on studies presenting spatialised results and that identify resource use and environmental effect drivers. The following section will present the methodology used discussing about the case study of Melbourne, the data collection process as well as the data analysis. Results about Melbourne's spatialised water use as well as its correlation with socioeconomic and territorial organisation indicators will then be illustrated. This study will conclude by discussing some limitations and future pathways for investigation.

Spatially disaggregated urban metabolism and the identification of metabolic drivers

As mentioned here above, UM is an urban environmental assessment technique that provides a synthetic view of flows entering, being stocked and exiting the urban system. However, the quantification of these flows does not necessary allow to know which economic activities are using or producing them. In addition, it is hard to understand which part of the city and which socioeconomic and demographic profiles are more prone to put more pressure on the environment. Therefore, in order to avoid seeing urban areas as static and homogeneous entities it is necessary to disaggregate metabolic flows and map them.

Mapping metabolic flows allows to illustrate subtle differences in resource use and pollution emission patterns (Pincetl *et al.*, 2015). The emergence of different consumption patterns pin downs different land uses; territorial organisations; infrastructures; economic activities; but also different lifestyles and consumption behaviours (Howard *et al.*, 2012, Heinonen *et al.*, 2013, Wilson *et al.*, 2013). Thus, mapping urban consumption can lead to a preliminary identification of drivers and measure the efficiency of territorial organisations. In reality, the identification of drivers is a major step towards a better understanding of urban resource use and the intertwined relationships that exist between components of a city mobilizing matter and energy (see Figure 1).

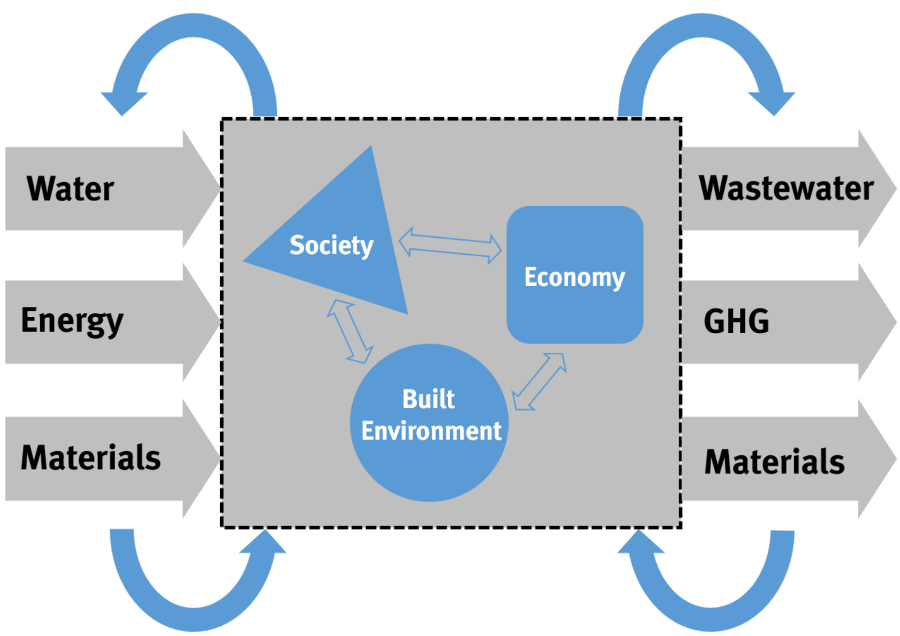


Figure 1: The interrelationships between an urban area and its metabolic flows

The relationship between resource use and local factors enables to take into account the dynamic and ever-changing character of urban systems and consequently of the metabolic flows it requires. In addition, by further explicating this relationship it is possible to contextualize environmental assessments and determine why such figures are exclusively valid for one city (Pincetl *et al.*, 2012, Athanassiadis and Bouillard, 2013). This is especially relevant for the urban scale which is an amalgam of economic, social, cultural, political and many other forces that constantly evolve, thus making each urban system unique and incomparable to any other. A major step has been made by Kennedy *et al.* (2015) in identifying microscale correlations of London boroughs and Buenos Aires municipalities. However, it is important to underline that spatially disaggregated metabolic data are rarely available.

Methodology

The previous section underlined the relevance of mapping metabolic flows and of identifying their associated drivers. The present one will focus on how this study spatialised Melbourne's water use and will discuss about the necessary steps to investigate on its drivers.

In order to identify drivers of metabolic flows, a large number of values for metabolic flows and socioeconomic or territorial organisation factors are needed. Depending on the statistical test, the number of values needed to establish a relationship between metabolic indicators and local factors can vary and reach up to several hundreds. In the case of spatially disaggregated metabolic flows this implies that metabolic data should be available for a large sample of smaller spatial entities. Ideally, in order to obtain a relevant relationship between metabolic flows and urban characteristics, data should be collected at spatial scales which have a homogeneous social and territorial characteristics, i.e. a similar landuse, building typologies, socioeconomic and sociodemographic profiles. While, disaggregated urban characteristics data, can be easy to obtain through national, regional or urban census and surveys. However, metabolic data at smaller urban scales are difficult to obtain due to the sensitivity of these data. In order to obtain accurate data for water, it is necessary to access data from water suppliers or grid operators. In a number of cities, the water market is owned by one or a number of public and/or private companies. Therefore, mapping the metabolism of an entire city could reveal to be the difficult task of putting together a patchwork of confidential data.

The rest of this section will thus provide more information about the case study of Melbourne as well as the data used to perform this identification of drivers.

Case study

The case study for this study is Greater Melbourne. As defined by the Australian Bureau of Statistics (ABS), Greater Melbourne is a Greater Capital City Statistical Area (GCSSA) or in other words, a geographical area that represents the functional extent of Victoria's state capital city (ABS 2015c). It is important to notice that GCSSAs do not correspond to the continuous built up area of cities but also include population that work or shop within the city but live in smaller urban areas or more remote area in the periphery of the urban core.

In 2013, Greater Melbourne hosted 4,347,955 inhabitants on a territory of 9990 km² which leads to a population density of 435.2 inh/km² (ABS 2015b). Greater Melbourne also has a labour force of 2,039,381 people and host slightly more than 400,000 businesses. The most significant sectors are Construction (64,800), Professional scientific and technical services (56,163), Rental, hiring and real estate (44,386) and Financial and insurance services (36,966).

Data collection

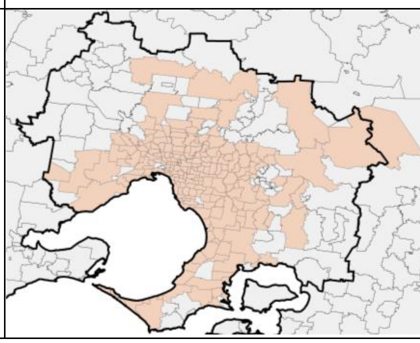
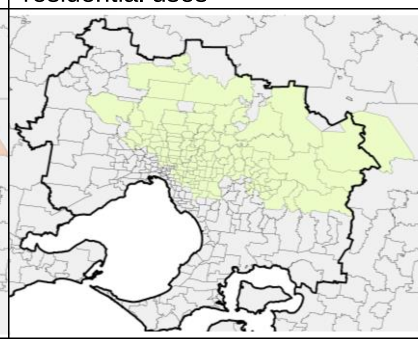
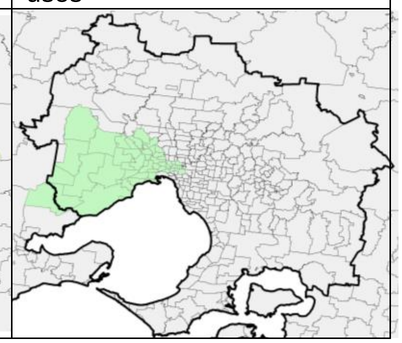
From a statistical geography perspective Melbourne can be characterised at different spatial scales. Some of these spatial units are geographical standards created by the ABS such as the Mesh Blocks and Statistical Areas from level 1 to level 4 (SA1 to SA4). However, there also exist a number of non ABS geographical delimitations including Postal Areas (POA) and Local Government Areas (LGA).

As this study wished to disaggregate the metabolic flows of Melbourne in order to investigate their statistical relationship with urban characteristics the first task was to found such metabolic flows. To do so, the datasets of ABS and AURIN were scanned. In this search, three promising datasets about water use were found in the AURIN portal, namely:

- Postcode Water Use 2008 2009 for Melbourne Water in Melbourne
- Postcode Water Consumption 2010 2014 for City West Water Postcode Regions in Melbourne
- Postcode Water Consumption 2011 2014 for Yarra Valley Water Regions in Melbourne

Some more details about each of these data are found in Table 1. At this point it is important to provide some clarification about water supply and operators in Melbourne. In fact, at the very top level there is Melbourne Water which is the governmental authority that manages water catchment, bulk water supply, sewage treatment and recycling of water[1]. Melbourne Water provides water to the three Melbourne retail companies, namely Yarra Valley, City West Water and South East Water which in turn supply water within a specified area of Greater Melbourne (see Table 1).

Table 1: Source of disaggregated data for Melbourne's water use

	Melbourne Water	Yarra Valley	City West Water
Year	2008 and 2009	2011–2014 (quarterly readings)	2010–2014 (quarterly readings)
Unit	liters per household per day	kilo liters	kilo liters
Use	Total use	commercial, industrial and residential uses	residential and nonresidential uses
Area			

As illustrated in Table 1, data coming from the two retail companies are more detailed as they offer not only four different values per year, but also disaggregate water use into at least residential and nonresidential use. In addition, water use is expressed in absolute terms and not with a composite indicator such liters per household. This avoids any loss of information but also to investigate if residential and nonresidential water use share the same socioeconomic and territorial drivers. Using the retail companies data would also enable to make more meaningful statistical relationships with local factors as they provide information about the year 2011. However, spatially disaggregated water use data from South East Water retail company are not available implying that a large part of Greater Melbourne water use is not covered and represented. Consequently, this would also greatly reduce the sample size used for the statistical relationship. Therefore, for this study it seemed more appropriate to use data from the 211 postal areas covered by Melbourne Water despite the limitations mentioned here above.

To contextualise the water metabolism of Melbourne and in order to identify what urban characteristics drive the water use, a number of 2011 Census data at postal areas was collected (ABS 2015a). It is important to mention that ABS definition of postal areas is an approximation of Australian postcodes based on the addition of SA1s. Therefore the boundaries between water use and urban characteristics are not precisely the same but are a very good approximation. The urban characteristics from the 2011 census (from the Basic Community Profile tables) that were chosen for the statistical analysis are detailed in Annex 1. In summary, those data contained information about the socioeconomic and demographic profile of inhabitants as well as the territorial organisation of Melbourne including population density and different types of housing typologies.

[1] http://www.melbournewater.com.au/whatwedo/Pages/whatwedo.aspx

Results

This section will present the spatialisation of Melbourne's water use and a brief visual comparison between this water use and some selected urban characteristics (Figure 2). A more significant comparison between water use and local factors is then described through the results of a Pearson correlation in Table 2. Finally, this section will discuss which urban characteristics have the highest influence on water use.

The following figure depicts four different maps of Greater Melbourne postal areas water use, median weekly income per person, the number of private dwellings and population density. As illustrated, the water use per household and per day is spread in a heterogeneous way. It should be underlined that the distribution of total water use could represent a very different distribution pattern. In any case, water use as presented in Figure 2, shows a very different spatial distribution the selected urban characteristics. For instance, population density is decreasing steadily when going further from the city center. On the contrary, the number of private dwellings seems higher in postal areas that are in the periphery of the city center. In this case, it is worth noticing that some of the largest postal areas are the one with the highest number of private dwellings which can concur with single detached dwelling of the outer suburbs. In this case it could be interesting to also map the dwelling density or the gross floor area density expressing thus how densely these postal areas are built up. Finally, the spatial distribution of the median income per person does not follow a particular pattern of distribution. Indeed it appears that inhabitants living at city center and at the periphery of Greater Melbourne earn more income and in the areas in between inhabitants seems to earn a lower income.

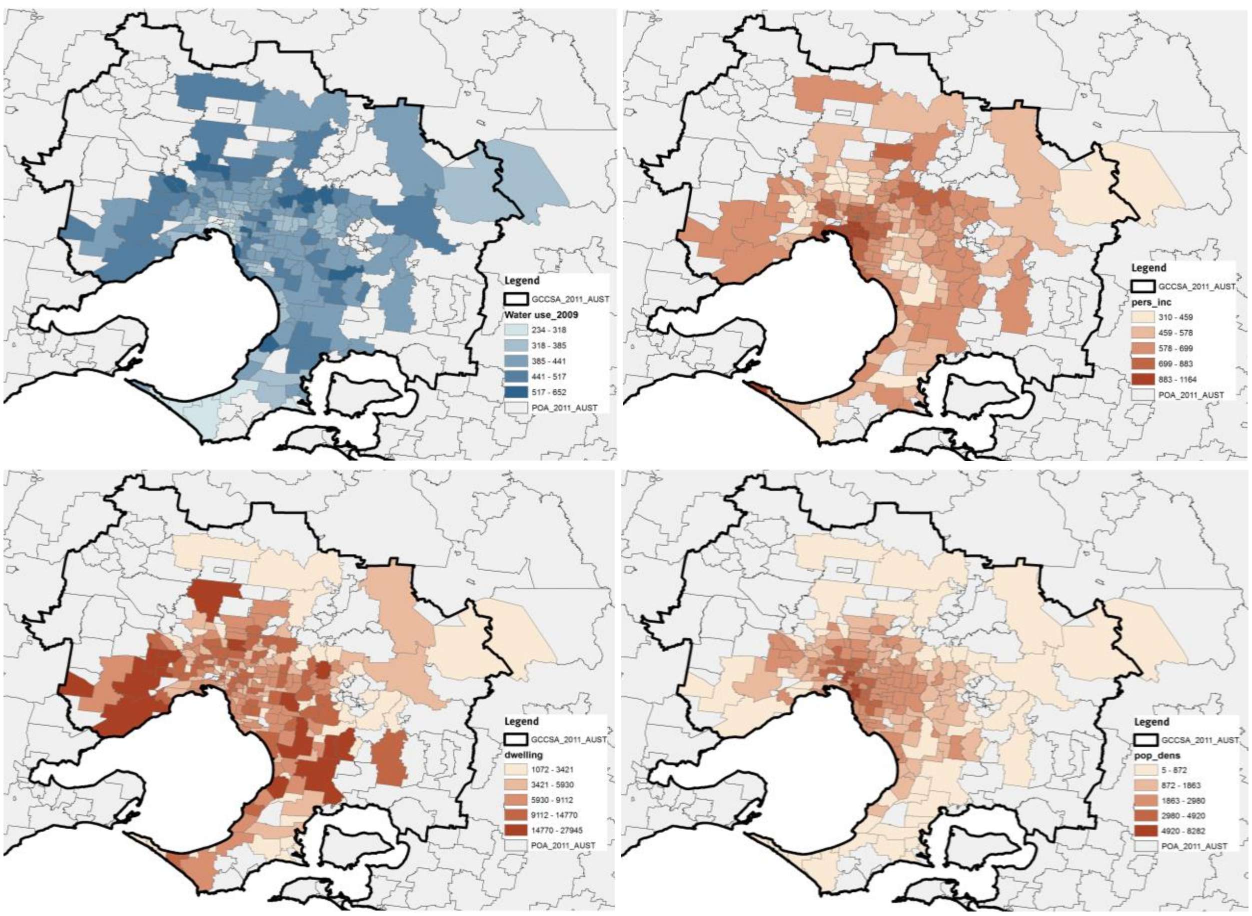


Figure 2: Water use in l/household*day (top left), Median weekly income per person (top right), number of private dwellings (bottom left) and population density in inh/km² (bottom right) in Melbourne's postal areas.

This first visual comparison between urban characteristics between Melbourne's water use and some selected urban characteristics confirms the hypothesis that cities are heterogeneous systems but also raises the question of what are the parameters that drive this difference.

To further understand the relationship between urban characteristics and to attempt identifying resource use drivers, this part will carry out a Pearson correlation between resource use figures and local factors (a full list of indicators is presented below the table). At this point it is necessary to remind that the water use presented is a total consumption per households figure. This aggregated figure does not distinguish the different uses. The following table presents the results of this correlation. The results are shown in the form of a gradient of colours ranging from light orange to red for the results presenting a negative statistical relationship, and light orange to green for the positive statistical relationship. Through this table it is possible to explore the intra and interrelationships that were hinted in Figure 1.

Table 2: Correlation table of Melbourne's water use and some its urban characteristics

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	t	v	w	x	y	z	aa	ab	ac	ad	ae	af	ag	ah	ai	aj	ak	al	am	an	ao
a	1,00	0,99	0,14	0,03	0,35	0,10	0,09	0,10	0,10	0,10	0,05	0,15	0,11	0,01	0,07	0,15	0,07	0,07	0,30	0,35	0,18	0,14	0,29	0,38	0,00	0,03	0,00	0,00	0,19	0,25	0,39	0,00	0,05	0,12	0,12	0,30	0,03	0,12	0,05
b		1,00	0,01	0,00	0,32	0,11	0,11	0,11	0,11	0,11	0,06	0,17	0,13	0,06	0,09	0,13	0,08	0,09	0,32	0,33	0,15	0,15	0,29	0,38	0,02	0,01	0,02	0,02	0,20	0,23	0,37	0,02	0,04	0,13	0,14	0,27	0,01	0,13	0,07
c			1,00	0,28	0,27	0,14	0,14	0,14	0,13	0,12	0,10	0,14	0,13	0,38	0,15	0,14	0,10	0,13	0,09	0,19	0,23	0,08	0,03	0,01	0,16	0,12	0,16	0,16	0,06	0,18	0,22	0,16	0,14	0,07	0,10	0,25	0,19	0,11	0,14
d				1,00	0,27	0,03	0,03	0,03	0,06	0,02	0,07	0,04	0,03	0,01	0,23	0,13	0,23	0,19	0,16	0,10	0,03	0,05	0,07	0,11	0,01	0,01	0,01	0,01	0,08	0,15	0,12	0,01	0,01	0,04	0,10	0,06	0,01	0,03	0,04
e					1,00	0,08	0,09	0,09	0,00	0,17	0,01	0,14	0,07	0,39	0,48	0,38	0,41	0,36	0,15	0,70	0,34	0,04	0,17	0,25	0,19	0,16	0,18	0,18	0,15	0,48	0,75	0,18	0,19	0,09	0,08	0,57	0,27	0,05	0,14
f						1,00	1,00	1,00	0,95	0,91	0,89	0,82	1,00	0,31	0,08	0,14	0,06	0,15	0,08	0,38	0,89	0,96	0,93	0,84	0,98	0,86	0,98	0,98	0,95	0,46	0,22	0,98	0,97	0,84	0,94	0,71	0,94	0,94	0,95
g							1,00	1,00	0,96	0,90	0,91	0,80	1,00	0,29	0,05	0,12	0,04	0,12	0,07	0,38	0,89	0,97	0,93	0,84	0,99	0,85	0,99	0,99	0,95	0,48	0,22	0,99	0,97	0,86	0,94	0,70	0,94	0,96	0,94
h								1,00	0,95	0,91	0,90	0,81	1,00	0,30	0,07	0,13	0,05	0,13	0,07	0,38	0,89	0,97	0,93	0,84	0,99	0,86	0,99	0,99	0,95	0,47	0,22	0,99	0,97	0,85	0,94	0,70	0,94	0,95	0,94
i									1,00	0,73	0,98	0,61	0,95	0,23	0,02	0,03	0,04	0,04	0,03	0,24	0,83	0,98	0,93	0,87	0,94	0,73	0,94	0,94	0,94	0,46	0,12	0,94	0,93	0,81	0,96	0,60	0,92	0,98	0,82
j										1,00	0,64	0,96	0,90	0,34	0,12	0,26	0,05	0,25	0,20	0,48	0,82	0,81	0,79	0,68	0,88	0,88	0,88	0,88	0,82	0,40	0,30	0,88	0,87	0,78	0,76	0,71	0,82	0,76	0,95
k											1,00	0,47	0,90	0,20	0,03	0,05	0,01	0,04	0,08	0,24	0,80	0,94	0,88	0,83	0,91	0,66	0,90	0,90	0,89	0,46	0,15	0,90	0,90	0,76	0,92	0,59	0,89	0,96	0,76
l												1,00	0,81	0,33	0,17	0,35	0,09	0,32	0,25	0,42	0,71	0,70	0,70	0,60	0,76	0,84	0,77	0,77	0,74	0,33	0,21	0,77	0,75	0,71	0,66	0,60	0,70	0,63	0,88
m													1,00	0,29	0,07	0,14	0,06	0,14	0,07	0,36	0,88	0,97	0,94	0,85	0,98	0,85	0,98	0,98	0,96	0,46	0,19	0,98	0,97	0,85	0,94	0,68	0,94	0,95	0,94
n														1,00	0,03	0,02	0,05	0,04	0,02	0,42	0,31	0,20	0,17	0,13	0,30	0,29	0,30	0,30	0,16	0,23	0,37	0,30	0,25	0,01	0,30	0,45	0,38	0,22	0,41
o															1,00	0,78	0,78	0,89	0,80	0,12	0,05	0,04	0,16	0,20	0,01	0,19	0,02	0,02	0,20	0,38	0,32	0,02	0,02	0,00	0,10	0,12	0,10	0,01	0,16
p																1,00	0,66	0,91	0,82	0,05	0,02	0,09	0,20	0,21	0,06	0,27	0,07	0,07	0,26	0,26	0,38	0,07	0,07	0,18	0,08	0,11	0,11	0,03	0,22
q																	1,00	0,75	0,74	0,12	0,00	0,03	0,10	0,12	0,02	0,21	0,02	0,02	0,16	0,23	0,27	0,02	0,02	0,02	0,09	0,06	0,08	0,01	0,11
r																		1,00	0,93	0,00	0,04	0,08	0,17	0,16	0,08	0,31	0,09	0,09	0,25	0,26	0,27	0,09	0,10	0,09	0,12	0,02	0,05	0,00	0,25
t																			1,00	0,17	0,10	0,00	0,02	0,02	0,06	0,32	0,07	0,07	0,13	0,12	0,07	0,07	0,09	0,06	0,01	0,11	0,07	0,07	0,20
v																				1,00	0,60	0,19	0,08	0,01	0,48	0,53	0,48	0,48	0,15	0,48	0,86	0,48	0,50	0,30	0,19	0,84	0,48	0,27	0,51
w																					1,00	0,81	0,68	0,55	0,94	0,89	0,95	0,95	0,76	0,67	0,51	0,95	0,95	0,80	0,75	0,90	0,91	0,82	0,85
x																						1,00	0,96	0,89	0,94	0,74	0,94	0,94	0,97	0,41	0,06	0,94	0,93	0,84	0,96	0,56	0,91	0,97	0,86
y																							1,00	0,97	0,88	0,70	0,87	0,87	0,97	0,26	0,07	0,87	0,85	0,81	0,94	0,42	0,83	0,93	0,83
z																								1,00	0,77	0,58	0,77	0,77	0,90	0,14	0,15	0,77	0,75	0,73	0,88	0,29	0,73	0,88	0,73
aa																									1,00	0,87	1,00	1,00	0,91	0,55	0,34	1,00	0,99	0,86	0,90	0,79	0,96	0,95	0,92
ab																										1,00	0,87	0,87	0,78	0,47	0,34	0,87	0,87	0,77	0,70	0,78	0,76	0,71	0,89
ac																											1,00	1,00	0,91	0,55	0,34	1,00	0,99	0,87	0,90	0,79	0,96	0,94	0,92
ad																												1,00	0,91	0,55	0,34	1,00	0,99	0,87	0,90	0,79	0,96	0,94	0,92
ae																													1,00	0,29	0,06	0,91	0,90	0,85	0,94	0,49	0,84	0,93	0,87
af																														1,00	0,43	0,55	0,55	0,47	0,35	0,66	0,59	0,47	0,40
ag																															1,00	0,34	0,36	0,14	0,05	0,78	0,41	0,14	0,30
ah																																1,00	0,99	0,87	0,90	0,79	0,96	0,94	0,92
ai																																	1,00	0,86	0,88	0,80	0,95	0,93	0,91
aj																																		1,00	0,68	0,55	0,76	0,85	0,72
ak																																			1,00	0,53	0,89	0,93	0,86
al																																				1,00	0,80	0,60	0,75
am																																					1,00	0,92	0,88
an																																						1,00	0,82
ao																																							1,00

a: water use 2008, b: water use 2009, c: relative difference between water use 2009 and 2008, d: area, e: population density, f: total males, g: total females, h: total population, i: birthplace Australia, j: birthplace elsewhere, k: language spoken at home English, l: language spoken at home other, m: count of persons in occupied private dwellings, n: median age, o: median mortgage repay, p: median personal income, q: median rent, r: median family income, t: median househod income, v: no motor vehicles per dwelling, w: 1 motor vehicles per dwelling, x: 2 motor vehicles per dwelling, y: 3 motor vehicles per dwelling, z: 4+ motor vehicles per dwelling, aa: total motor vehicles per dwelling, ab: motor vehicles not stated, ac: total dwellings, ad: total households, ae: separate house dwelling, af: row house dwelling, ag: flat or unit apartment dwellings, ah: occupied dwellings, ai: occupied + non occupied dwellings; aj: owned outright dwellings, ak: owned with mortagage dwellings, al: rented dwellings, am: full employed persons, an: part time employed persons, ao: unemployed person looking for work

The first observation in this Table is that the water use across Greater Melbourne's postal areas for both years is almost perfectly correlated. This could imply that either there has been almost no change in water use from 2008 to 2009 or if there has been a variation in water use then it has been similar across all postal areas. The second observation to be made is that water use is not highly correlated with almost any of the others urban characteristics. The highest correlation is with population density (-0.35), no motor vehicles per dwellings (-0.35), 4+ motor vehicles per dwellings (0.38), flat or unit apartment dwellings (-0.38). While these correlation coefficients are relatively low, they seem to concur that postal areas with a great number of cars, low population density and low built-up density use more water. These low correlation coefficients lead us to assume that the water use metric use in this study is not the most appropriate to find statistical relationships with the chosen urban characteristics. To counter this, different water metrics and/or urban characteristics indicators should be used. In addition, this statistical relationships are exclusively applicable for Greater Melbourne's postal areas. Therefore choosing a different geographical boundaries or disaggregation unit could lead to different results.

Another important information that this table can provide are the relationships between Greater Melbourne postal areas urban characteristics. For instance this shows that indicators concerning population, gender, nationality and language spoken are very well positively correlated between each other. These indicators are also highly correlated with almost all other indicators except median age, median mortgage repay, median personal income,median rent, median family income, median househod income, no motor vehicles per dwelling, row house dwelling and flat or unit apartment dwellings. The indicators median age, median mortgage repay, median personal income, median rent, median family income, median househod income, no motor vehicles per dwelling, row house dwelling and flat or unit apartment dwellings are very poorly correlated with almost all other indicators. The rest of the indicators, are well correlated with the indicators of the same group and with the rest of urban characteristics.

Discussion and Conclusion

This study presents a first investigation of relationship between Greater Melbourne's postal areas water use and some urban characteristics. This was achieved firstly through a visual identification and a more extended Pearson correlation. The results of this study show that this water use metric was not highly correlated with the studied urban characteristics. However, this enables to see that cities are not static and homogeneous systems. Indeed, the resource needs of cities, which are often imported from their global hinterland, are complex and diverse for different land use, building typologies, socio-economic and demographic profiles.

However, it is necessary at this point to mention again that there are a number of limitations in the current study. In the future, water use data from Melbourne Water should be replaced by those coming from the three principal retailers, if water use data from South East Water become available for 2011 and are disaggregated in residential and non-residential use. Such data will enable a more thorough and relevant statistical analysis as it will seek relationships between resource use and urban characteristics of the same year. In addition, by having more accurate and further disaggregated water use data, a number of resource use indicators could be created such total and residential water use/cap, total and residential water use/m² of total and residential space, total and residential water use/GDP and income, etc. in order to further expand our understanding about water use drivers.

Another potential limitation of this study is that data are collected in postal areas. As these are non ABS geographical divisions, this could imply that postal areas are not necessarily spatial territories with homogeneous socioeconomic and territorial patterns. Indeed within them there could persist a number of heterogeneous elements. This could result into finding relationships between average behaviours. While at the moment water use data are only available at postal areas, to counter this limitations the same statistical relationships should be investigated at different spatial scales such as SA1 and SA2. Finally, it should be mentioned that these results are only valid for water use and are not necessarily the same for other resource use. In the future, if disaggregated energy and material use data become available, it would become possible to explore if the use of different resources is due to the same drivers.

To conclude the results of this study could be of great relevance for context-specific policies, to validate or calibrate urban resource use modelling, but also and most importantly to better understand the complex articulation of urban areas between local and global challenges ranging from resource needs to unemployment and housing affordability.

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References

Athanassiadis, A. & Bouillard, P., 2013. Contextualizing the Urban Metabolism of Brussels: Correlation of resource use with local factors. *CISBAT.* Lausanne.

Australian Bureau of Statistics (Abs), 2015a. *Datapacks downloads - Basic Community Profile of Postal Areas for Victoria* [online]. https://www.censusdata.abs.gov.au/datapacks/DataPacks?release=2011 [Accessed Access Date

Australian Bureau of Statistics (Abs), 2015b. *Greater Melbourne (GCCSA) Statistics* [online]. http://stat.abs.gov.au/itt/r.jsp?RegionSummary&region=2GMEL&dataset=ABS_REGIONAL_ASGS&geoconcept=REGION&datasetASGS=ABS_REGIONAL_ASGS&datasetLGA=ABS_REGIONAL_LGA&regionLGA=REGION&regionASGS=REGION [Accessed Access Date 08/07/2015].

Australian Bureau of Statistics (Abs), 2015c. *Statistical Geography Fact Sheet - Greater Capital City Statistical Areas* [online]. http://www.abs.gov.au/websitedbs/D3310114.nsf/4a256353001af3ed4b2562bb00121564/6b6e07234c98365aca25792d0010d730/$FILE/Greater%20Capital%20City%20Statistical%20Area%20-%20Fact%20Sheet.pdf [Accessed Access Date 08/07/2015].

Corvalan, C., Hales, S. & Mcmichael, A., 2005. *Ecosystems and human well-being: health synthesis: a report to the Millenium Ecosystem Assessment*: W. Press.

Heinonen, J., Jalas, M., Juntunen, J.K., Ala-Mantila, S. & Junnila, S., 2013. Situated lifestyles: I. How lifestyles change along with the level of urbanization and what the greenhouse gas implications are—a study of Finland. *Environmental Research Letters,* 8**,** 025003.

Howard, B., Parshall, L., Thompson, J., Hammer, S., Dickinson, J. & Modi, V., 2012. Spatial distribution of urban building energy consumption by end use. *Energy and Buildings,* 45**,** 141-151.

Kennedy, C. & Hoornweg, D., 2012. Mainstreaming Urban Metabolism. *Journal of Industrial Ecology,* 16**,** 780-782.

Kennedy, C.A., Stewart, I., Facchini, A., Cersosimo, I., Mele, R., Chen, B., Uda, M., Kansal, A., Chiu, A., Kim, K.-G., Dubeux, C., Lebre La Rovere, E., Cunha, B., Pincetl, S., Keirstead, J., Barles, S., Pusaka, S., Gunawan, J., Adegbile, M., Nazariha, M., Hoque, S., Marcotullio, P.J., González Otharán, F., Genena, T., Ibrahim, N., Farooqui, R., Cervantes, G. & Sahin, A.D., 2015. Energy and material flows of megacities. *Proceedings of the National Academy of Sciences,* 112**,** 5985-5990.

Mcmichael, A.J., Friel, S., Nyong, A. & Corvalan, C., 2008. Global environmental change and health: impacts, inequalities, and the health sector. *BMJ : British Medical Journal,* 336**,** 191-194.

Müller, D.B., Liu, G., Løvik, A.N., Modaresi, R., Pauliuk, S., Steinhoff, F.S. & Brattebø, H., 2013. Carbon Emissions of Infrastructure Development. *Environmental Science & Technology,* 47**,** 11739-11746.

Pincetl, S., Bunje, P. & Holmes, T., 2012. An expanded urban metabolism method: Toward a systems approach for assessing urban energy processes and causes. *Landscape and Urban Planning,* 107**,** 193-202.

Pincetl, S., Graham, R., Murphy, S. & Sivaraman, D., 2015. Analysis of High-Resolution Utilty Data for Understanding Energy Use in Urban Systems. The case of Los Angeles, California. *Journal of Industrial Ecology*.

Seto, K.C., Dhakal, S., Bigio, H., Blanco, H., Delgado, C., Dewar, D., Huang, L., Inaba, A., Kansal, A., Lwasa, S., Mcmahon, J.E., Müller, D., Murakami, J., Nagendra, H. & Ramaswami, A., 2014. Chapter 12: Human Settlements, Infrastructure, and Spatial Planning. *In* Edenhofer O., Pichs-Madruga R., Sokona Y., Farahani E., Kadner S., Seyboth K., Adler A., Baum I., Brunner S., Eickermeier P., Kriemann B., Savolainen J., Schlömer S., Von Stechow C., Zwickel T. & Minx J.C. (eds.) *Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change.* Cambridge, United Kingdom and New York, USA: Cambridge University Press.

United Nations - Department of Economic and Social Affairs (Un), 2014. *Urban Population at Mid-Year by Major Area, Region and Country, 1950-2050 (thousands)* [online]. http://esa.un.org/unpd/wup/CD-ROM/Default.aspx [Accessed Access Date

Wilson, J., Tyedmers, P. & Spinney, J.E.L., 2013. An Exploration of the Relationship between Socioeconomic and Well-Being Variables and Household Greenhouse Gas Emissions. *Journal of Industrial Ecology,* 17**,** 880-891.

Zhang, Y., 2013. Urban metabolism: A review of research methodologies. *Environmental Pollution,* 178**,** 463-473.

Annex 1

Table number	Table name	Table population	Sequential	Short	Long
B01	Selected Person Characteristics by Sex	Persons	B1	Tot_P_M	Total_Persons_Males
B01			B2	Tot_P_F	Total_Persons_Females
B01			B3	Tot_P_P	Total_Persons_Persons
B01			B57	Birthplace_Australia_P	Birthplace_Australia_Persons
B01			B60	Birthplace_Elsewhere_P	Birthplace_Elsewhere_Persons
B01			B63	Lang_spoken_home_Eng_only_P	Language_spoken_at_home_English_only_Persons
B01			B66	Lang_spoken_home_Oth_Lang_P	Language_spoken_at_home_Other_Language_Persons
B01			B105	Count_psns_occ_priv_dwgs_P	Count_of_Persons_in_occupied_private_dwellings_Persons
B02	Selected Medians and Averages		B109	Median_age_persons	Median_age_of_persons
B02			B110	Median_mortgage_repay_monthly	Median_mortgage_repayment_monthly
B02			B111	Median_Tot_prsnl_inc_weekly	Median_total_personal_income_weekly
B02			B112	Median_rent_weekly_	Median_rent_weekly
B02			B113	Median_Tot_fam_inc_weekly	Median_total_family_income_weekly
B02			B114	Average_num_psns_per_bedroom	Average_number_of_Persons_per_bedroom
B02			B115	Median_Tot_hhd_inc_weekly	Median_total_household_income_weekly
B02			B116	Average_household_size	Average_household_size
B29	Number of Motor Vehicles by Dwellings	Occupied private dwellings	B5020	Num_MVs_per_dweling_0_MVs	Number_of_motor_vehicles_per_dwelling_No_motor_vehicles_Dwellings
B29			B5021	Num_MVs_per_dweling_1_MVs	Number_of_motor_vehicles_per_dwelling_One_motor_vehicle_Dwellings
B29			B5022	Num_MVs_per_dweling_2_MVs	Number_of_motor_vehicles_per_dwelling_Two_motor_vehicles_Dwellings
B29			B5023	Num_MVs_per_dweling_3_MVs	Number_of_motor_vehicles_per_dwelling_Three_motor_vehicles_Dwellings
B29			B5024	Num_MVs_per_dweling_4mo_MVs	Number_of_motor_vehicles_per_dwelling_Four_or_more_motor_vehicles_Dwellings
B29			B5025	Num_MVs_per_dweling_Tot	Number_of_motor_vehicles_per_dwelling_Total_Dwellings
B29			B5026	Num_MVs_NS	Number_of_motor_vehicles_not_stated_Dwellings
B29			B5027	Total_dwelings	Total_Dwellings
B30	Household composition by Number of Persons Usually Resident	Occupied private dwellings	B5048	Total_Total	Total_Total
B31	Dwelling Structure	Occupied private dwellings	B5049	OPDs_Separate_house_Dwellings	Occupied_private_dwellings_Separate_house_Dwellings
B31			B5055	OPDs_SD_r_t_h_th_Tot_Dwgs	Occupied_private_dwellings_Semi_detached_row_or_terrace_house_townhouse_etc_with_Total_Dwellings
B31			B5065	OPDs_Flt_unit_apart_Tot_Dwgs	Occupied_private_dwellings_Flat_unit_or_apartment_Total_Dwellings
B31			B5077	OPDs_Tot_OPDs_Dwellings	Occupied_private_dwellings_Total_occupied_private_dwellings_Dwellings
B31			B5081	Total_PDs_Dwellings	Total_private_dwellings_Dwellings
B32	Tenure Type and Landlord Type by Dwelling Structure	Occupied private dwellings	B5088	O_OR_Total	Owned_outright_Total
B32			B5094	O_MTG_Total	Owned_with_a_mortgage_Total
B32			B5136	R_Tot_Total	Rented_Total_Total
B37	Selected Labour Force, Education and Migration Characteristics by Sex	Persons	B5479	lfs_Emplyed_wrked_full_time_P	Labour_force_status_Employed_worked_full_time_Persons
B37			B5482	lfs_Emplyed_wrked_part_time_P	Labour_force_status_Employed_worked_part_time_Persons
B37			B5488	lfs_Unmplyed_lookng_for_wrk_P	Labour_force_status_Unemployed_looking_for_work_Persons
B37			B5497	Percent_Unem_loyment_P	Percent_Unemployment_Persons