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ENVIRONMENTAL SYSTEMS ANALYSIS OF URBAN WATER SYSTEMS – HISTORICAL ACCOUNT OF PUBLISHED WORK IN SCIENTIFIC JOURNALS

Miljö-systemanalys av urbana vattensystem – historik av publicerade verk i vetenskapliga tidskrifter

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Abstract

This paper is a literature review of environmental systems analysis studies – adopting the LCA (life-cycle assessment) approach – of urban water and wastewater systems. Both with respect to the number of scientific journals referred to and the time-period of publication, the scope has been limited. The time period considered is 2000–2014, and the number of journals referred to, is 12. Of the 93 papers found, 51 focus on wastewater treatment. Over one-third of the publications (35 of 93) have a focus on a city, region or country in Europe, with Spain topping the list with 10 of these. As far as the origin of the publications is concerned, Spain is *numero uno* again with 14. Four papers adopt a dual scope (as far as sub-systems within the urban water system are concerned), while 12 of them are pan-systemic. As far as sub-scopes are concerned, within wastewater treatment, there are 12 publications dealing with treatment technologies. About 39 % (38 publications) are comparative analyses – among different processes/options/approaches or among different single case studies. The country being focused in (in a case study) is different from the country from which the publication originates (country in which the university/institute to which the first author belongs, is located) in 7 publications. The set of 93 papers is by no means comprehensive as all possible journals in which papers using LCA as a tool to study urban water systems, have not been browsed through. Also, such publications from before year-2000 have not been taken into consideration. However, one may still conclude that looking at urban water systems as a whole (holistically) is gradually becoming more common. Further, a lot of potential research in this field is expected and urgently needed in the developing world.

Key words – Life-cycle assessment, LCA, Urban water system, Environmental Systems Analysis, Water treatment, Wastewater treatment, Water distribution, Wastewater transport

Sammanfattning

Denna artikel är en litteraturgenomgång av miljösystemanalytiska studier – med ett livscykelanalytiskt (LCA) tillvägagångssätt – av urbana vatten- och avloppssystem. Både när det gäller antalet vetenskapliga tidskrifter och tidsperioden för publicering har omfattningen varit begränsad. Tidsperioden som beaktas är 2000–2014, och antalet tidskrifter som undersökts är 12. Av de 93 artiklarna hittade hade 51 fokus på rening av avloppsvatten. Över en tredjedel av de publikationerna (35 av 93) hade fokus på en stad, region eller ett land i Europa. Spanien toppar listan med 10 av dessa. När det gäller ursprungsland är Spanien *numero uno* igen med 14. Fyra artiklar har dubbla målsättningar (angående delsystem inom det urbana vattensystemet), medan 12 av dem är pan-systemiska. Inom avloppsrening finns det 12 publikationer som behandlar reningsteknik. Cirka 39 % (38 publikationer) är jämförande analyser – mellan olika processer/alternativ/strategier eller mellan olika enskilda fallstudier. Landet i fokus (i en fallstudie) skiljer sig från det land från vilket publikationen har sitt ursprung (land där universitetetet/institutet som förste författare tillhör) i 7 publikationer. De 93 artiklarna studerade är på intet sätt heltäckande eftersom alla tidskrifter där LCA används som ett verktyg för att studera urbana vattensystem inte har undersökts. Dessutom har publikationer från tiden före år 2000 inte beaktats. Dock kan man fortfarande konstatera att studier av urbana vattensystem som helhet (helhetssyn) gradvis blir allt vanligare. Vidare kan en stor potential av forskning inom detta område förväntas i utvecklingsländerna.

Introduction and background

When one carries out system analysis, one starts by defining the system with its sub-systems, components and interrelationships/dependencies among them, identifying the system boundaries and labelling what is outside the boundaries set, as surroundings or the 'environment' (ambience, in other words). The system can be considered to be open or closed, and thermodynamically we are talking about the presence or absence of an exchange of matter and/or energy.

The surroundings here could either be the physical environment – atmosphere, hydrosphere, lithosphere/pedosphere, biosphere (flora and fauna), the economy (primary, tertiary and secondary sectors) or the human society. The human society and the economy together could be labelled as the anthroposphere (see Figure 1).

One could think of a system's interactions with the economy in terms of monetary flows (expenses, loans, interest payments, subsidies, taxes, etc.) and that with human society in terms of services provided, employment generation etc. Interactions with the different compartments of the environment take the form of inflows of raw materials of various kinds (where the environmental media act as sources; water, minerals, fuel materials etc.) and outflows of solid, liquid and gaseous emissions / wastes (where the environment acts as a sink).

The system could be studied as a black box with focus only on the inflows and outflows and no attention paid to the metabolism within the system (the various processes to which the inflows are subjected, the interrelationships and dependencies among the sub-systems and the emissions resulting from these processes); or one could delve deeper into the system and understand the structure and functioning of the individual sub-systems and the components they are made of. The first approach would simply enable one to describe the status quo of the interactions between the system and its surroundings; while the latter becomes imperative if one sets out to manipulate the functioning of the system (its sub-systems in effect) to modify the inflows and/or outflows.

If we take the surroundings to be the physical environmental media, studying the interactions would amount to an environmental systems analysis. If the surroundings are defined as the economy in which the system is situated, we would be performing an economic systems analysis. Likewise, if the interactions between the system and the human society are to be studied, a socio-cultural systems analysis may have to be performed.

Urban water (and sanitation) systems, situated in the anthroposphere, a part of the economy (primary-secondary-tertiary public/private sector) and providing water supply and sanitation services to society, have been researched extensively over the years, and several publications have resulted therefrom. A good proportion of these focus on either simple emissions accounting or more comprehensive environmental life cycle analyses (LCA). If the system in Figure 1 is an urban water/sanitation system, and if one looks inside this 'black box', one can identify sub-systems like the ones depicted in Figure 2, which can be looked upon as a standard simplified block diagram of the system.

'Human consumers' or more appropriately 'anthropospheric consumers' depicted within the system actually belong to both the society and the economy and can in fact also be depicted as parts of the surroundings – society and economy. However, as has been argued by Venkatesh and Brattebø (2014), an environmental systems analysis of urban water/sanitation systems is usually incomplete without factoring in the consumers. Each of the sub-systems, when studied individually, will

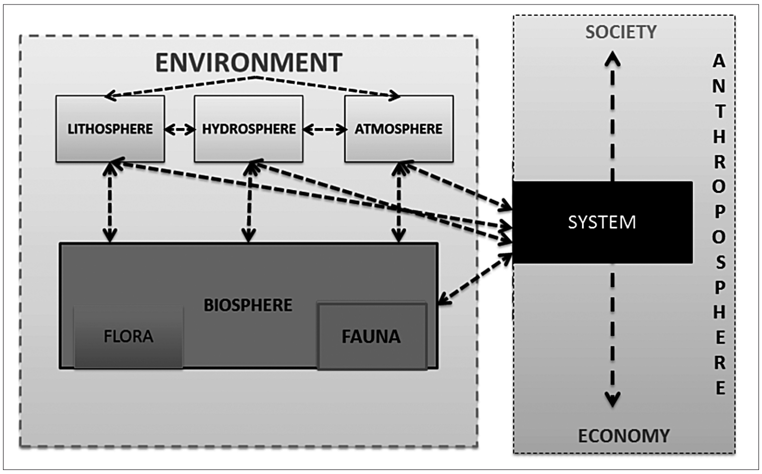

Figure 1. *Anthropospheric system and interactions within the anthroposphere and the various interacting compartments of the environment.*

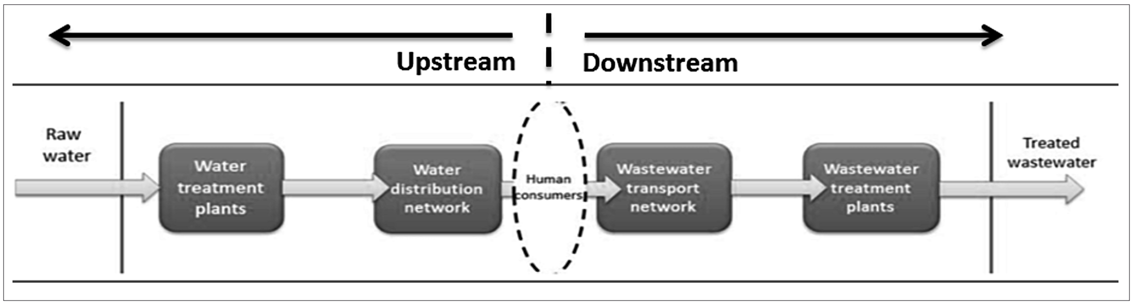

Figure 2. *A standard urban water-sanitation system with sub-systems, and the primary environmental inflow (raw water) and outflow (treated wastewater).*

have its own sets of inflows from and outflows to the environment. The urban water system also interacts with the environment indirectly through other systems in the economy – for instance, the power sector which supplies electricity to it and the water-treatment-chemicals producing companies, inter alia. LCA enables the determination of the environmental impacts associated with (or caused by) the direct and indirect inflows from and the outflows to the different environmental media.

This paper is a literature review of environmental systems analysis studies – adopting the LCA approach – of urban water and wastewater systems, the scope (temporally and with respect to the scientific journals referred to) being described in detail in the Methodology section which follows. As this paper essentially is a literature review paper, a separate Literature Review section has not been included. Instead, the review has been done in the 'Discussion of Findings' section. Before proceeding, the author would like to point to the paper – Loubet et al. (2014) – which is also a review paper of life-cycle assessment studies of urban water systems. The approach of the paper being submitted though, is different, and while it does fall into the genre – Review paper – it analyses published literature somewhat differently, providing in the process different and additional information to readers.

Methodology

The research work for this paper was conducted as part of a Master's thesis supervised by this author (student acknowledged at the end of this paper), within the precincts of the Norwegian University of Science and Technology in Trondheim. The 'playfield' so to say, was the online library system of the university through which students and employees of the university find access to several scientific journals. The work was commenced in 2014, and the time period of analysis was restricted to the 15-year period from 2000 to 2014. The journals accessed for the said time period – in which publications being sought were found – by searching solely for the terms '**LCA**' or '**Life Cycle Analysis**' ('**Life-Cycle Analysis**') or '**Life Cycle Assessment**' ('**Life-Cycle Assessment**') among publications related to the urban water/sanitation sector, in the Title, Abstract and set of Keywords provided, are listed in Table 1. It should be noted that there are possibly many other journals not listed in Table 1, which have published the types of papers being considered for this study (Venkatesh and Brattebø, 2014 in *Environmental Technology* is one such). So, the methodology adopted in this paper will account for most, but certainly not all such papers. It was safely assumed that if LCA was used as a tool in any published paper, the term would figure in the title and/or abstract and/or the set of keywords. These are predominantly journals related to water and wastewater; but also include those in which LCA or the environment is one of the main subject areas.

While LCA has been an approach of interest, and a tool which has been used by researchers since the 1990s, it was in the 21st century, that its popularity shot up in

Table 1. *Journals accessed for papers focusing on environmental LCA-studies of urban water and sanitation systems for the period 2000 to 2014 and the numbers of papers found in each of them.*

Journal	# papers found
Desalination and Water Treatment	7
Journal of Industrial Ecology	15
Journal of Water Supply, Research and Technology – AQUA	1
The International Journal of Life Cycle Assessment	9
Urban Water	2
Urban Water Journal	5
Water and Environment Journal	4
Water Environment Research	1
Water Research	11
Water Resources Management	4
Water Science and Technology	25
Water Science and Technology – Water Supply	9

universities and research institutes, as life-cycle thinking gradually started entrenching itself more and more firmly. The choice of year-2000 as the left extremity of the time period chosen thereby is quite appropriate. Needless to add, one may surely find publications related to environmental systems analysis of urban water systems, before the turn of the century. The 12 journals zeroed in, is actually a watered down list, which started off being a bit longer. Publications focusing on LCA of urban water systems (or sub-systems) were not found in a fraction of the original list, which was subsequently deleted from the list. The papers fished out of the sea of scientific publications in these 11 journals for the 15-year time period considered, are, needless to say, listed in the References-list at the end of the paper.

Papers were categorised on the basis of:

1. Year of publication
2. Scope adopted: Total system (with or without the consumption phase), freshwater resources, water treatment, water distribution, wastewater transport, wastewater treatment (including the sink and biosolids handling)
3. Sub-scopes (wherever these could be identified), to narrow down to specific fields or areas of analysis within the scope chosen
4. Type (genre) of study/analysis: Single case study, Pilot study, Theoretical study, Comparative analysis (among processes/approaches or among different case studies), Review of previous studies (like this paper for instance)
5. The city, region (and the country) being studied in the paper
6. The university/institute from which the paper originates – the corresponding author's place of work in other words
7. The country in which the university/institute from where the paper originates, is based (bearing in mind that this could be different from the country of #5 above).

It must be mentioned here that some papers did use the term 'LCA' in the title, abstract or keywords, but did not really use the tool to analyse an urban water system or one of its sub-systems for that matter. The final paper count was 93, from 12 journals (an average of between 7 and 8 papers per journal, with a span of 1 to 25; and a little over 6 papers per year).

Discussion of findings

Number of papers and distribution over time

Figure 3 indicates a fluctuating trend from 2000 to 2007, and thereafter, with the exception of the drop in 2009, a steady rise in the number of publications, till 2014. This journal (Journal of Industrial Ecology) has clearly been consistently publishing papers focusing on LCA of urban water systems from 2009 onwards, with 2010 witnessing four such. The journal Water Research has the most papers of this nature in one single year – 5 in 2014. Water Science and Technology, perhaps the most-sought-after water-related scientific publication, leads the dozen with 25 publications of this type over time – at least one in 11 of the 15 years considered for this analysis. The fact that a minimum of 10 such publications appeared from 2010 onwards, can make one reasonably state that there has been a rise in interest in environmental systems analysis of urban water systems – among researchers and thereby policy-makers (or vice versa) in general. Carrying out this analysis again after a few years from the time of writing, will tell us if this has really been so.

Scopes and sub-scopes

As far as the scope goes, it would be interesting to analyse this journal-wise and also year-wise. It must be mentioned here, that as per our definition of possible scopes, it is possible that some papers may have multiple scopes, while not focusing on the entire system. For instance, water treatment and water distribution (part of the upstream), or water resources and water treatment (part of upstream again), or wastewater transport and wastewater treatment (part of downstream) or for that matter, just the water distribution and sewage transport systems (pipelines and/or pumping stations both upstream and downstream). Further, the author has used his own discretion when it comes to slotting the papers in their respective scope-categories. For instance, a paper dealing with reuse or reclamation of wastewater may be slotted in wastewater treatment (because that is what one does when one reclaims), water treatment (because there is a looping back to the upstream) or water resources (because reclaimed wastewater can be looked upon as a water resource). In this paper, such papers have been slotted under 'wastewater treatment'. Also, all papers slotted under 'Total system' may not be equally comprehensive with respect to the analysis of the sub-systems shown in Figure 2.

Starting with the *International Journal of Life Cycle Assessment,* five of the nine papers have wastewater treatment as the scope (see Figure 5). Of the remaining four, three deal with the entire system (Barjoveanu et al., 2013; 2014; Renzoni and Germain, 2007), while one has a dual scope – water resources and water treatment (Stokes and Horvath, 2006).

The *Journal of Industrial Ecology* has covered all the scopes defined in the Methodology section, over the 2000–2014 period. Though wastewater treatment still dominates (8 of 15), there are 2 papers each for the total

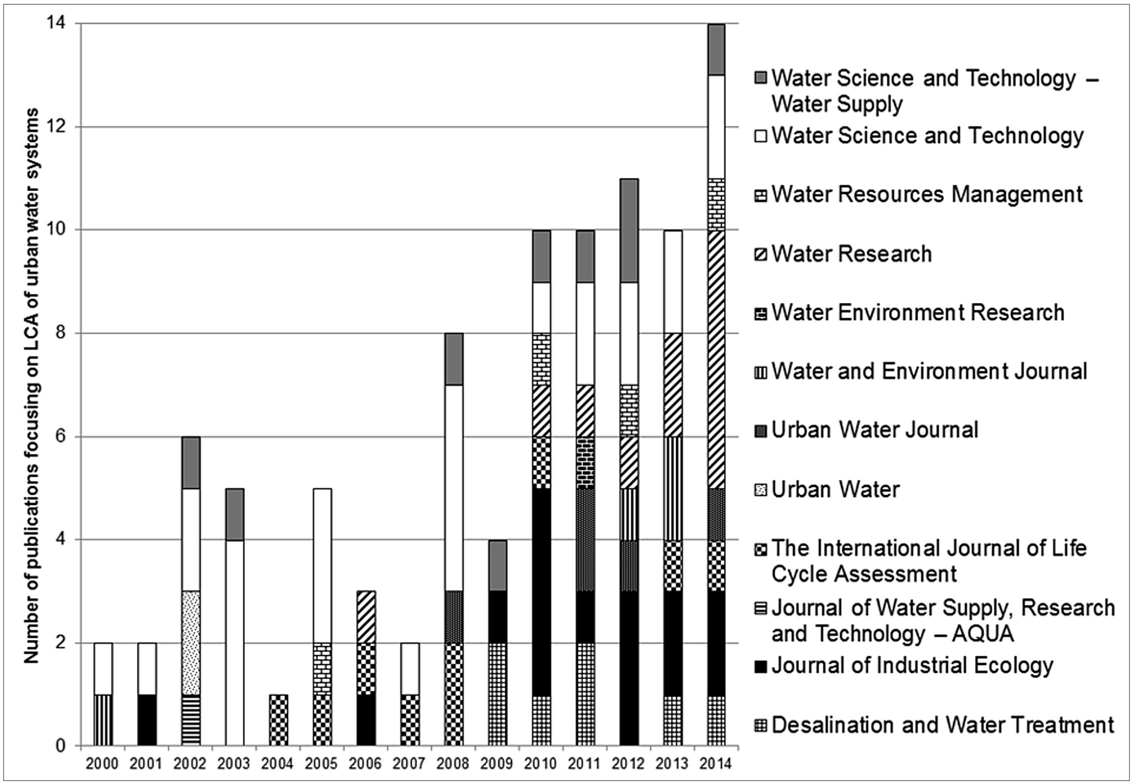

Figure 3. *The journal-wise publication-trend over time.*

system (Arpke and Hutzler, 2006; Muñoz et al., 2010B), and wastewater transport (Venkatesh et al., 2009; De Sousa et al., 2012), and one each for water treatment (Meneses et al., 2010), water distribution (Venkatesh and Brattebø, 2012A), and water resources (Owens, 2001). As shown in Figure 5, the lone paper found in the *Journal of Water Supply, Research and Technology (AQUA)* has its focus on water treatment (Mohapatra et al., 2002), while the only one in the journal *Water Environment Research*, has its focus on wastewater treatment (Coats et al., 2011). The journal *Water Resources Management* features two papers on wastewater treatment (Tangsubkul et al., 2005; Tjandraatmadja et al., 2013), and one each on water resources (Nazer et al., 2010), and wastewater transport (Petit-Boix et al., 2014). The journal *Desalination and Water Treatment* yielded seven matches, three of which focus on wastewater treatment (Vera et al., 2009; Nogueira et al., 2009; de Hoces et al., 2011), 3 on water treatment (Shahabi et al., 2014; Beery et al., 2010; Beery et al., 2011) and one on the total urban water system (Uche et al., 2013).

Of the five papers from *Urban Water Journal* (refer Figure 5), one has a dual scope (Venkatesh and Brattebø 2011A), two focus on the total water system (Lai et al., 2008; Slagstad and Brattebø 2014), one focuses on water distribution (Basupi et al., 2014) and the last one on wastewater transport (Venkatesh and Brattebø 2011B). *Urban Water* on the other hand, is represented by two papers – one focusing on the total water system (Lundin et al., 2002) and the other on wastewater treatment (Balkema et al., 2002). Three of the four papers from

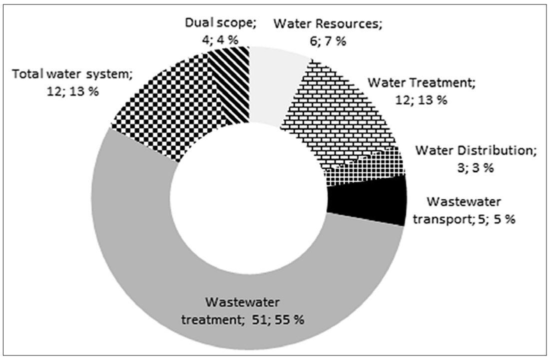

Figure 4. *Doughnut representation of the distribution of the scopes of the papers.*

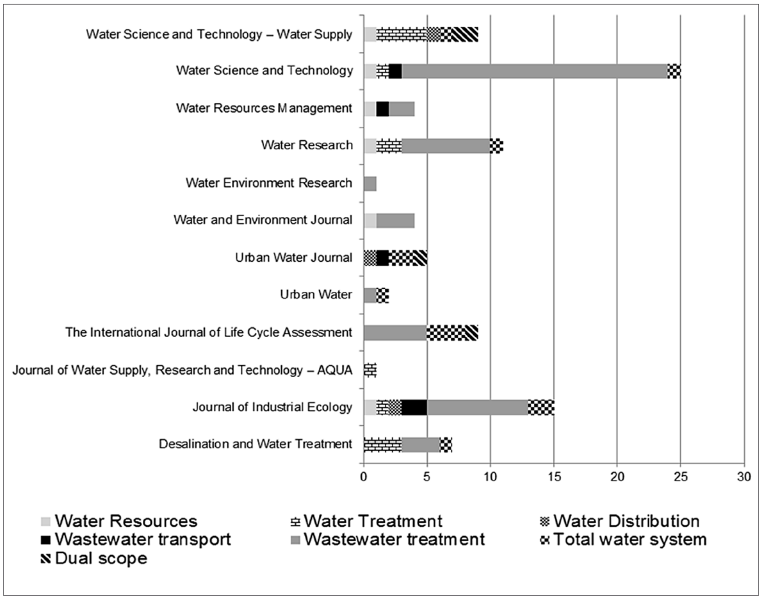

Figure 5. *Journal-wise representation of the scopes of the published papers.*

Water and Environment Journal focus on wastewater treatment ; with the fourth one (Ward et al., 2012) dealing with water resources. Wastewater treatment dominates the 11 papers from *Water Research* (7 in all), with one each focusing on the total water system (Loubet et al., 2014) and water resources (Godskesen et al., 2013) and two on water treatment (Zhou et al., 2014; Hancock et al., 2012). Quite obviously, all the papers in *WaterScience and Technology – Water Supply* focus on the upstream. While most of the papers focus on water treatment (4 of 9), there are two papers with dual scopes – one focusing on water resources and water treatment (Lyons et al., 2009) and the other on water distribution and wastewater transport (Herz and Lipkow, 2002). The inclusion of a paper part-focusing on wastewater transport of course is a curiosity, as far as this journal is concerned. One paper each has focus on water distribution (Engelhardt et al., 2003), water resources (Ghimire et al., 2012) and the total water system (Godskesen et al., 2010). Lastly, in the journal with 25 of the 94 publications unearthed in this analysis – *Water Science and Technology* – 21 focus on wastewater treatment, and one each on water resources (Suridge et al., 2008), water treatment (Friedrich, 2002), wastewater transport (Gouda et al., 2003) and the total water system (Lundie et al., 2005).

As depicted in Figure 4, 55 % of the publications have focused solely on wastewater treatment. One publication has a dual scope dealing with both water treatment and wastewater treatment (Venkatesh and Brattebø, 2011A). Of the other three with a dual scope, one has already been referred to earlier. The other two appeared in Water Science and Technology – Water Supply. Of these two, one focused on water distribution and wastewater transport (Herz and Lipkow, 2002), and the other on water resources and water treatment (Godskesen et al., 2010). The relative shares of the different scopes (in absolute values) can be read from Figure 5.

To understand how many sub-scopes the publications could be categorised into, one can proceed on a scope-by-scope basis (#2 in Methodology). Take water distribution first. There are 3 publications with three distinct sub-scopes: Pipelines and impact accounting (Venkatesh and Brattebø 2012A), impact accounting for decision-making (Engelhardt et al., 2003); and water distribution system redesign (Basupi et al., 2014).

Among the 12 publications which have adopted a pan-systemic focus, there is one which is a review paper with no sub-scope as such. Six of the remaining eleven have simple environmental impact accounting as a sub-scope – (Barjoveanu et al. (2014; Renzoni and Germain, 2007; Slagstad and Brattebø, 2014; Godskesen et al. (2010; Lundie et al. (2005; Uche et al. (2013). Muñoz et al. (2010B) has also performed impact accounting with the end-motive of studying different water supply plans. Lai et al. (2008) have reviewed the multi-criteria decision aid in integrated sustainability assessment, while Lundin and Morrison (2012) have written about sustainability indicators for decision-making. Then, there is Bayart et al. (2014), which focuses on a Water Impact Index – again, a possible metric/aid for decision-makers. Arpke and Hutzler (2006) have their sub-scope as domestic water use in the United States, and the environment impacts thereof.

Publications with a dual scope may have both scopes in the upstream (Lyons et al. (2009) & Stokes and Horvath (2006); both of which deal with water resources and water treatment), both in the downstream (none among the 93 publications being analysed in this paper) or one each on either side (Venkatesh and Brattebø (2011A) which deals with water and wastewater treatment; and Herz and Lipkow (2002) which focuses on water distribution and wastewater transport). Both Lyons et al. (2006) and Stokes and Horvath (2009) have compared different water supply options by impact accounting method. While Herz and Lipkow (2002) focus on the environment impacts of water and wastewater pipelines, Venkatesh and Brattebø (2011A) have as the sub-scope a general comparison between the chemicals and energy consumptions in water and wastewater treatment in Oslo, Norway.

Of the five publications having wastewater transport as a focus, two deal with impact accounting of pipelines in the network (Venkatesh et al., 2009; Venkatesh and Brattebø, 2011B). Of the remaining three, one has sewer construction as a sub-scope (Petit-Boix et al., 2014), one deals with sewer overflow control (De Sousa et al., 2012), and the last with the transport of sewer solids (Gouda et al., 2003).

There are six publications having 'Water Resources' as the main scope (Figure 4). Of these, two have water quality as a sub-scope (Suridge and Brent, 2008; Owens, 2010) and two, rainwater harvesting (Ward et al., 2012; Ghimire et al., 2012). Of the other two, one focuses on domestic water use in West Bank, Palestine (Nazer et al., 2010) and the other on impact accounting of freshwater withdrawal technologies (Godskesen et al., 2013).

Water treatment and wastewater treatment account for the bulk of the publications. The sub-scopes (and sub-sub scopes, wherever those can also be defined) are thereby numerous. To simplify the presentation of the results for these two scopes and their sub-scopes, a tabular format has been adopted (Table 2 and Table 3). The categorisation on the basis of sub-scopes is entirely at one's discretion. In this study, 18 sub-scopes for wastewater treatment and 4 for water treatment were identified. Among the 18 for wastewater treatment, 'Treatment Technologies' dominates (12 of 50 or 24 %), while among the four for water treatment, 'Desalination' accounts for 5 of the 12 publications (41 %). One of the 51 publications under wastewater treatment is a review paper and does not have a sub-scope as such (Corominas et al., 2013)

Geographical focus of paper

Nearly 60 % (55 of 93) of the papers are case studies adopting a national or regional (within a country or a group of countries) or urban focus. Figure 6 illustrates the spread across the globe. As shown in Figure 6, 35 of

Figure 6. *Distribution of the geographical focus of the case studies.*

Table 2. *Sub-scopes of publications within wastewater treatment.*

WASTEWATER TREATMENT				
Contaminant removal	Nutrients / Nutrient extraction (nitrogen, phosphorus, organic matter, energy etc.)	Plant optimisation	Decision-making through impact accounting	Sludge treatment
O'Connor et al. (2013) De Hoces et al. (2011) Igos et al. (2012)	Muñoz et al. (2010A) Coats et al. (2011) Remy et al. (2014) Maurer et al. (2003) Mulder (2003) Lazarova et al. (2012)	De Gussem et al. (2011)	Bao et al. (2013) Tjandraatmadja et al. (2013) Clauson-Kaas et al. (2001) Beavis and Lundie (2003)	Hospido et al. (2005) Edelmann et al. (2005) Li et al. (2013) Stefaniak et al. (2014) Remy et al. (2012) Yasui et al. (2005) Hwang and Hanaki (2000) Sablayrolles et al. (2010A)
Sustainability indicators	Contaminant load (impact accounting)	Wastewater recycling/reuse	Stormwater treatment	Decentralization of treatment
Balkema et al. (2002)	Sablayrolles et al. (2010B)	Pasqualino et al. (2011) Tangsubkul et al. (2005) Pillay et al. (2002)	Andrew and Vesely (2008)	Machado et al. (2007)
CO_2-emissions	Impact accounting methodology	Treatment technologies	Water consumption	Data collection
Mouri and Oki (2010)	Godin et al. (2012)	O'Connor et al. (2014) Higgins and Kendall (2012) Lin (2011) DiMuro et al. (2014) Nogueira et al. (2009) Vera et al. (2009) Kalbar et al. (2013) Fuchs et al. (2011) Muñoz et al. (2006) Foley et al. (2010) Hoibye et al. (2008) Wenzel et al. (2008)	Risch et al. (2014)	Yoshida et al. (2014)
Eco-efficiency analysis	General environment impact accounting		Product category rules	
Lorenzo-Toja et al. (2014)	Hospido et al. (2004) Hospido et al. (2008) Zhang et al. (2000)		Del Borghi et al. (2008)	

Table 3. *Sub-scopes of publications within water treatment.*

WATER TREATMENT			
Contaminant removal	Desalination	General environmental impact assessment	Treatment technologies
Jones et al. (2013)	Tarnacki et al. (2011) Zhou et al. (2014) Beery et al. (2011) Beery and Repke (2010) Shahabi et al. (2014)	Venkatesh and Brattebø (2012B) Friedrich (2002)	Mohapatra et al. (2002) Hancock et al. (2012) Van der Helm et al. (2008)

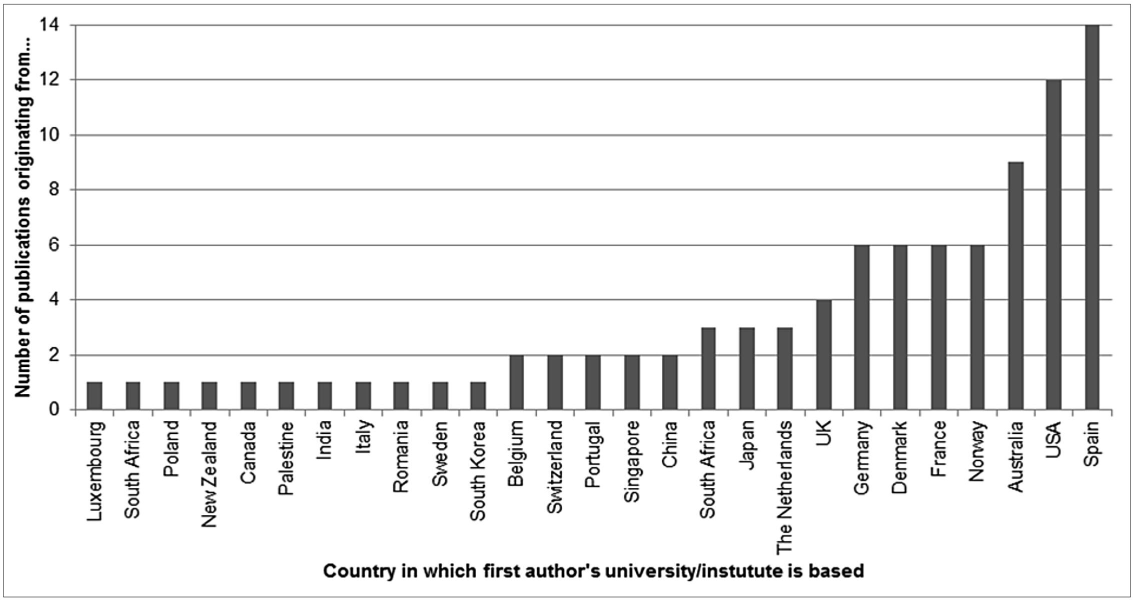

Figure 7. *Publications on the basis of the country in which the first author's university/institute is located.*

the 55 papers have a European focus. The cities /regions which figure among these case studies are Berlin (Germany – Remy et al., 2013), Bree (Belgium – De Gussem et al., 2011), Copenhagen (Denmark – 4 times – Godskesen et al., 2013; Yoshida et al., 2013; Clauson-Kaas et al., 2001; Godskesen et al., 2010), Toulouse (France – Sablayrolles et al., 2010B), Oslo and Trondheim (both in Norway, with Oslo figuring 5 times), Amsterdam (the Netherlands – 2 times – Van der Helm et al., 2008; Mohapatra et al., 2002), Galicia (Spain – Hospido et al., 2008), Iasi City (Romania – Barjoveanu et al., 2014), Milan (Italy – Bayart et al., 2014), Wallonia (Belgium – Renzoni and Germain, 2007), and the rural areas of Spain. While Oslo, as a city, has been focused on in 5 publications, Spain leads the pack of countries with 10 (Uche et al., 2013; Muñoz et al., 2006; Muñoz et al., 2010A; Muñoz et al., 2010B; Hospido et al., 2008; Lorenzo-Toja et al., 2014; Pasqualino et al., 2011; Vera et al., 2009; Petit-Boix et al., 2014; Meneses et al., 2010), followed by Norway (6) (Venkatesh and Brattebø 2011A; 2011B; 2012A; 2012B; Venkatesh et al., 2009; Slagstad and Brattebø, 2014).

Of the remaining 20, 6 are Asian, 5 North American (only USA though), 6 from Australia and New Zealand, and 3 from Africa (only South Africa though). The Asian cities / regions which figure in the list are Tokyo (Japan – Lin, 2011), Palm Jumeirah (United Arab Emirates – Beery et al., 2011), Palestine (West Bank – Nazer et al., 2010), Southeast Asia (Zhang et al., 2000) and Toan-Thang (Vietnam – Bao et al., 2013). The sixth is a paper focusing on India (Kalbar et al., 2002). The States / regions in the USA which comprise the five publications with an American focus are Arizona (Lyons et al., 2009), Texas (DiMuro et al., 2014), California (Stokes and Horvath 2006) and New York (De Sousa et al., 2012).

First author's university – country of origin

The university the first author of the publication hails from is considered to be the source of the same; and thereby the country in which the university is located becomes the country of origin. Figure 7 represents the distribution graphically. It is interesting to note that there are quite a few papers which originate from one country but focus on another (see Table 4).

Of the seven papers listed in Table 4, six have been

Table 4. *Instances where origin and focus are not (in) the same country.*

Publication	Source country	Focus country
Bayart et al. (2014)	France	Italy
Lin (2011)	China	Japan
Li et al. (2013)	China	Germany
Beery et al. (2011)	Germany	UAE
Mohapatra et al. (2002)	India	The Netherlands
Bao et al. (2013)	Japan	Vietnam
Jones et al. (2013)	USA	Hungary

published in this decade, indicating perhaps the growing interest in understanding how urban water systems in other countries are functioning (with the help of immigrant students from those countries for instance). It possibly points to a trend of international collaborations whereby exchange of ideas and expertise enables the spread of best practices in a globalizing world. In four of these seven cases, the source country and the focus country are in different continents.

Genre

The publications can also be categorised on the basis of their genres/types (#4 in Methodology). Almost half of all the publications are single case studies (city, country or region). About 39 % of them (38 in number) are comparative case studies, the comparisons being either among processes or approaches, or for that matter between two (or among more than two) individual case studies. Interestingly, there are two publications which could be classified as 'dual genre'. One of these is Munoz et al. (2006); which is a paper from the journal *Water Research,* originating from and focusing on Spain, and dealing with wastewater treatment. It is both a comparative and a pilot study. The other, a single case study as well as a pilot study, is a more recent publication in *Water Resources Management,* related to wastewater transport. Incidentally, it also originates from and focuses on Spain (Petit-Boix et al., 2014).

Desalination and Water Treatment has carried more pilot studies than any of the other journals, while *Water Research* features more Review papers (quite like the current one). There are more single case studies in the *Journal of Industrial Ecology* (12 of the total of 45) than any of the other eleven. Except *Urban Water*, all the other journals have published at least one comparative case study (Refer Figure 8).

Conclusions

This paper, based on a Master's thesis submitted at the Norwegian University of Science and Technology, and co-supervised by this author, was a limited literature review of environmental systems analysis studies – adopting the LCA approach – of urban water and wastewater systems, the scope (temporally and with respect to the scientific journals referred to) being limited to the period 2000–2014 and 12 journals related to water and/or environment. Of the 93 papers zeroed in, in the 12 journals, 51 were found to focus on wastewater treatment. Over one-third of the publications (35 of 93) were found

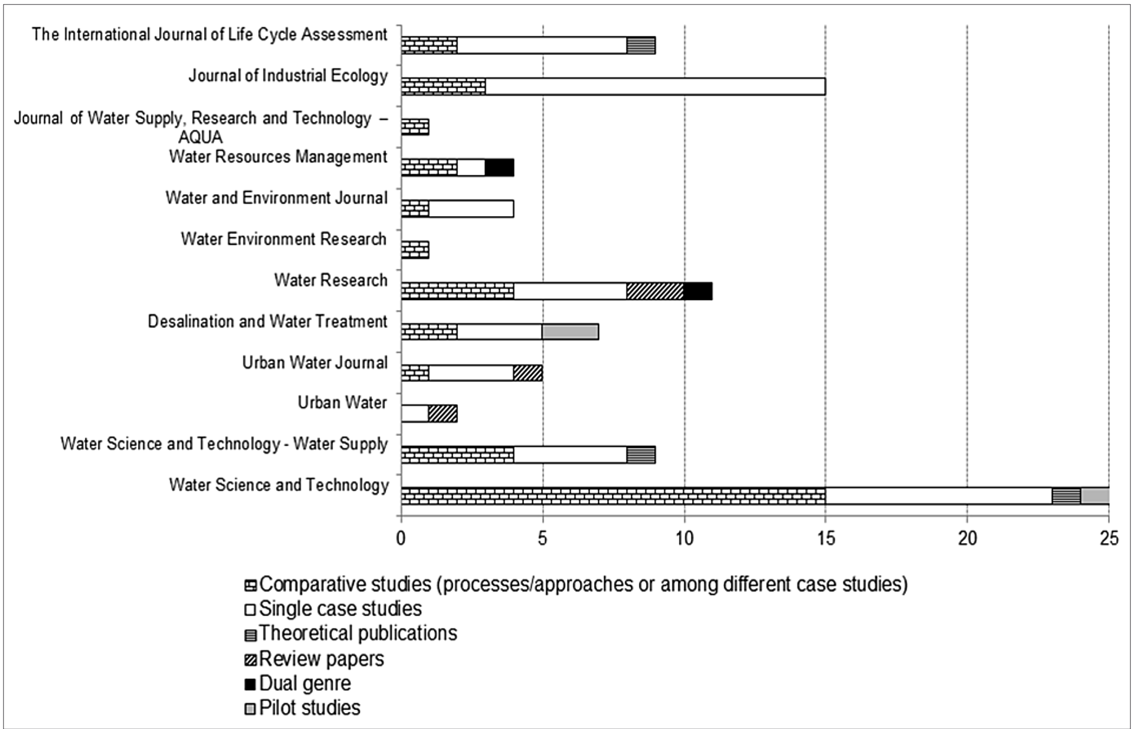

Figure 8. *Split of the publications on the basis of genres per journal.*

to have a focus on a city, region or country in Europe, with Spain topping the list with 10 of these. As far as the origin of the publications goes, Spain emerged as *numero uno* again with 14. Four papers have adopted a dual scope (as far as sub-systems within the urban water system are concerned), while 12 of them were pan-systemic. As far as sub-scopes are concerned, within wastewater treatment, a dozen publications dealt with treatment technologies. It was found that 38 publications were comparative analyses – among different processes/options/approaches or among different single case studies.

The set of 93 papers is by no means comprehensive as all possible journals in which papers using LCA as a tool to study urban water systems, were not browsed through. Also, such publications from before year-2000 were not been taken into consideration. However, one may still conclude that holistic analyses are now becoming more common. While the papers which form the subject of this paper are essentially those performing environmental systems analysis, a true holistic approach entails an economic as well as a socio-cultural analysis in addition. Further, a lot of potential research in this field is expected and urgently needed in the developing world.

In general, there are enabling factors as well as obstacles to practically-significant environmental systems analyses in general, and environmental systems analysis of urban water systems in particular. The 'what' and 'why' of these is worth understanding. Perhaps this would be an interesting research area for social scientists; and certainly for industrial ecologists keen on helping practitioners to overcome the obstacles which may exist and usher in the enabling factors.

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