Review Paper

The cost of urban sanitation solutions: a literature review

Loïc Daudey

ABSTRACT

The main objective of this paper is to review the literature on and compare the lifecycle costs of full sanitation chain systems in developing cities of Africa and Asia. Overall, financial cost reporting methodologies have been inconsistent and many studies only focus on capital costs or do not report cost data on desludging, transport and treatment. In addition, a comparative analysis of raw cost data across cities and countries would be of low utility, owing to the numerous determinants of costs (e.g. density, level of service) and their high sensitivity to local contexts. To circumvent this, this paper compares the cost ratios between different sanitation systems analysed in a same study. It concludes that conventional sewer systems are in most cases the most expensive sanitation options, followed, in order of cost, by sanitation systems comprising septic tanks, ventilated improved pit latrines (VIP), urine diversion dry toilets and pour-flush pit latrines. The cost of simplified sewer systems is found to be lower than both conventional sewer systems and septic tank-based systems, but lack of data prevented further comparisons with other types of sanitation solutions.

Key words | faecal sludge management (FSM), lifecycle costs, sanitation chain, septic tank, sewerage, urban sanitation

Loïc Daudey
Agence Française de Développement/French Agency for Development (AFD),
5 Rue Roland Barthes, 75 598 Paris Cedex 12, France
E-mail: *loic.daudey@gmail.com*

INTRODUCTION

Global sanitation challenges

According to the Joint Monitoring Programme (JMP) for Water Supply and Sanitation conducted by the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), the share of global population using an improved sanitation facility has increased from 54% in 1990 to 68% in 2015 – a net increase of 2.1 billion people (improved sanitation is defined by WHO/UNICEF as a sanitation system that hygienically separates waste from human contact). However, achievements are far below the Millennium Development Goal (MDG) 2015 target of 77%. Almost 2.4 billion people still lack access to improved sanitation worldwide. In urban areas specifically, while the share of population not having access to improved sanitation has decreased from 21 to 18% from 1990 to 2015, the total population affected has increased from 1.1 billion to 1.3 billion people over the same period. In other words, population growth has outpaced gains in sanitation coverage in cities. In terms of total population, Southern Asia and Sub-Saharan Africa are the two most affected regions, with 953 million and 695 million people without access to improved sanitation, respectively. This includes 592 million and 593 million urban residents (33 and 60% of their total urban population) (UNICEF & WHO 2015).

The impact of poor sanitation on other global development objectives has been widely documented. WHO estimates that inadequate sanitation causes around

doi: 10.2166/washdev.2017.058

280,000 diarrheal deaths annually and is a major factor behind some tropical diseases and malnutrition, which particularly affect children (WHO 2014). Inadequate sanitation also considerably undermines economic performance: for example, a recent study estimated that the global cost of poor sanitation reached USD 223 billion in 2015, up from USD 183 billion in 2010 (LIXIL & Oxford Economics 2016). In Africa, economic losses due to poor sanitation account for around 1–2.5% of GDP (The World Bank 2012a).

Due to the magnitude of unimproved sanitation and its environmental, health and economic impacts, universal clean sanitation has been promoted as one of the pillars of the United Nations' Sustainable Development Goals (SDGs) for 2030. Reaching this ambitious objective, however, will require tackling a range of obstacles, including selecting the most appropriate sanitation option in each local context. Toilets to piped sewer systems (conventional or simplified), septic tanks, ventilated-improved pit latrines (VIP), pour-flush and dry pit latrines (with slab) are examples of different on-site facilities that can all deliver access to improved sanitation. In addition, a range of treatment options can be associated with each type of on-site sanitation technology. In this perspective, stakeholders involved in the implementation of sanitation projects will need guidance on the different characteristics of each sanitation option, such as their respective costs and benefits.

Objectives of the literature review

The main objective of this paper is to review the literature on the financial costs of urban sanitation solutions. While global cost estimates of reaching sanitation SDGs have been produced, these are mostly based on the assumption that a certain type of sanitation solution – e.g. improved latrines – would be selected to meet basic sanitation targets, without differentiating between and comparing the multiple types of sanitation options available. It is estimated that providing universal access to safe, equitable drinking water, sanitation and hygiene (SDGs 6.1 and 6.2) will cost USD 114 billion annually until 2030, including USD 19.5 billion for basic sanitation and USD 49 billion for safe faecal sludge management (FSM) (Hutton & Varughese 2016). The global scope of such studies also make them unfit for use in specific local contexts. In parallel, financial cost data on specific sanitation systems seem much weaker and inconsistent.

Robust knowledge on the financial cost of urban sanitation options would help ensure sustainable management of sanitation project finance. This is all the more important given that financial resources for sanitation projects tend to be low in developing countries (WaterAid 2011; UN-GLAAS 2014). Similarly, being able to anticipate the full economic costs of sanitation projects would help avoid project failure. Such knowledge would be of high utility to three groups of stakeholders, in particular: (1) service providers (governments, utilities) managing urban sanitation systems and bearing at least part of the cost of such systems; (2) users (e.g. households) and those who represent their interest, such as community-based organisations and politicians (depending on the type of sanitation solution, households indeed financially contribute to a variable extent to the installation and maintenance of sanitation technologies); and (3) donors and financiers who support the development of sanitation solutions throughout the developing world (McIntyre *et al.* 2014).

This literature review primarily aims to compare the financial costs of different urban sanitation systems and identify patterns in terms of relative costs, based on existing comparisons in the literature and original analyses of cost data from various sources. It also addresses a set of secondary objectives:

- to identify the most useful research articles and project reports published to date on this subject, both in terms of methodology and in terms of cost data;
- to review the main approaches adopted by the literature and methodological issues in the calculation of sanitation costs;
- to identify the main categories of financial cost determinants. The objective is to get a clear understanding of what parameters affect financial costs;
- to identify the main research and data gaps in terms of urban sanitation costs;
- finally, to review the findings of the relevant literature on who bears the cost of sanitation systems, and identify potential differences across sanitation options.

This paper does not analyse the economic cost of urban sanitation systems, which would imply a broader, macroeconomic approach, including and monetising non-financial expenditures such as the opportunity cost for public authorities of building a new urban sanitation technology instead of using the same funds to support a different project or policy.

Structure of the literature review

The contents of this review are divided into four sections. The next section presents the methodology used to review the literature on financial costs of urban sanitation systems, followed by a section covering the main qualitative findings, including an overview of the main publications on this subject and the main methodological issues and obstacles to the calculation of lifecycle costs of urban sanitation chains. The following section presents the results of the analysis of financial cost data, including direct findings from the most relevant studies published to date and original quantitative analyses undertaken for the purpose of this paper. It also rapidly reviews the main findings of major studies looking at cost-benefits and cost-effectiveness of different sanitation options. The final section provides a summary of findings and elaborates on steps ahead to enhance knowledge on the financial costs of urban sanitation systems.

METHODOLOGY

The analysis is framed by a focus on lifecycle costs and on the full sanitation chain. According to the International Water and Sanitation Centre (IRC), lifecycle costs 'include the construction and maintenance of systems in the short and longer term, taking into account the need for hardware and software, operation and maintenance (O&M), capital maintenance, the cost of capital, source protection, and the need for direct and indirect support' (Fonseca *et al.* 2011; McIntyre *et al.* 2014). Table 1 provides further details of what each category of costs entails. This literature review however primarily focuses on capital costs, O&M costs, capital maintenance costs and the cost of capital, if available. Expenditures on direct and indirect support, such as educational programmes, institutional development and policy support, are excluded from the analysis.

A sanitation chain typically comprises four elements: on-site facilities (e.g. toilet connected to piped sewer systems, septic tank, pit latrine, etc.); extraction and conveyance (through sewer pipes for sewerage systems, or manual transport for faecal sludge management system); treatment (typically at a wastewater treatment site or plant); and reuse (e.g. fertilisers) or disposal. Figure 1 illustrates the four components of the sanitation chain, depending on the main type of sanitation option. This literature review will mainly cover cost data on the sanitation chain related to human excreta management. The objective of covering both lifecycle costs and the full sanitation chain is to capture the full economic costs of urban sanitation options, and thereby maximise the utility of cost estimates to service providers, consumers and donors.

The review covers the academic literature and the grey literature published after 2000, such as project briefs and professional reports published by development agencies, NGOs and multi-lateral development banks. Priority is given to studies and project reports covering Sub-Saharan Africa, Southern Asia and South Eastern Asia. Documents reviewed are extracted from online platforms such as the

Table 1 | Components of lifecycle costs

Type of cost	Description
Capital expenditure	Initial costs of putting new services into place: hardware such as pipes, toilets and pumps and one-off software such as training and consultations
Cost of capital	The cost of borrowing money or investing in the service instead of another opportunity. It also includes any profits of the service providers not reinvested
Operation and minor maintenance expenditure	Routine maintenance and operation costs crucial to keep services running, e.g. wages, fuel or any other regular purchases
Capital maintenance expenditure	Occasional large maintenance costs for the renewal, replacement or rehabilitation of a system
Expenditure on direct support	Pre and post-construction support costs not directly related to implementation, e.g. training for community or private sector operators, users or user groups
Expenditure on indirect support	The cost of planning and policy making at government level and capacity building of professionals and technicians

Source: McIntyre *et al.* (2014).

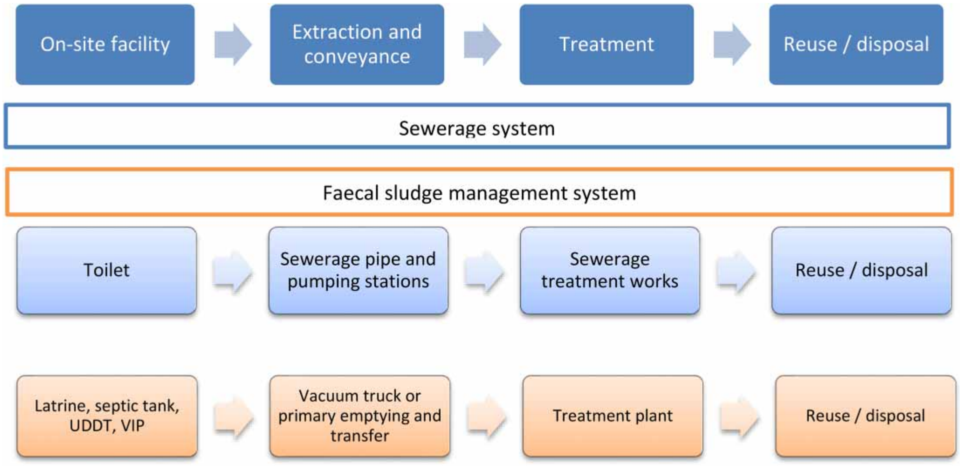

Figure 1 | Components of the sanitation chain. Adapted from Kyomugisha (2016).

Sustainable Sanitation Alliance's website (Susana), from the website of major International Financial Institutions (IFIs), such as the World Bank and the African Development Bank, and from keyword-based inquiries on web browsers. Cross-country analyses, global cost data reports and specific single project publications are all included in the analysis. An emphasis is placed on studies and project reports comparing two or more sanitation options.

OVERVIEW OF THE LITERATURE RELATED TO THE FINANCIAL COSTS OF URBAN SANITATION

Major international research programmes on economics of sanitation

The review of the literature first shed light on three major international research initiatives on the economics of sanitation, and often referred to by other studies and reports. Each of these initiatives, however, does not fully fit the scope or purpose of the present literature review:

- **IRC's WASHCost Initiative** was a 5-year (2007–2012) project supported by the Bill and Melinda Gates Foundation. Some of its objectives included obtaining information on the disaggregated costs of providing WASH service delivery models and understanding the relative importance of factors that influence cost levels (McIntyre *et al.* 2014). The project focused on rural areas and peri-urban areas and therefore did not aim to collect data on the cost of sanitation systems in cities. The findings of this project are nonetheless of high relevance from a methodological point of view.
- The **Economics of Sanitation Initiative of the World Bank's WSP** was launched in 2007, and comprises two streams of work. The first phase of the project aimed to address major gaps in evidence among developing countries on the economic impacts of sanitation. Areas covered include Africa, East Asia (including South East Asian countries), South Asia and Latin America and the Caribbean (LAC). The second phase of the project delivers economic assessments of sanitation interventions and provides cost data on different sanitation options in rural and urban areas. Its main objective, however, is to compare the cost-benefits and cost-effectiveness of sanitation options, and cost data is not always fully disaggregated. In addition, this second phase has only been completed in East Asia (see www.wsp.org/content/economic-impacts-sanitation; last accessed 24 January 2017).
- The **World Health Organization** has published two main studies on the global costs and benefits of drinking water supply and sanitation interventions, the latest in 2012 (Hutton 2012). In addition to assessing cost-benefit ratios of various sanitation options in rural and urban areas, the study provides global cost estimates of reaching the MDG target and universal coverage. Such global data do not compare the cost of different sanitation options

but provide unit cost data for sewer connections and septic tanks. The costs of other sanitation options and full sanitation chains are not included.

Few studies have thoroughly reported the lifecycle costs of urban sanitation chain systems

Beyond these three major international research programmes, the number of academic and non-academic studies reporting the lifecycle costs of urban sanitation solutions is relatively small. Trémolet *et al.* (2010) notes that 'despite decades of field experience, reliable estimates for the hardware and software costs of sanitation access are still scarce'. Among the main 50 documents of the literature reporting the cost of urban sanitation and identified for this research work, the following limitations are persistent:

- Some studies only report one or two types of cost, and thus do not look at the full lifecycle costs of urban sanitation systems. Out of 50 studies and reports covered by the research, only six clearly included at least capital, recurrent and capital maintenance costs, however many studies consider capital maintenance costs as capital costs or O&M costs. A total of 10 documents only reviewed one type of cost – in most cases capital costs (see for example Ulrich *et al.* (2016) and Okan-Adjetey (2013)). Capital costs, however, only cover a highly variable share of total sanitation costs: a study on sewerage and FSM systems in Dakar, Senegal, for instance indicated that capital costs only account for 78 and 33% of total costs associated with these two sanitation systems, respectively (Dodane *et al.* 2012). In some studies, various types of costs are included but there is no clarity on what each category entails. It is therefore impossible to verify whether the cost approach is comprehensive and includes all or at least the main components of lifecycle costs as described in Table 1.
- Some studies only look at the costs of on-site sanitation facilities, omitting the cost of extraction and transport, treatment, and reuse/disposal. Out of 50 documents reviewed, only 19 report costs on at least the first three elements of the sanitation chain. Looking at costs of the full sanitation chain is critical as the share of costs borne by extraction, conveyance, treatment and reuse/disposal can be substantial. The same study on Dakar, Senegal, reported that on-site facility costs only account for 28 and 9% of total costs associated with the full sanitation chain (Dodane *et al.* 2012).

Poor thoroughness of reporting in the literature further limited the number of relevant studies identified during the review. Data is often not sufficiently disaggregated for the purpose of this research work. This is observed at different levels:

- In some cases, cost data provided do not clearly distinguish between rural and urban areas (see for instance Water Sanitation and Hygiene (WASH) Institute 2015). This issue is still persistent in the sector, in particular regarding unit cost data. For instance, Hutton & Bartram (2008) observed that lack of distinction between rural and urban areas in existing unit cost data is a source of uncertainty for their quantitative model. Many studies have demonstrated that the costs of sanitation options tend to vary significantly between rural and urban areas (Klutse *et al.* 2010; Hutton 2012).
- In many cases, cost data provided do not specify sanitation options clearly enough. For instance, Ross *et al.* (2016) provide cost data on faecal sludge management systems without distinguishing between those using pit latrines and those using septic tanks as on-site facilities. Kennedy-Walker (2014) compares the cost of sewerage to public toilets, without specifying the type of toilets and treatment applied. A similar observation was made by the experts of the IRC WASHCost initiative: according to the synthesis report *Priceless!*, the initial review of cost studies concluded that 'most cost estimates failed to specify technology choices clearly, making cost comparisons meaningless' (McIntyre *et al.* 2014). This is further complicated by the fact that some systems mix different sanitation solutions into hybrid systems.

Generally speaking, existing cost studies have been limited by the lack of robust and accurate cost data, in particular those aiming to estimate regional and global costs and not focusing on a specific sanitation project. The lack of unit cost data by country, in particular, is often described as a limit by the authors of such studies. For instance, Hutton (2012) grounds its cost-benefits and cost-effectiveness analyses of urban sanitation options on unit cost data but these are not available in every country. To circumvent this problem, the author filled the gap by replicating unit cost data of neighbouring countries.

The lack of data is partly due to the absence of efforts at the national level to report sanitation costs thoroughly, but it also owes to the absence of proper urban sanitation systems in developing countries. Many cities indeed lack integrated FSM systems: on-site facilities such as septic tanks, for instance, are not properly and frequently desludged, or no proper treatment process is applied to faecal sludge (Kyomugisha 2016). The various studies of the Economics of Sanitation Initiative of The World Bank's Water and Sanitation Programme (WSP) in Southeast Asia for instance reports costs on urban sewerage systems and on-site sanitation systems. However, since the cities studied do not always have an integrated FSM system, reported cost sometimes only cover on-site facilities. The following issues also explain the lack of data on the cost of urban sanitation:

- a lack of available data at the level of sanitation service providers, partly linked to the lack of transparent accounting;
- the fact that methodologies that have been used to estimate costs are muddled. This may be explained by the lack of a financial and economic background in the sanitation sector; and
- a lack of transparency on the methodology, including with respect to which costs have been reported, which makes it difficult to understand what has been done and therefore to assess whether thorough comparisons can be made.

Owing to these limitations, only 15 of the 50 documents reviewed were judged as having a 'high' relevance to the purpose of this research article, i.e. attempting to report the lifecycle costs of various sanitation options in an urban context, clearly covering the full sanitation chain and avoiding the caveats listed in the bullet points above. Only 11 documents within this shortlist provide cost data. This should allow for a more robust comparison of costs across studies. These studies include among others: a research article on the costs of conventional sewerage and FSM systems based on septic tanks in Dakar, Senegal (Dodane *et al.* 2012) (FSM systems refer to sanitation systems that collect, transport and treat faecal sludge from pit latrines, septic tanks and other on-site sanitation options, it is opposed to centralised sewerage and wastewater treatment systems); a report comparing the costs of a FSM system based on septic tanks to various types of simplified sewer systems in Dhaka, Bangladesh (Ross *et al.* 2016); a report comparing the costs of conventional sewer systems, simplified sewer systems and septic tank based systems (Cairns-Smith *et al.* 2014); and two World Bank reports comparing the costs of conventional sewerage options to various FSM system alternatives in West Africa and South Africa (The World Bank 2009).

Most of these studies however only look at one city context and do not compare all types of sanitation options. As such, there is no existing major research work analysing the lifecycle costs of a large diversity of urban sanitation options over a wide geographical area. In addition, even within the shortlisted studies, there is uncertainty about the thoroughness and consistency of methodologies employed to calculate lifecycle costs. For instance, some studies aim to report lifecycle costs but only two types of costs are reported (usually capital and recurrent costs), and it is unclear whether other types of costs (capital maintenance costs, cost of capital) are also included in these two categories. The sources of data and methodologies for estimating costs of different sanitation options are not always consistent across studies but also within a same study looking at several different sanitation options. In some cases, there is not much information on the methodology employed to calculate lifecycle costs. For these reasons, the analysis of urban sanitation cost data will adopt a conservative approach and refer to 'sanitation costs' instead of 'lifecycle sanitation costs'. More details on the characteristics and caveats of the methodologies employed in these shortlisted studies are provided below under 'Analysis of urban sanitation cost data'.

The interest of comparisons across studies is limited by the numerous determinants of costs

The inconsistent methodologies and lack of data observed in the literature on the costs of urban sanitation significantly limit opportunities to compare lifecycle costs across studies, hence the need to shortlist studies with the most thorough cost data reporting. However, the relevance of comparing cost data between these shortlisted documents remains limited, in particular owing to the numerous determinants of the costs of urban sanitation systems identified through the review and summarised in Table 2.

The existence of many cost determinants complicates the comparison of cost data across projects and across geographical contexts, in particular because they have a high sensitivity to local contexts. The cost of a septic tank-based FSM system may differ significantly from one country to another, in this regard. Burr & Fonseca (2011) also point out that 'even equivalent latrine types vary considerably in their construction quality, dimensions and specifications as a result of local geographical and socio-economic circumstance'. This explains why some studies choose to report a wide cost range for each sanitation option, which is not very useful for comparative purposes (see for instance IRC WASHCost (2012), Parkinson *et al.* (2012) and Cairns-Smith *et al.* (2014)). This also means that, unless very detailed information on all these cost determinants are provided in each study and project report, comparing different sanitation options across different contexts is meaningless (Ulrich *et al.* 2016): the cost of a sewerage system in one country may be found to be less expensive than the cost of an FSM system based on septic tanks in another country because of external factors such as energy cost and density, and not because of the technology itself. Likewise, global or continental cost estimates as found in some publications are not much use for specific city-based projects, since local conditions are bound to significantly affect costs (Whittington *et al.* 2012).

Table 2 | Main determinants of urban sanitation financial costs

Determinant of cost	Description
Type of technology	This is the most obvious cost determinant. For instance, septic tanks do not have the same unit cost as traditional pit latrines, owing to very different design and material characteristics
Labour cost	Labour is needed to build and install on-site and treatment facilities, and also to extract and transport sludge in the case of FSM systems. Higher labour costs imply higher overall cost for sanitation systems
Material and utility cost	Different types of raw materials can be used to build a given sanitation facility. The cost of materials partly depends on their availability. Some studies for instance have pointed out that an identical sanitation component may cost significantly more in Africa than in Asia (or vice-versa) because supply markets are unequally developed. Transport vehicles also need to be purchased to convey sludge to treatment stations
Density	Density particularly affects the cost of sewerage systems. Higher densities allow reaching a larger number of people and thereby help to reduce cost per capita or per household. The World Bank indicates that 'simplified sewer systems become cheaper than FSM systems at a population density of around 160 people per hectare'[a]. However, high densities may also make urban areas – in particular slums – more difficult to access, which may increase costs
Topography	Sanitation systems can be more easily put in place in flat areas. Projects undertaken in undulating urban areas may require more workmanship and time to achieve the same result
Level of service provided by the sanitation system	Different levels of service can be provided by the same sanitation system. For instance, a pit latrine could be installed for one household or several households, which would be likely to decrease the quality of the service, and also the costs
Soil condition	Bad soil conditions will require more time and more workmanship to install a sanitation component
Energy cost	Fuel and electricity are needed to power transport vehicles, pumps and treatment facilities. Higher energy costs imply higher costs for the overall sanitation system
Others	Distance to treatment facility, climate, end-use of treatment products, business models, water table height

Sources: Dodane *et al.* (2012) and Ulrich *et al.* (2016).
[a]http://water.worldbank.org/shw-resource-guide/finance/assigning-costs-sanitation.

Ideally, it would be worth analyzing the weight of each cost determinant in total costs across studies and projects, in order to further understand to what extent each factor affects financial costs of urban sanitation systems, and how costs can be anticipated to vary across different geographical, urban and socioeconomic contexts. However, the large majority of documents reviewed do not include detailed information on the above listed cost determinants, such as service level. The analysis of urban sanitation cost data presented below under 'Analysis of urban sanitation cost data' therefore cannot be augmented with a detailed characterisation of the local context in which each study was undertaken.

Other elements that present obstacles to comparison of urban sanitation costs across different studies include the fact that different metrics are chosen across the literature to account for sanitation costs. A study of WSP in India (2008) for instance provides cost data on on-site facilities expressed as cost per unit, and provides cost data on wastewater treatment facilities, expressed as cost per volume of water treated. Many studies and reports also use cost per capita or cost per household as their main metrics.

ANALYSIS OF URBAN SANITATION COST DATA

Methodology

In order to circumvent the aforementioned methodological issues and obstacles to cost data comparison, the quantitative analyses presented in this section focus on a comparison of cost ratios between different urban sanitation systems taken within a same study or report. The objective is to avoid comparing the cost of two or more urban sanitation systems in place in different contexts – which could significantly affect the determinants of costs – and to avoid comparative obstacles associated with different reporting methods used across the shortlisted documents (e.g. use of different metrics such as cost per capita, cost per unit, cost ranges, etc.). As previously mentioned, despite being the most thorough research works found in the literature, the lack of clear information on methodologies employed in these selected studies incites the author to adopt a more conservative approach and refer to 'cost ratios' instead of 'lifecycle cost ratios'.

In most cases, calculations were made using the annualised capital and recurrent costs (and other types of costs if specified) directly given in the literature. However, in some documents capital costs are not annualised (since these are one-off investment costs) and therefore no overall cost is given for the entire sanitation system at focus. In these cases (City of Ulaanbaatar 2006; Burr & Fonseca 2011; Cairns-Smith *et al.* 2014), overall cost data were calculated by the author himself. This required assigning a lifetime to each type of technology option included in these studies. The lifetime was selected based on the lifetime most frequently given to these specific elements of the sanitation chain in the literature. Therefore they may not reflect the actual asset life in the cities at study.

In addition to the comparison of sanitation cost ratios, three secondary analyses are provided in this section:

- A comparison of costs of on-site technologies with the full sanitation chain associated. The purpose is to assess the weight of on-site facilities in total costs. The result of the analysis could help decision-makers and operators anticipate on which elements of the sanitation project are likely to drive costs upwards, and pay particular attention to the associated choice of technology.
- A comparison of costs of different on-site technologies. The purpose is to help decision-makers and operators have a better understanding of the full cost associated with each on-site option. If on-site technologies are found to account for a significant share of total costs, such data may be particularly useful to guide relevant authorities in their choice of sanitation technology.
- A comparison of O&M costs with total costs. Such analysis can also help to assess whether the share of O&M costs vary across sanitation options, so that decision-makers and operators can be informed before opting for a specific technology.

This article only aims to compare the cost of different sanitation options, without taking into account the effectiveness and benefits of each system. For instance, each sanitation system does not provide the same level of service, both at the user interface level (in terms of hygienic conditions) and in terms of on-site treatment of faecal sludge. This should also be taken into account by decision-makers in developing countries before choosing which sanitation system to set up. The final subsection briefly introduces the challenges and future research needed about knowledge on the benefits of sanitation.

Primary analysis: lifecycle cost ratios of urban sanitation systems covering the full sanitation chain

First, an analysis of lifecycle cost ratios of full urban sanitation chain systems was undertaken. Individual ratios were calculated from studies and projects analysing the lifecycle costs of two or more urban sanitation systems. These individual ratios were then compiled and compared, in order to assess whether general patterns could be identified across all ratios calculated. Out of 50 documents reviewed, only 11 provided the data necessary for this analysis, i.e. data on the lifecycle costs of at least two different urban sanitation systems, all covering the full sanitation chain. Most of these studies only cover capital and operating and maintenance costs. Very few documents report capital maintenance costs and the cost of capital (however it is often not indicated whether such costs are considered as capital costs or O&M costs, or simply ignored), and often do not satisfy other criteria (e.g. covering the whole sanitation chain or reporting cost data on more than one sanitation option). Most studies from which the data was collected look at one or two particular local contexts, however some provide data at a continental scale (e.g. Evans & Mara 2011). The most recurrent comparison found in the literature is between conventional sewer systems and FSM systems based on septic tanks, and between conventional sewer systems and FSM systems based on wet pit latrines.

The analysis highlighted general patterns in terms of cost ratios:

- Conventional sewer systems are in all cases the most expensive sanitation option, followed, in order of cost, by sanitation systems comprising septic tanks, ventilated improved pit latrines (VIP), urine diverting dry toilets (UDDT) and wet pit latrines.
- The cost ratio between conventional sewer systems and FSM systems based on septic tanks is not always significant, as it ranges from around 1 (i.e. same cost) to 4.7 (i.e. almost five times more expensive).
- The cost ratio of FSM systems based on septic tanks is found to be systematically higher than wet pit latrines, VIP and UDDT, with cost ratios ranging from 1.9 to 4.9, 1.6 to 2.1, and 1.6, respectively.
- The cost ratio of UDDT to VIP ranges from 0.8 to 1.1 and therefore do not allow a clear hierarchy to be established. Their separate cost ratios to conventional sewers and FSM systems based on septic tanks are also similar. Both UDDT and VIP tend to be more expensive than wet pit latrines.
- Not surprisingly, the cost of simplified sewer systems is found to be lower than conventional sewer systems, but it is also found to be cheaper than septic tank-based systems. However, cost ratio data relative to other sanitation systems is almost nonexistent, which does not allow drawing further conclusions and locating this particular sanitation solution on the sanitation cost ladder. Interestingly however, data retrieved from a study of The World Bank (2012c) indicate that the cost of simplified (condominial) sewerage is lower than FSM systems based on wet pit latrines in Senegal, in particular because such latrines have been installed in areas characterised by high population density, impermeable soils and high water table, which is less suitable (and therefore more costly) for this type of solution.

Amongst the studies reviewed to extract the data presented in Figure 2, some of the most thorough references in terms of methodology and cost reporting include a study comparing the lifecycle costs of sewerage systems with the lifecycle costs of septic tank-based systems in Dakar, Senegal (Dodane *et al.* 2012). The authors calculated a total annual cost of USD 55 per capita for the sewerage to wastewater treatment plant system and a total annual cost of USD 12 per capita for the FSM system based on septic tanks and drying beds. The study also identifies which stakeholders bear the costs of both sanitation systems, and concludes that the utility bears the majority of costs in the case of the sewer based system, while users bear the majority of costs of the FSM system. In the case of the sewerage system, the authors calculate that households bear only around 3.7% of total lifecycle costs for the full sanitation chain, while they bear around 83.7% of total lifecycle costs of the FSM system. (In this study, the breakdown of costs by stakeholders includes transfer costs such as the sanitation tax paid by householders to the utility. Since it is reported as (negative

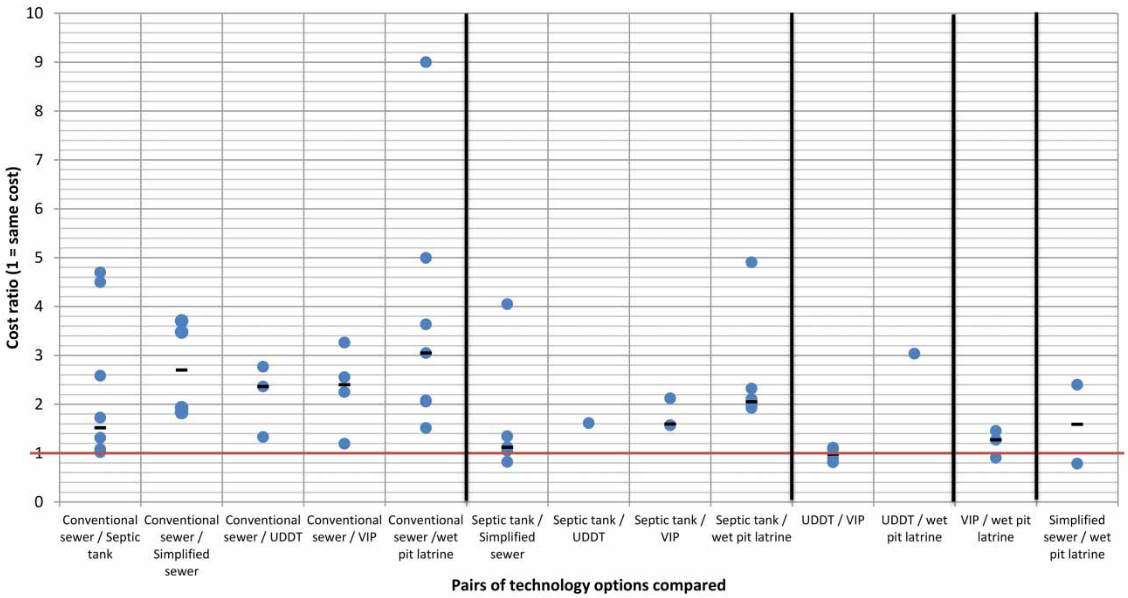

Figure 2 | Compilation of lifecycle cost ratios of full sanitation chain solutions. (1) The data has been retrieved and analysed from the 11 studies mentioned previously. Although sanitation systems are here indicated by the name of their on-site facility (e.g. septic tank), they nonetheless refer to the full sanitation chain. (2) A cost ratio above 1 indicates that the first type of sanitation system mentioned is more expensive than the second type of sanitation system mentioned. A cost ratio below 1 indicates the reverse. This threshold is represented by a red line on the graph. For instance, the first category on the horizontal axis shows that conventional sewer systems are between 1.03 and 4.7 times more expensive than decentralised septic tank-based systems. (3) Median values are represented by a black dash. They are the 'middle' value for each category. Please refer to the online version of this paper to see this figure in colour: http://dx.doi:10.2166/washdev.2017.058.

and positive) cash flows for both stakeholders, its effect is cancelled when aggregating to total costs.) This is mainly due to the fact that households have to pay for septic tank installations and desludging (23.6 and 43% of total costs, respectively) for the FSM system, while they only have to pay for the sanitation tax for the sewerage system. Similar observations are made in a study of the World Bank in Indonesia (The World Bank 2011b).

In order to make their calculations, the authors of this study collected data from existing reports, databases and interviews. Capital and operating costs were then itemised against the major component of each sanitation system, and the financial flows of each stakeholder were also determined for both. Finally, the financial flows were converted to an annual per capita basis. Each major component of the sanitation chain was given a specific lifetime and a real interest rate was chosen in order to make this calculation. It was also assumed that both types of sanitation systems (FSM and sewerage) provide the same level of service.

Another relevant study looks at the lifecycle costs of hypothetical FSM systems vs. a range of hybrid sewer systems comprising simplified sewer components in the context of Dhaka, Bangladesh (Ross *et al.* 2016). The authors conclude that the FSM system based on septic tanks or pit latrines, depending on cases, is slightly more expensive than any hybrid solutions involving simplified sewerage (Figure 3). This study illustrates the complexity of sanitation systems and the fact that categorising sanitation options is not straightforward as hybrid solutions have been put in place in some cities. In this study, data on the cost of sanitation technology was systematically collected from secondary sources on FSM systems in Dhaka or extrapolated from contexts outside Bangladesh. According to the

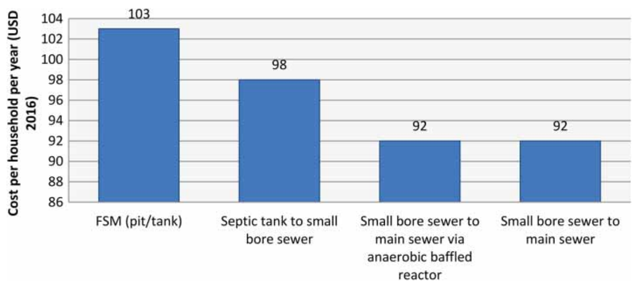

Figure 3 | Annual lifecycle costs per household of FSM vs. hybrid sewer systems in Dhaka, Bangladesh (full sanitation chain). *Source:* Ross *et al.* (2016).

author, methodologies employed in these sources are not always fully described, so a strong assumption is made on the correspondence between the context of these secondary sources and the context of Dhaka. Costs per capita were calculated based on a household survey which served the purpose of other analyses in the same study. No information is given on specific lifetime given to each component for the sanitation systems, and it seems that the difference in asset life was not taken into account. This may unfairly bias the results in favour of sanitation options whose asset life is shorter than the other options.

Another study, undertaken by The Boston Consulting Group (BCG), also concludes that FSM systems based on septic tanks tend to be more expensive than simplified sewerage systems, although the difference is not so clear (Cairns-Smith *et al.* 2014). It also concludes that both tend to be less expensive than conventional sewerage systems (Figure 4). The data presented do not refer to a specific city context but rather targets developing countries in general, hence the wide cost brackets. The authors extracted data from secondary sources such as project reports of the World Bank, the Asian Development Bank and IRC WASH-Cost initiative, and from BCG's own project with the Bill & Melinda Gates Foundation. However, no information is provided on the methodologies used in these secondary sources. Likewise, it seems authors did not apply a specific lifetime for each sanitation option (in particular as each category may imply multiple technology choices).

Several reports of the World Bank also provide thorough data on the costs of urban sanitation. WSP's Economics of Sanitation Initiative study in the Philippines compares the lifecycle costs of a wide range of urban sanitation options,

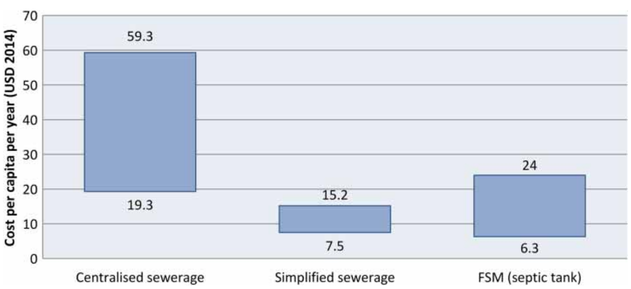

Figure 4 | Annual lifecycle costs per capita of centralised (conventional) and simplified sewerage, and septic tank based FSM systems (full sanitation chain). Cost calculations were made assuming a lifetime of 20 years for all the above sanitation options. *Source:* Cairns-Smith *et al.* (2014).

including sewerage systems and a variety of FSM systems (The World Bank 2011a). The results, summarised in Figure 5, are in line with the general cost hierarchy mentioned earlier and observable in Figure 2. In this study, annual equivalent costs of different sanitation options were calculated based on annualised investment cost (taking into account the estimated length of life of hardware and software components) and adding annual maintenance and operational costs. The data was collected from project documents, the database of the operators and surveys designed for the purpose of this research work. Detailed explanation is also given on what each type of costs entail and how they were calculated. The study adopted a standard design for costing the cubicles, toilets and septic tanks across the study sites. Hence, differences in cost estimates are attributable solely to variations in prices and labour costs.

Another report on sanitation in Senegal and Burkina Faso also shows that conventional sewers are more expensive than simplified sewerage, VIP and wet latrines; interestingly, it also shows that wet latrines are more expensive than simplified sewerage, as mentioned previously (The World Bank 2012c). The level of service is assumed to be the same for all sanitation systems at study, and is simply defined as a system that covers the full sanitation chain. Similarly to Dodane *et al.* (2012) and The World Bank (2011b), households are found to contribute much more significantly – in terms of percentage – to on-site sanitation options (73.4% of wet latrine cost) than sewerage options (36.7%). Sanitation costs were calculated by annualising capital costs and adding them to recurrent costs. Annualised capital costs in this study refer to the annual repayment of capital cost over the lifespan of the sanitation equipment with an 8% interest rate. It is unclear how the data for each type of sanitation system was retrieved.

Comparison of the cost of on-site sanitation options with the cost of the full sanitation chain

The second objective of the analysis was to compare the cost of on-site sanitation options to the cost of the full sanitation chain which includes these on-site sanitation facilities. The objective was to assess whether on-site facilities account for a significant share of total costs of sanitation systems. Again, only the 11 relevant studies mentioned previously

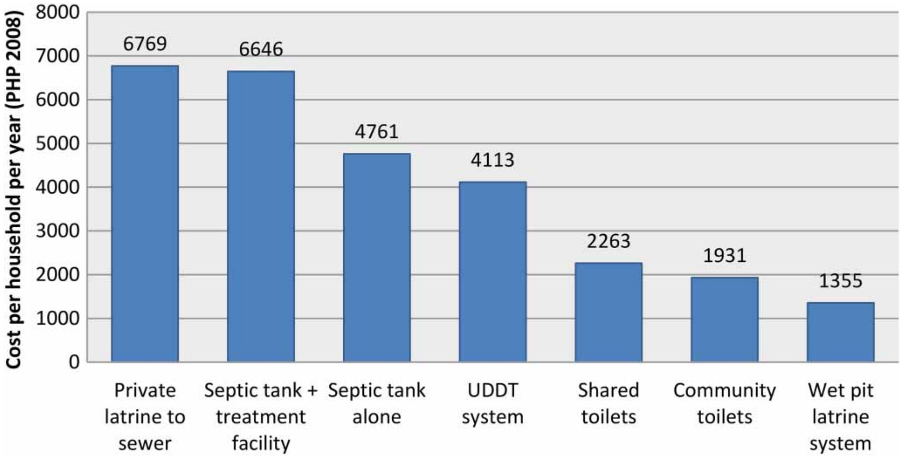

Figure 5 | Annual lifecycle costs per household of urban sanitation systems in the Philippines (full sanitation chain). *Source:* The World Bank (2011a).

can be used to undertake this analysis, and only three of them provide breakdown data which allows comparing on-site facility costs and total costs. Results are therefore not robust and would need to be strengthened with further data.

The analysis from these documents nonetheless suggest that the share of on-site facility costs out of total costs tend to be much higher in the case of FSM systems that in the case of conventional sewer systems (Figure 6). Data from sewerage and FSM systems in Dakar, Senegal, for instance shows that the annual cost of sewer connection only accounts for around 9% of the annual cost of the full sewerage system including wastewater treatment plants, while the annual cost of septic tanks accounts for around 29% of the total cost of the associated FSM system (Dodane *et al.* 2012). Likewise, a study on Lusaka, Zambia, concludes that the annual cost of VIP and UDDT accounts for around 53 and 51% of the annual cost of the full FSM systems that include these technologies, respectively (von Muench & Mayumbelo 2007). Ross *et al.* (2016) report that the annual costs of simplified sewerage and septic tank account for 29.9 and 30.2% of annual costs of the full sanitation systems, respectively.

However, such data must be handled carefully as the share of on-site sanitation facilities is highly dependent on the type of treatment applied at a later stage of the sanitation

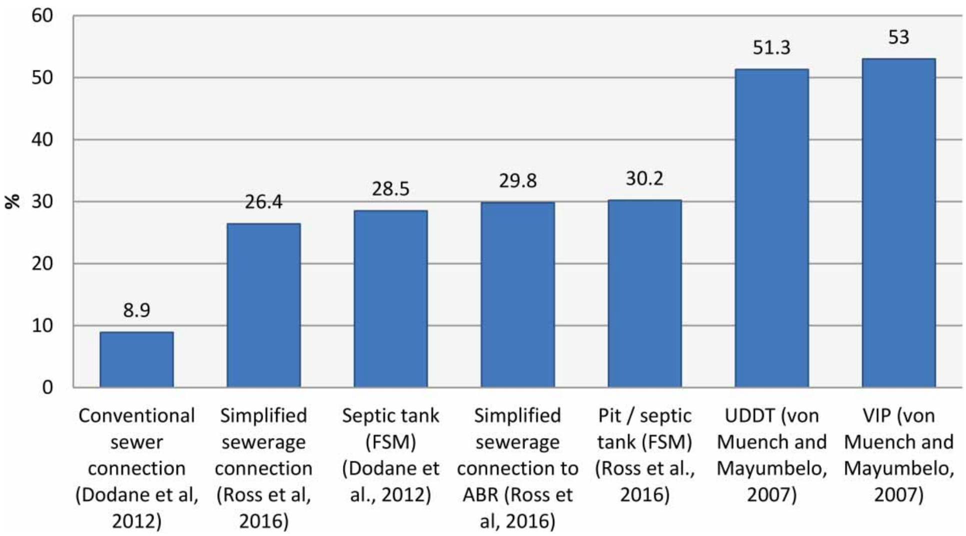

Figure 6 | Share of on-site facility cost out of total system cost of various sanitation solutions. *Sources:* von Muench & Mayumbelo (2007), Dodane *et al.* (2012) and Ross *et al.* (2016).

chain. The share of on-site facility costs to total costs is likely to be lower if the treatment method is more advanced. Data from Ross *et al.* (2016) for instance indicate that the share of on-site facility costs is lower when simplified sewer systems include anaerobic baffled reactor technologies than when it does not (Figure 6). Likewise, the costs of on-site sanitation can vary significantly depending on the type of solution selected, and therefore modify its weight in total costs. Indeed, on-site sanitation options may perform partial treatment before being transported to a final treatment site.

Dodane *et al.* (2012) calculated the cost of sewer connections based on the cost of installation retrieved from the database of the local utility. There is no O&M cost associated with this element of the sanitation chain. In the context of Dhaka, Ross *et al.* (2016) calculated the cost of the different types of sewerage connections based on data from the local utility and by extrapolating data from other studies. The costs are broken down into capital costs and capital maintenance costs. Similarly to the study in Dakar, there is no O&M cost associated with household sewerage connection.

Comparison of the lifecycle costs of on-site sanitation options

The third analysis focused on the comparison of the lifecycle costs of different on-site sanitation options, therefore excluding the cost of extraction and conveyance, treatment and reuse/disposal. The objective was to determine whether patterns differ substantially from those identified for the full sanitation chain. The results are displayed in Figure 7. Overall, cost patterns for on-site facilities alone are quite similar to those identified for the full sanitation chain. However, the following observations can be made:

- The cost ratios of septic tanks to VIP and septic tanks to pit latrines tend to be higher than when the full sanitation chain is compared, as in Figure 2.
- The cost ratio of VIP and UDDT to pit latrine tends to be higher if compared to dry pit latrines than if compared to wet pit latrines.
- The cost ratio of VIP to UDDT is higher than shown in Figure 2, which could be explained by the revenues obtained by UDDT system which are not included in the calculations for on-site facility costs alone.

Comparison of O&M costs to total lifecycle costs

The fourth analysis undertaken through the literature review is a comparison of O&M costs, also called recurrent costs, to total lifecycle costs comprising capital costs and other costs if reported (e.g. capital maintenance costs, cost of capital etc.), across the full sanitation chain. The objective is to

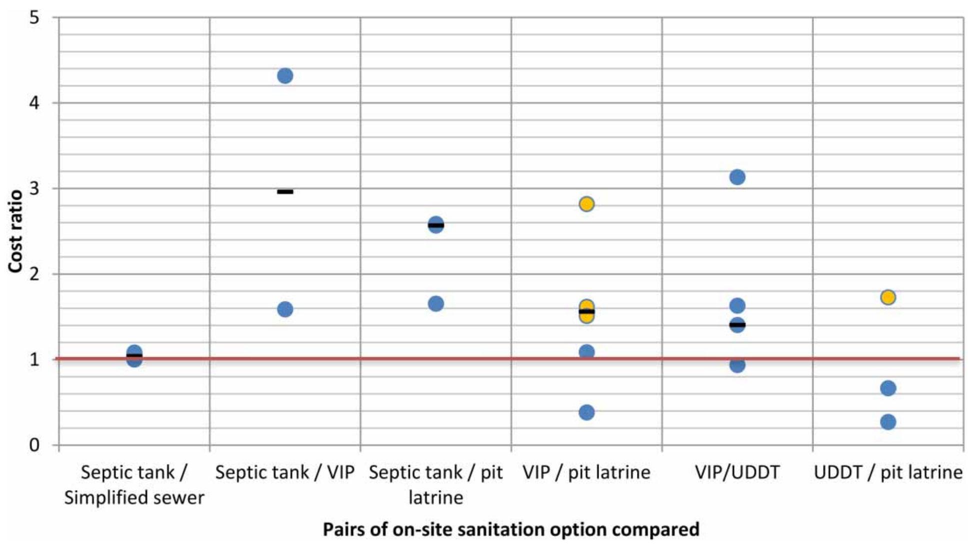

Figure 7 | Compilation of lifecycle cost ratios of on-site sanitation solutions. For this particular analysis more data on dry pit latrines were available than for the cost ratio comparison for the full sanitation chain. Dry pit latrines are marked as 'yellow' dots while wet pit latrines are marked as 'purple' dots. Please refer to the online version of this paper to see this figure in colour: http://dx.doi:10.2166/washdev.2017.058.

determine whether O&M costs account for a major share of total lifecycle costs, and if project finance can therefore be generally expected to be mainly affected by recurrent costs.

The results of the analysis show that patterns are difficult to identify, and that the share of O&M costs out of total lifecycle costs is extremely variable for any type of urban sanitation system. Figure 8 provides a summary of the analysis of O&M costs extracted from the literature. The share of O&M costs for instance ranges from 6 to 66% for conventional sewer systems, from 31.6 to 61% for FSM systems based on septic tanks, and from 25 to 62% for FSM systems based on wet pit latrines. Conventional sewer systems present the lowest median value (25.7%), followed, in ascending order, by UDDT-based systems (27.5%), FSM systems based on VIP (34.3%), simplified sewers (38.8%), FSM systems based on septic tanks (44%) and FSM systems based on wet pit latrines (44.6%). The lower median values for conventional sewer systems can be explained by the high capital investment needed to build such systems. One potential explanation for the low median values associated with UDDT-based systems is that revenues derived from the sale of fertilisers are integrated in the calculation of O&M costs.

A few studies present interesting data. The World Bank WSP's Economics of Sanitation Initiative in Cambodia for instance shows that O&M costs for sewer-based systems only account for 6% of total costs, mainly due to the high capital costs required to build sewer pipes and treatment plants. In comparison, O&M costs for FSM systems based on wet and dry pit latrine account for nearly 56% of total costs, in particular because pit latrine facilities do not require much capital investment (The World Bank 2012b). Similarly, Dodane *et al.* (2012) reports that the share of O&M costs is much lower for conventional sewer systems (22%) than for FSM systems based on septic tanks (65%). Another study of WSP in Indonesia finds that O&M costs of sewer-based systems are much higher, around 45% of total lifecycle costs, but are nonetheless lower than for communal sewerage (65%) and FSM systems based on shared latrines (50%), septic tanks (61%) and wet pit latrines (62%) (The World Bank 2011b). Similar results were obtained in a study conducted by Cairns-Smith *et al.* (2014), where the share of O&M costs of conventional sewers were found to be lower than for simplified sewerage (62%) and FSM systems based on septic tanks (53%).

This analysis is however limited by the fact that the categorisation by type of costs is highly inconsistent across studies. Indeed, while some research works provide a complete breakdown of costs, as listed in Table 1, the majority of documents reviewed provide a simple division between capital costs and recurrent costs, without specifying whether capital maintenance costs are taken into account and if yes, in which category they were included. The cost of capital is also absent from most studies found in the literature.

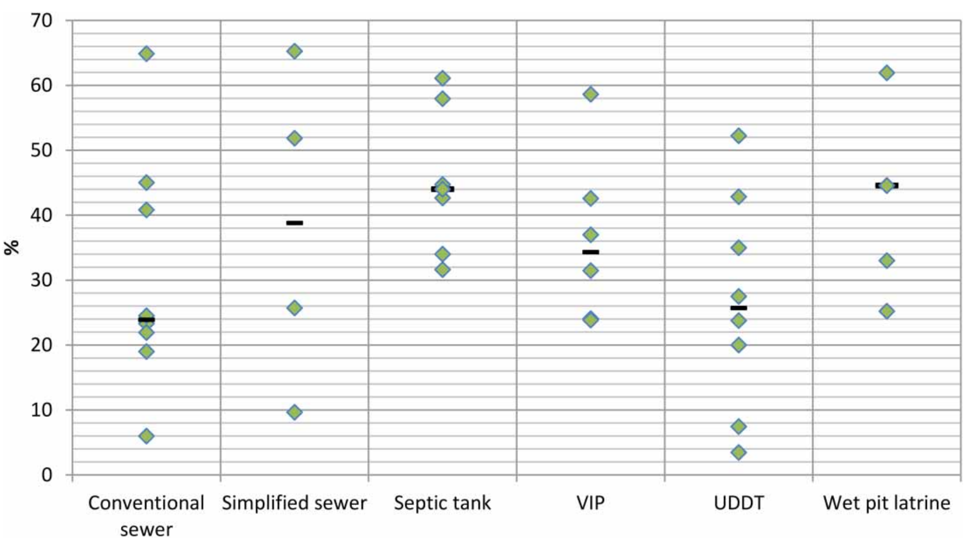

Figure 8 | Share of O&M costs out of total lifecycle costs, by type of sanitation system.

Comments on methodologies used in the shortlisted studies

The characterisation of the shortlisted studies highlighted significant variations in methodologies employed. The two most advanced documents in terms of methodology include the study on Dakar (Dodane *et al.* 2012) and those of the Word Bank's Economics of Sanitation Initiative, in particular because they provide a complete breakdown of cost data, they specify the lifetime of each specific technology option and most of the data consists of primary data. It must be noted however that the lifetime selected in these studies are hypothetical only (since it is not possible to accurately anticipate the lifespan of each hardware component) and may not reflect the reality on the ground. In addition, lifetimes are not consistent across studies, which does not allow for a perfect comparison of cost data.

The other shortlisted documents, despite belonging to the most thorough studies on the costs of urban sanitation in the literature, still present serious methodological flaws which limit the robustness of the above analyses. First, some studies have not reported data for the full lifetime of the different hardware components constituting the sanitation chain (see City of Ulaanbaatar (2006), Burr & Fonseca (2011), Cairns-Smith *et al.* (2014) and Ross *et al.* (2016)). Ross *et al.* (2016) directly provide annualised costs but there is strong suspicion that the same lifetime was used for all technology options compared, which may create, as previously mentioned, an unfair bias towards solutions with shorter asset life. The lifetime of a pit latrine may be much shorter than the sludge treatment facility, for instance, and ideally this should be factored in any long-term cost calculation (Ulrich *et al.* 2016). Some studies initially reviewed but not shortlisted only report costs observed during the first months or year of the operation of sanitation systems (see for instance Okan-Adjetey (2013) and Tilmans *et al.* (2015)).

Second, most studies do not use primary data for their calculation, and instead extrapolate cost data such as unit costs from other studies which sometimes do not focus on the same cities. These data are then used to calculate capital and O&M costs. Because of the numerous determinants of costs and their high sensitivity to local contexts, using secondary data source may significantly bias quantitative analyses and limit the utility of comparing documents of the literature. Of course, collecting primary data implies a much more time and resource intensive fieldwork, which may explain why some researchers have relied on secondary data. Finally, not all studies provide a clear breakdown of costs (capital, O&M, capital maintenance, etc.) and specify what each category includes. As a result, there are serious doubts on whether costs provided can be qualified as 'life-cycle costs'.

Cost analyses must be compared to service levels and other benefits

Ideally, a comprehensive comparison of several urban sanitation options must not only take into account costs but also the wide range of potential or achieved benefits associated with each option. Indeed, a sheer cost comparison of different sanitation options is useful to manage urban sanitation systems, but from a development point of view, it is also important to know what financial and non-financial benefits can be expected from each type of solution. Amongst the studies reviewed, few have attempted to assess such benefits thoroughly and compared them with cost data. However, this was not a core objective of this research work therefore the present review may not cover the whole literature on cost-benefit comparison.

An option to undertake such analysis is to compare costs to the level of service provided by each sanitation system. A methodology to assess service level has for instance been designed by the IRC WASHCost initiative (Potter *et al.* 2010) and proposes a sanitation ladder comprising five levels of service (no service, limited, basic, improved and highly improved), based on four main criteria: accessibility, use, reliability and environmental protection. The authors suggest that a different ladder shall be assigned separately for excreta and urine management, for greywater, and for solid waste. In its synthesis report on Southeast Asia, the World Bank's ESI initiative also proposes a 'pathway for sanitation improvements', in the form of a diagram. In terms of on-site sanitation option, septic tank-based systems are considered as providing a higher level of service than wet pit latrines and dry pit latrines, in descending order of level of service (The World Bank 2015).

While this rough ranking may be generally accepted in the sector, the specific benefits of each sanitation option with respect to the four criteria listed by IRC must be thoroughly assessed in each urban context. Many factors could indeed affect the level of service provided by a same type of sanitation solution across cities and countries, such as project design and the type of materials used to build sanitation infrastructure. Most of the shortlisted studies from which data was retrieved for the above analyses do not attempt to characterise the level of service achieved by each sanitation option, or do not provide thorough data. Dodane *et al.* (2012) for instance assume that the sewerage and septic tank-based FSM systems of Dakar provide the same level of service. A study of The World Bank (2009) also only compares ecosan technologies and other sanitation options that, according to the authors, provide the same level of service (VIP and sewerage). However, there is no explanation on how the level of service was assessed, which may mean the methodology was basic. Similarly, another study of The World Bank (2012c) states that all sanitation options compared (sewerage, VIP and wet pit latrine) provide the same level of service since they cover the full chain of sanitation, which is a basic – and not sufficiently elaborate – definition of service level.

Some research works, nonetheless, have developed a more advanced methodology. Two main types of analyses, in this regard, can be identified in the academic and grey literature: cost-benefit analyses (CBA) and cost-effectiveness analyses. A cost-benefit analysis is a comparison between the cost of sanitation options and their respective monetised benefits. Standard outputs of CBA include Benefit-Cost Ratios, annual internal rate of return (IRR), payback period (PBP) and net present value (NPV) – it is important here to distinguish between research works comparing costs to financial benefits only and those comparing costs to wider economic benefits. For instance, a study comparing centralised and decentralised sewer systems in Can Tho, Vietnam, calculated the NPV of each option but only financial cash flows (i.e. revenues from fertilisers) are considered as benefits. The only added value in such case is to discount costs to present values (Willetts *et al.* 2010). In comparison, WSP's Economics of Sanitation Initiative adopted a much more comprehensive approach by comparing costs to economic benefits (including objectives such healthcare, water access and treatment, and access time). A cost-effectiveness analysis compares the costs of sanitation options to non-monetised outputs, in particular cost per disability-adjusted-life-years (DALY) averted, cost per case averted and cost per death averted (The World Bank 2011a).

The main studies and projects on cost-benefit and cost-effectiveness of urban sanitation solutions include WSP's Economics of Sanitation Initiative in East Asia (The World Bank 2015) and WHO's global sanitation cost and benefit reports (Hutton 2012). The results of WSP's analysis indicated that septic tanks are economically viable in all countries of the region, and that their BCRs are overall similar to sewerage with wastewater treatment systems. Significant variations in BCRs were found across sanitation solutions and across countries in Southeast Asia. Interestingly, private wet pit latrines were found to have a higher BCR than private toilets with sewerage. The results of WHO's global water and sanitation costs and benefits analysis concluded that the BCR of sanitation improvement is positive in all regions and ranges from 2.8 in Sub-Saharan Africa to 8 in East Asia. However, no specific cost-benefit or cost-effectiveness analyses were undertaken by type of sanitation solution.

Further work needs to be carried out in this area to improve the quality of cost-benefit assessments. In particular, the aforementioned studies acknowledge the limits of their results as they were unable to quantify and monetise some intangible outcomes such as environmental benefits (The World Bank 2015). Similarly, a brief paper on financial and economic analysis of sanitation in developing countries indicates that quantifying sanitation benefits and converting them to monetary values is a challenging task for various reasons: first, robustly designed studies are needed to account for the range of variables which simultaneously affect outcomes such as health, education, and agriculture; second, the authors note that 'the step of monetisation adds a further layer of uncertainty on the already uncertain physical/natural measurements of sanitation benefits. Prices can be highly variable, or markets may be imperfect thus distorting prices from the market equilibrium price level (which is the standard measure of welfare impact in economics)'; finally, as already mentioned previously, they also note that prices for some benefits of sanitation may be non-existent and thus need to be ascertained through proxy pricing or contingent valuation techniques (Parkinson *et al.* 2012).

CONCLUSION

Lessons learnt

The objective of this paper was to review the academic and grey literature on the lifecycle costs of sanitation systems in developing cities of Africa and Asia. Three major international research programmes on the economics of sanitation, WSP's Economics of Sanitation Initiative, IRC WASHCost and WHO's global cost studies, are frequently referred to in the literature but for various reasons do not fully fit the purpose of the present research. As a matter of fact, only a handful of studies provide comprehensive data on lifecycle costs clearly covering the full urban sanitation chain, but are in most cases limited to one city context and two or three types of sanitation systems. Most other documents only report one or two types of costs – in particular capital costs – or do not report cost data on desludging, transport and treatment.

The analysis of the cost data across the literature revealed that the quality of the data and the complexity of urban sanitation costs significantly limit opportunities for quantitative analyses and comparisons across studies. Data reported sometimes do not distinguish clearly between urban and rural areas, do not sufficiently specify sanitation options, do not provide breakdown of overall cost, or make use of different metrics which are not always convertible due to lack of information (e.g. cost per capita vs. unit cost). In some cases, cost data found in the literature do not cover the full sanitation chain because systems in place in developing countries are incomplete and cost data simply does not exist. Another major obstacle to identifying patterns of costs across sanitation options is the numerous determinants of costs (e.g. type of technology, labour, material and energy costs, density, topography, soil condition, service level, etc.) and their high sensitivity to local contexts, which implies that unless detailed information on these factors are provided, cross-analysing sanitation cost data taken from different cities and countries is of low interest. The lack of data also does not allow for a clearer understanding of the extent to which each cost determinant affects financial costs.

To circumvent these issues, lifecycle cost ratios between different sanitation systems analysed in a same study/report were calculated, and then compared between each other. The results show that conventional sewer systems are in most cases the most expensive sanitation options, followed, in order of cost, by sanitation systems comprising septic tanks, ventilated improved pit latrines (VIP), urine diversion dry toilets (UDDT) and wet or dry pit latrines. The cost ratio of conventional sewer systems to septic tank-based systems ranges from 1 to 4.7. The cost ratio of FSM systems based on septic tanks is found to be systematically higher than wet pit latrines, VIP and UDDT, with cost ratios ranging from 1.9 to 4.9, 1.6 to 2.1, and 1.6, respectively. The cost ratio of UDDT to VIP ranges from 0.8 to 1.1 and therefore do not allow to establish a clear hierarchy. Their separate cost ratios to conventional sewers and FSM systems based on septic tanks are also similar. Both UDDT and VIP tend to be more expensive than wet pit latrines. The cost of simplified sewer systems is found to be lower than both conventional sewer systems and septic tank-based systems, but data on its cost ratio relative to other sanitation systems is almost non-existent.

The article also pointed out that households tend to bear the cost of FSM systems in a much larger proportion that for sewer systems which are mainly paid for by utilities. This can be explained by the fact that users need to pay for the installation, maintenance and desludging of on-site facilities such as septic tanks. This should be carefully considered by decision-makers in their choice of sanitation system, in particular in projects taking place in low-income communities.

Secondary analyses were also undertaken within the framework of this research. They point out that the share of costs of on-site hardware components out of total costs is more significant in the case of FSM systems than for conventional sewer systems; that comparative cost patterns for on-site sanitation facilities only do not significantly deviate from those for the full sanitation chain; and that no clear pattern regarding the share of O&M costs (and capital costs) could be identified by type of sanitation option. Data retrieved was too weak to make any robust comparison at the continental level between Africa and Asia.

Steps ahead to enhance knowledge on the costs of urban sanitation systems

The results of the analyses undertaken within the framework of this research paper are undermined by the weakness and low availability of data in the literature. Considerable efforts must be made to build sanitation cost databases at country level and even city level. Development partners could play a central role in this regard in building capacity of governments and utilities in Sub-Saharan Africa and developing Asia. Knowledge on the costs of urban sanitation solutions would also benefit from academics and development professionals adopting more thorough reporting methods. Ideally, every study or project brief reporting cost data should clearly cover each type of costs and each component of the sanitation chain, and provide breakdowns. They should also include information on the factors affecting costs and listed in Table 2. This would open opportunities to compare cost data across different contexts, in particular. An example of possible cost reporting template is provided in Table 3.

The literature review also pointed to a certain number of studies comparing sanitation costs to a range of benefits, although this was not the primary focus of the research. A sheer cost comparison of different sanitation options is useful to manage urban sanitation systems, but from a development point of view, it is also important to know what financial and non-financial benefits can be expected from each type of solution. Further work however needs to be carried out in this area to improve the quality of cost-benefit assessments. Studies and project reports can characterise more systematically the level of service provided by their sanitation option, following the methodology of IRC WASHCost. In terms of quantitative cost-benefit analyses (e.g. BCR), the challenge lies in quantifying and monetising some intangible outcomes such as environmental benefits. Some studies have also reflected on the difference in practicality of implementation offered by various sanitation systems, as a means to prioritise options (Dodane *et al.* 2012).

Finally, other interesting types of analyses can be carried out to enhance the knowledge on the costs of urban sanitation options and provide valuable information to users, utilities and donors. A small number of studies for instance have aimed to determine the proportion of cost borne by each type of stakeholder. Dodane *et al.* (2012) and Ross

Table 3 | Simplified cost reporting template

Type of sanitation system	Element of the sanitation chain	Cost (currency and year)	Lifetime (years)	Population served by the system	Average density (pop/km2)	Material cost (currency and year)	Energy cost (currency and year)	Level of service achieved	Other factors
Septic tank-based FSM system	Toilet to septic tank (specify quantities)	Capital = O&M = Capital maint. = Etc.	Toilet (e.g. 20 years) Septic tank (e.g. 30 years)	50,000 persons	2,000 pop/km^2	Toilet unit cost Septic tank unit cost	Cost of electricity Cost of fuel Etc.	Limited / basic / improved / highly improved	Topography, water table height, etc.
	Desludging and transport by truck	Capital = O&M = Capital maint. = Etc.	Truck = 40 years			Truck unit cost			
	Treatment (e.g. drying beds)	Capital = O&M = Capital maint. = Etc.	Drying beds = 25 years			Drying bed			
	Reuse/disposal (specify)	Capital = O&M = Capital maint. =Etc.	Pipe = 30 years			Truck or pipe			
	Total	**Capital = O&M = Capital maint. = Etc.**	–			–	–		

Note: values included in the table are only indicative.

et al. (2016) have shown that users bear most of the cost in the case of FSM systems, whereas utilities bear most of the cost in the case of sewer-based systems. Sensitivity analysis to different variables could also be undertaken to understand better how sanitation costs evolve as a function of various factors: a study for instance compared the evolution of the cost per household of sewerage systems and FSM systems as density increases, and concluded that sewer systems become financially viable from a certain density level. Likewise, a report by the Boston Consulting Group compared the evolution of cost over time for FSM systems and simplified sewerage. These types of analyses are however rarely encountered in the literature and would be particularly helpful, if replicated more frequently, for practitioners to ensure the long-term financial sustainability of sanitation projects.

REFERENCES

Burr, P. & Fonseca, C. 2011 *Applying the Lifecycle Costs Approach to Sanitation: Costs and Service Levels in Andhra Pradesh, Burkina Faso, Ghana and Mozambique*. IRC WASHCost, The Hague, The Netherlands.

Cairns-Smith, S., Hill, H. & Nazarenko, E. 2014 *Urban Sanitation: Why a Portfolio of Solutions is Needed*. The Boston Consulting Group, Boston, USA.

City of Ulaanbaatar 2006 Manual on low cost sanitation technologies for Ger areas, Mongolia. Report prepared by Community-led Infrastructure Development Project. Project Management Unit of the Second Ulaanbaatar Services Improvement, City of Ulaanbaatar, Mongolia.

Dodane, P.-H., Mbéguéré, M., Sow, O. & Strande, L. 2012 Capital and operating costs of full-scale fecal sludge management and wastewater treatment systems in Dakar, Senegal. *Environ. Sci. Technol.* **46**, 3705–3711.

Evans, B. & Mara, D. 2011 *Sanitation and Water Supply in Low-Income Countries*. Ventus Publishing, Leeds, UK.

Fonseca, C., Dubé, A. & Verhoeven, J. 2011 *Cost-based Decision Support Tools for Water and Sanitation*. IRC International Water and Sanitation Centre, The Hague, The Netherlands.

Hutton, G. 2012 *Global Costs and Benefits of Drinking-Water Supply and Sanitation Interventions to Reach the MDG Target and Universal Coverage*. World Health Organization, Geneva, Switzerland.

Hutton, G. & Bartram, J. 2008 *Regional and Global Costs of Attaining the Water Supply and Sanitation Target (Target 10) of the Millennium Development Goals*. World Health Organization, Geneva, Switzerland.

Hutton, G. & Varughese, M. 2016 *The Costs of Meeting the 2030 Sustainable Development Goal Targets on Drinking Water, Sanitation, and Hygiene: Summary Report*. The World Bank, Water and Sanitation Programme, Washington, DC, USA.

IRC WASHCost 2012 *Providing a Basic Level of Water and Sanitation Services That Last: COST BENCHMARKS*. IRC WASHCost Infosheet 1, The Hague, The Netherlands.

Kennedy-Walker, R., Holderness, T., Alderson, D., Evans, B., Malambo, W. & Muhammad, H. 2014 Assessing the long term operating costs of improved sanitation infrastructure using network modelling. In *WASH for Everyone Everywhere Conference*.

Klutse, A., Bouraima, Z. & Amegnran, C. 2010 Sanitation costs in Burkina Faso. In *IRC Symposium 2010 Pumps, Pipes and Promises*. The Hague, The Netherlands.

Kyomugisha, T. S. 2016 *Initiatives to Improve Faecal Sludge Management in Uganda: Clustering, Collection and Treatment*. Water and Environment Sector Joint Sector Review, Kampala, Uganda.

LIXIL & Oxford Economics 2016 *The True Cost of Poor Sanitation*, in collaboration with WaterAid. Lixil Group Corporation, Tokyo, Japan.

McIntyre, P., Casella, D., Fonseca, C. & Burr, P. 2014 *Priceless! Uncovering the Real Costs of Water and Sanitation*. IRC, The Hague, The Netherlands.

Okan-Adjetey, P. 2013 *Urine Diversion Dehydration Toilets at Valley View University in Oyibi, Greater Accra Region, Ghana*. Sustainable Sanitation Alliance Case Study Brief, Sustainable Sanitation Alliance, Eschborn, Germany.

Parkinson, J., Hutton, G., Pfeiffer, V., Blume, S. & Feiereisen, P. 2012 *Financial and Economic Analysis*. Sustainable Sanitation Alliance Factsheet, Sustainable Sanitation Alliance, Eschborn, Germany.

Potter, A., Klutse, A., Snehalatha, A., Bachtelor, C., Uandela, A., Naafs, A., Fonseca, C. & Moriarty, P. 2010 *Assessing Sanitation Service Levels*. IRC WASHCost Working Paper 3. The Hague, The Netherlands.

Ross, I., Scott, R. & Joseph, R. 2016 *Faecal Sludge Management: Diagnostics for Service Delivery in Urban Areas: Case Study in Dhaka, Bangladesh*. The World Bank, Water and Sanitation Programme, Washington, DC, USA.

The World Bank 2009 *Study for Financial and Economic Analysis of Ecological Sanitation in Sub-Saharan Africa*. Water and Sanitation Programme, Washington, DC.

The World Bank 2011a *Economic Assessment of Sanitation Interventions in the Philippines*. A Six Country Study Conducted in Cambodia, Indonesia, Lao PDR, the Philippines, Vietnam and Yunnan Province (China) under the Economics of Sanitation Initiative. The World Bank, Washington, DC.

The World Bank 2011b *Economic Assessment of Sanitation Interventions in Indonesia*. A Six Country Study Conducted in Cambodia, Indonesia, Lao PDR, the Philippines, Vietnam and Yunnan Province (China) under the Economics of Sanitation Initiative. The World Bank, Washington, DC.

The World Bank 2012a *Economic Impacts of Poor Sanitation in Africa*. Factsheet, Water and Sanitation Programme. The World Bank, Washington, DC, USA.

The World Bank 2012b *Economic Assessment of Sanitation Interventions in Cambodia*. A Six Country Study Conducted in Cambodia, Indonesia, Lao PDR, the Philippines, Vietnam and Yunnan Province (China) under the Economics of Sanitation Initiative. The World Bank, Washington, DC, USA.

The World Bank 2012c *Urban Sanitation Experiences of Senegal and Burkina Faso: Broadening Urban Sanitation Activities*. The World Bank, Washington, DC.

The World Bank 2015 A Six-Country Study Conducted in Cambodia, Indonesia, Lao PDR, the Philippines, Vietnam and Yunnan Province (China) Under the Economics of Sanitation Initiative, *Economic Assessment of Sanitation Interventions in Southeast Asia*. The World Bank, Washington, DC, USA.

Tilmans, S., Russel, K., Sklar, R., Page, L., Kramer, S. & Davis, J. 2015 *Container-based Sanitation: Assessing Costs and Effectiveness of Excreta Management in Cap Haitien, Haiti*. Environment & Urbanization, International Institute for Environment and Development (IIED), London, UK.

Trémolet, S., Kolsky, P. & Perez, E. 2010 Financing on-site sanitation for the poor. A six-country comparative review and analysis. Water and Sanitation Program Technical Paper. World Bank, Washington, DC.

Ulrich, L., Salian, P., Saul, C., Justrich, S. & Luthi, C. 2016 *Assessing the Costs of on-Site Sanitation Facilities*. EAWAG Aquatic Research, Geneva, Switzerland.

UN-GLAAS 2014 *Investing in Water and Sanitation: Increasing Access, Reducing Inequalities*. UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water, Geneva, Switzerland.

UNICEF & WHO 2015 *Joint Monitoring Programme Update 2015*. World Health Organization, Geneva, Switzerland.

von Muench, E. & Mayumbelo, K. M. K. 2007 Methodology to compare costs of sanitation options for low-income peri-urban areas in Lusaka, Zambia. *Water SA* **33** (5), 503–602.

Water, Sanitation and Hygiene (WASH) Institute 2015 *Faecal Sludge Management – A Landscape Study of Practices, Challenges, and Opportunities*. Population Service International, Washington, DC, USA.

WaterAid 2011 *Public Finance for Water Supply and Sanitation: Focus on National Budgets*. Briefing Note. WaterAid, London, UK.

Whittington, D., Jeuland, M., Barker, K. & Yuen, Y. 2012 Setting priorities, targeting subsidies among water, sanitation, and preventive health interventions in developing countries. *World Dev.* **40** (8), 1546–1568.

WHO 2014 *Preventing Diarrhea Through Better Water, Sanitation and Hygiene: Exposures and Impacts in Low and Middle-Income Countries*. World Health Organization, Geneva, Switzerland.

Willetts, J., Carrard, N., Retamal, M., Mitchell, C., Nguyen Hieu Trung, Nguyen Dinh Giang Nam & Paddon, M. 2010 Cost-effectiveness analysis as a methodology to compare sanitation options in peri-urban Can Tho, Vietnam. IRC Symposium 2010, Pumps, Pipes and Promises, The Hague, The Netherlands.

First received 27 April 2017; accepted in revised form 6 September 2017. Available online 19 October 2017