The road not taken: how traditional excreta and greywater management may point the way to a sustainable future

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Abstract This paper argues that modern, end-of-pipe sanitation systems are not the pinnacle of centuries of wastewater technology development, and may actually prove to be a technological dead-end: expensive to build, operate and maintain, and out of step with traditional wastewater management philosophy. A brief examination of a series of excreta and wastewater management systems from around the world and throughout history clearly shows that viewing faeces, urine and grey water as a worthless waste to be disposed of is only a modern concept, which ignores the realities of limited resource availability, and the obvious benefits to be had from closed-loop systems – as was clearly recognised in the past. While currently, expensive, technically complicated end-of-pipe sanitation systems dominate, several modern systems have been developed specifically to ensure an efficient resource recovery and reuse. Reconsidering and researching historical approaches to wastewater management and applying modern technologies to improve their functionality may contribute to the solution of many of today's sanitation and environmental problems.

Keywords Agriculture; excreta and greywater reuse; sanitation philosophy; wastewater management systems

Introduction

The advent of agriculture around 10,000 BC enabled larger human populations to settle in a fixed location for longer periods than had been previously possible. With this settlement, people were for the first time faced with the question of what to do with the large volumes of excreta and used water that accumulated as a result of a sedentary lifestyle. Many old, traditional agricultural societies approached this problem in a logical and pragmatic manner that recognised the nutrient and organic value of excreta by practising the recovery and use of "night-soil" (faeces and excreta). This enabled them to live for centuries in closed loop systems, where nutrients and organic matter from liquid and solid household wastes were returned to the soil from whence they came. In China, where this is still widely practised, they have been able to maintain soil fertility over millennia, despite high population densities. This knowledge however was not based on scientific research, but was rather culturally codified and traditional practical knowledge. In general, historical descriptions on this theme are sparse.

Over the last century or so traditional reuse practices have been abandoned, and replaced by "end-of-pipe" wastewater disposal systems. Today, in view of the construction and operation and maintenance costs of these systems, the degrading quality and fertility of our soils, the limited availability of mineral phosphorus reserves, the high energy consumption of fertiliser production, and the need to protect our freshwater reserves, the resource value of excreta and greywater needs once more to be recognised and systematically implemented, using modern technological and operational solutions, and ensuring maximum health protection.

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To be able to apply such closed loop approaches in a modern and hygienically safe manner historical research is needed to learn from the mistakes of the past, as is an improved cooperation between scientific disciplines. The motivation for this paper was therefore to look to the past to provide a direction for the future.

A brief history of excreta and greywater use

In a very broad sense the recovery and use of urine and faeces has been practiced over millennia by almost all cultures. The uses to which they were put were not limited to agricultural production (although for modern application this may of course be of most relevance), and indeed covered a wide variety of practices. The Celts for example had many uses for urine, one of particularly practical importance being its use in dyeing and washing cloth. In India, ancient Sanskrit texts outlined the medicinal use of urine through *shivambu* (auto-urine therapy), which still has a popular following today. Like the Celts, the Romans were well aware of the cleaning power of urine and also used it for washing clothing, developing the logistics to collect larger volumes of urine in settlements. Fullers, who worked in laundries, would install amphorae in streets and alleyways as public urinals passing regularly to collect the urine, and transporting it back to the laundry for washing. Of course, washing with urine was a rather smelly business, but also an extremely lucrative one, inspiring Vespasian's famous quote "pecunia non olet". Throughout Europe fullers continued to work in this way right through to the Middle Ages.

From these examples it is clear that throughout history attitudes to excreta have not always been negative, and excreta was seen as a resource. This can most clearly be seen when one considers the use to which both excreta and greywater have been put in agriculture throughout the ages. The most widely known example of the diligent collection and use of human excreta in agriculture is of course that of China. It is reported that the Chinese were aware of the benefits of using excreta in crop production before 500 BC, enabling them to sustain "more people at a higher density than any other system of agriculture" (Brown, 2003). The value of "night soil" as a fertiliser was clearly recognised with well developed systems in place to enable the collection of excreta from cities and its transportation to fields. Like the work of the fuller, this was a lucrative enterprise. Contractors first had to pay for a license before collecting the excreta and selling it on to farmers, and larger towns were often zoned so that those living nearer the fields paid less for collection than those living in the centre. Scott (1952) estimated the annual market price of the excreta output of the entire population at "between 50 and 80 million pounds sterling at 1924 market prices."

The Japanese too practiced a disciplined use of excreta in agriculture, applying at rates of up to 4 t/ha on fields in an environment that was considerably more urbanised than that of China. King in 1911 reported seeing night soil transported out of Yokohama and Tokyo "carried on the shoulders of men and on the backs of animals, but most commonly on strong carts drawn by men bearing six to ten tightly covered wooden containers holding forty, sixty or more pounds each" (Brown, 2003). Statistics from the Japanese Bureau of Agriculture for 1908 state that 23,950,295 tons of excreta had been used on around 13.5 million ha of arable land (King, 1911). Like the Romans, the Japanese provided public toilets with the express aim of collecting excreta for use. The Japanese regarded urine as a particularly useful fertiliser and this would be collected separately for direct use (Matsui, 1997). The reuse of excreta was however not only limited to China and Japan, and was and continues to be practiced right across Asia.

The ancient Romans also practiced the use of excreta in agriculture, a practise they may have adopted from the ancient Greeks. The Romans also practiced the reuse of greywater – huge volumes of which were produced as a result of the Roman bath culture.

Daily per capita water consumption has been estimated at up to 600 L for the upper classes, whereas slaves and soldiers may have used around 200 L/cap·day (Guhl, 2004, unpublished). As the use of excreta for agriculture was the rule in Roman times, the wastewater from most settlements was greywater in the main. This was often led outside of the settlement and used to irrigate agricultural areas, as was the case at Barbegal in Provence, France. Here, greywater from the settlement with an estimated population of around 500 was mixed with the water passing through the largest grain mills in the Roman Empire and irrigated fields of around 22 ha.

Ancient Arab cultures also incorporated the collection and use of excreta into their agricultural systems for very many centuries. In the 12th and 13th Century, Ibn al-Awam, an Arab living in southern Spain wrote of composting techniques incorporating human excreta, and of its benefits in curing illnesses in plants such as bananas, apple trees, peach trees, citrus trees, figs, grapes, palms, cedars and wheat. Elaborate systems were developed in urban centres of Yemen enabling the separation of urine and excreta even in multi-storey buildings. Faeces were collected from toilets via vertical drop shafts, while urine did not enter the shaft but passed instead along a channel leading through the wall to the outside where it evaporated. Here, faeces were not used in agriculture but were dried and burnt as fuel. This was common practice for many centuries resulting in a sanitation system, which required very little water. In modern times this has changed with the introduction of water-flush toilets, leading to water shortages, a falling water table and land subsidence in the area of the Yemeni capital city of Sana'a (Winblad and Simpson-Hébert, 2004). In Mexico and Peru, both the great Aztec and Inca cultures collected human excreta for agricultural use. In Peru, the Incas had a high regard for excreta as a fertiliser and would store it, dried and pulverised to be used when planting maize.

After the fall of the Roman Empire, many of the centralised structures and systems of that period began to dissolve. However not all of their knowledge was lost. Indeed the collection and reuse of excreta continued. Monasteries, which served as repositories for information and learning throughout Europe at this time continued to apply the recovery of nutrients from excreta and greywater. For example near Milan, the Cistercians introduced the use of city refuse and excreta and wastewater on their land in around 1150 CE. The Cistercians had also developed sophisticated washing systems, and used the greywater from wash houses to either directly irrigate gardens or, as at their monastery at Silvacane, near Marseille, mixed it with wastewater from buildings and fresh water to feed fish ponds (Guhl, 2004, unpublished). In the Middle Ages, the use of excreta and greywater was the norm. European cities were rapidly urbanising and sanitation was becoming an increasingly serious problem, whilst at the same time the cities themselves were becoming an increasingly important source of agricultural nutrients. In Freiburg, Germany, meadows were irrigated with nutrient rich wastewater, first officially recorded in 1220 CE. The meadows were mainly located in areas with permeable soils along rivers. Cultivating these meadows ensured growth in dry periods and extended the vegetation period by washing away the snow in spring or winter. The irrigation also served to reduce the incidence of plant pests, and contributed to stabilising the nutrient balance in the meadows. Irrigation of the meadows reached its heyday in the early 19th century, although the practice itself only stopped in the 1960s.

The practice of using the nutrients in excreta and wastewater for agriculture therefore clearly continued in Europe into the middle of the 19th Century. Farmers, recognising the value of excreta, were eager to get these fertilisers to increase production and urban sanitation benefited. As the industrial revolution progressed it was becoming increasingly possible to develop more complex approaches to collect excreta for reuse. In 1865, Prince Heinrich der Niederlande had asked T. Charles Lienur to remove the sewage from Castle

Luxembourg without polluting the River Elz and without using wagons. (The introduction of sewer systems in the second half of the 19th century provoked hefty discussions, as treatment plants were non-existent and they were causing serious pollution of surface water bodies.) Lienur's system consisted of two pipes. One carried rainwater, greywater, and industrial water, while the other, which can be considered as the predecessor of modern vacuum sanitation systems, transported blackwater and wastewater from stables and slaughter houses. The vacuum toilets required very little flushing water and the blackwater collected was used to produce "poudrette" (a dried natural fertiliser). At that time the industrial production of mineral fertiliser had not yet started (the first factories were built in 1870) and the price for fertiliser was high enough to allow the production and successful marketing of "poudrette".

In developing areas of Amsterdam in 1906 more than 4,500 vacuum toilets where connected to a Lienur-system (Figure 1). Soon however the production of poudrette was seen as being too costly as prices for industrial mineral fertiliser decreased. Vacuum sewer systems have however regained popularity in modern times being used apartment blocks, public and office buildings (Figure 2). Although some information on Lienur's system is available, a thorough investigation of why the system could not compete with central sewer systems in urban areas, particularly under the specific and very difficult conditions in a city like Amsterdam, has not been carried out (Lange and Otterpohl, 2000, Lange, 2002).

Why did this change?

However, whilst the recovery of nutrients and organic matter from excreta and greywater was addressing the sanitation problems in settlements and contributing to securing and increasing agricultural productivity the practice was not destined to become the dominant approach to sanitation in the 20th Century. There appear to have been four main driving factors that lead to the demise in the recovery and use of excreta and greywater from cities.

(a) Urban settlements had grown dramatically over the centuries. The logistical challenge of removing the faeces of a booming population from densely packed city centres to bring to agricultural areas many miles away proved too great. The sanitary conditions in the hearts of major European cities degraded. In nineteenth century Britain an average of 26% of children died before the age of 5; whereas in the cities the average was double that at around 50% (Brown, 2003). In addition to this the collection, handling and use of partially or untreated waste was having extreme impacts on

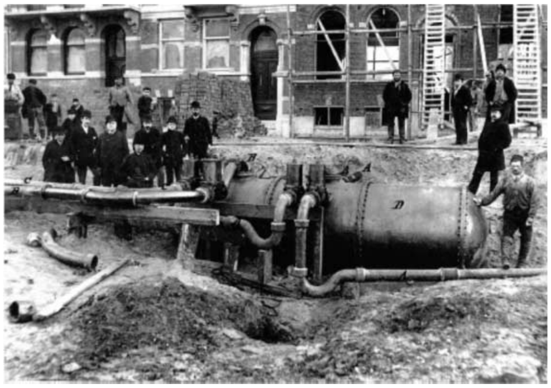

Figure 1 Vacuum-pumping-station in Amsterdam July 1873 (source: Roediger company, publishded in Lange, 2002). In Amsterdam in 1906 more than 4,500 vacuum toilets where connected to a Lienur-vacuum-system

Figure 2 Siphon for waterless urinals invented by Beets, 1885: Oil forms a layer on top of the urine and stops smells (left, Lange, 2002), waterless urinal of GTZ Headquarters (middle, Keramag) and vacuum toilet and pumping station of KfW Building (right, GTZ project data-sheets 2006)

public health. In China in the 1930s, life expectancy at birth was 34 years, compared to 60 years in Britain at that time, with 42% of all deaths occurring amongst children under 10 (Scott, 1952).

(b) Up until the end of the nineteenth century the dominant theory on the spread of illness was the miasma theory. This theory, with its roots in classical times, held that illness was caused by inhaling volatile substances. As bad smells were thought more likely to contain illness, everything that smelled had to be gotten rid off. To some degree the miasma theory contributed to containing disease, but did not allow for a suitable approach to safe excreta reuse to be adopted.

(c) The arrival of piped domestic water supplies in the nineteenth century made water flushed sewerage system possible. The water flushed system, often using existing storm water drains, was the answer to many people's prayers at the time. Governments had attempted to legislate to improve sanitation but this was proving difficult to implement, and physicians and hygienists were caught in a losing battle. Water flushing of course greatly increased the volume of sewage, at the same time diluting the nutrients, making it virtually impossible for them to be recovered and reused as they previously were.

(d) The nutrient demand of farmers was eventually met by cheap chemical fertilisers, making any efforts to recover and reuse the nutrients and organic material from the large volumes of sewage completely obsolete.

The evidence was clear. Sewered areas became cleaner, healthier places to live, city pollution became river pollution, downstream communities suffered and the concept of the water-borne sewer system became the standard approach for urban areas of industrialised countries during the second half of the 19th century and into the 20th (van Zon, 1986, Lange and Otterpohl, 2000, Lange, 2002, Panesar *et al.*, 2006).

The end of the pipe at the end of the line?

Of course for 19th Century engineers there was already a precedent for water flushed systems, from the days of the Roman Empire. The Roman Cloaca Maxima, built by Tarquinius Priscus (616–578 BC), was originally a system of channels draining rainwater from Rome, particularly the area around the Forum. It later became the main Roman sewer carrying wastewater and storm water out of the city, and discharging it downstream into the Tiber, thus protecting at least to a small degree the water quality of the river within the city. However, despite this water quality protection measure, the Tiber was still unsuitable as a water source, and fresh water had to be brought to the city via aqueducts. Today for many it remains a mystery as to why the achievements of this forerunner of modern centralised wastewater systems, and this form of wastewater "disposal" was completely forgotten until the 19th Century. What however is less often recognised is that the Cloaca Maxima was practically an emergency "solution" to deal with the vast quantities of wastewater (mainly greywater) generated in the capitol that could not be dealt with in any other way.

In many ways, the sewage systems of the 19th Century were a similar emergency solution to a social health crisis, and for 150 years engineers have continued to try and perfect this emergency solution. In order to improve the abysmal sanitary state of cities it was initially considered acceptable to discharge raw sewage to surface water bodies, spending large sums of money to install vast sewerage networks throughout cities to do so. Later, when the effects of the resulting severe river pollution became obvious, mechanical treatment of wastewater was introduced (the first German treatment plant being built in 1887 in Frankfurt-Niederrad), followed by biological treatment for the degradation of organic substances, and tertiary treatment to remove nutrients, reducing eutrophication in receiving water bodies. These three steps now represent the present state-of-the-art in wastewater treatment.

Although these conventional sewer systems have improved the public health situation in towns, cities and countries that can afford the massive installation, operation and maintenance cost, they have also drained economies, polluted and squandered fresh water resources, broken nutrient cycles and impoverished soils. For almost half of the world's population, the estimated 2.6 billion people who do not have access to adequate sanitation today (WHO/UNICEF JMP, 2005), "end-of-pipe" systems remain both unaffordable and inappropriate. As millions are spent perfecting these expensively wasteful systems, an estimated 2.2 million people, most of them children under the age of five, die every year as a result of illnesses caused by contaminated drinking water and poor sanitation and hygiene in developing countries. 80% of all diseases and 25% of all deaths in developing countries are caused by polluted water (UN, 1992). At the same time soils are impoverished and nutrients lost to water bodies as the "end-of-pipe" paradigm discourages recovery and reuse. In Africa, 85% of arable land is losing an average of 30 kg of nutrients per hectare per year (Morin, 2006).

However it is not only in the developing world that end-of-pipe systems are at the end of the line. In Europe for example, of 540 major cities, only 79 have advanced tertiary sewage treatment, 223 have secondary treatment, 72 have incomplete primary treatment and 168 cities have no or an unknown form of treatment of their wastewater. (EcoSanRes, 2002). The conventional sewer system was developed at a time, in regions, and under conditions where the priority was to remove liquid wastes and dilute excreta from cities. Today with increased population pressure, changes in consumer habits and increasing pressure on freshwater and other resources, this human waste disposal system is no longer able to meet the pressing global needs. In the light of dwindling natural resources there is a need to reassess the functioning of conventional sewage collection and treatment stems. The motivation and inspiration behind end-of-pipe systems needs to be reassessed from a historical perspective and in the light of technological advances. Around the globe the reflections have begun and a range of systems have been developed, based on the recycling principals of the past and using modern technological and systems approaches (Panesar *et al.*, 2006).

Closing the loop once more

In Sweden, near a nature reserve in a suburb of Stockholm, the Gebers collective housing project was founded by a network of people, who converted a deserted and vandalized building complex into 32 apartments. With the installation of a closed-loop system for toilet and organic waste, the project contributes to the environmental protection of the reserve (GTZ, 2006).

Toilets designed to separately collect faeces and urine were installed, with each fraction treated before reuse. The urine is flushed with water and piped to polypropylene collection tanks whilst the faeces are collected without flushing water, falling straight into individual plastic bins, with both the tanks and the bins located in the cellar of the complex. The plastic bins are housed in a special compartment which is constantly under negative pressure, improving dehydration of the faeces and preventing odours from entering the homes. The urine tanks are emptied about twice a year by a tanker truck and the treated urine is used as fertiliser in agriculture. The faeces are composted together with other organic household wastes. The resulting compost has a soil-like appearance, and will be used as a soil conditioner in agriculture to produce horse feed.

The village of Haran Al-Awamied is located south east of Damascus, Syria. The villagers are poor, and farming the main source of income. Untreated wastewater from the existing gravity sewers was commonly used for irrigation, resulting in a high incidence of disease. A new combined public sewer system was therefore recently installed to collect and transport rain and wastewater to a new treatment plant. This consists of bar screens and a sedimentation tank as a pre-treatment, two reed beds to treat the wastewater, and one reed bed for the soilification of the sludge. The treated water is store in a tank, and pumped to irrigate the fields near the plant, with distribution being organised by the farmers.

The improved availability of irrigation water with a high nutrient content has reduced the farmer's expenditure on commercial mineral fertilisers, contributed to higher yields, and increased the number of harvests from one to several per year. The reeds from the wetland are used for wicker and roofing materials and the treated sludge as a soil conditioner. As the farmers benefit from the system, they have provided a great deal of support to ensure its correct functioning (GTZ, 2006). A further example of how closed-loop systems are being implemented can be seen at the headquarters of the German Technical Cooperation (GTZ) in Eschborn, near Frankfurt. During the renovation of the main office building, a modern, ecologically sustainable concept for the management of wastewater from the toilets was installed. The main building is equipped with waterless urinals and water flushed urine diversion toilets. Through the separate, undiluted collection of urine, the water demand for flushing toilets is expected to be significantly reduced. With this concept, the GTZ will not only save 900 m^3 of water per year, but also significantly reduce the load of nutrients and other substances from the urine on the water treatment facilities (GTZ, 2006).

Conclusion: looking back to go forward more sustainably

A brief examination of excreta and wastewater management systems from around the world and throughout history clearly shows that viewing faeces, urine and grey water as a worthless waste to be disposed of is a modern concept, which ignores the realities of limited resource availability, and the obvious benefits to be had from closed-loop systems – which was clearly recognised in the past. 150 years ago this changed dramatically and unsustainable, end-of-pipe, wastewater disposal systems were developed as a way out of a sanitation crisis in wealthy, water rich cities, where they contributed to improving the hygienic situation. With a century and a half of research and development behind them, end-of-pipe systems have become the state of the art in waste water management.

The unreflected export of this end-of-pipe philosophy has however also contributed to the alarming sanitation statistics there, with 4,000 children under 5 dying daily from the effects of contaminated water. Historical research is needed to help establish how we have arrived at this situation and to highlight alternatives to the current dominant approach. In attempting to understand the road that has been taken in sanitation it is important to understand the context of the time. Clearly this includes the technological, economic and environmental context, but the cultural context in which sanitation developments have taken place is also of prime importance. For example the influence of the ultimately erroneous Miasma Theory on the development of cultural attitudes to excreta in Europe can help explain to a degree the "faecophobic" thinking behind end-of-pipe systems. Socio-cultural considerations are also important for new developments in sanitation. Research on history and traditions of sanitation-related socio-cultural aspects can therefore greatly contribute to the socio-cultural sustainability of sanitation systems.

Historical research on the urbanisation of 19th Century Europe has already shed some light on the driving forces behind sewered, water-borne sanitation, and end-of-pipe treatment systems in Europe. In order to effectively address the current global sanitation crisis, and to move towards a paradigm change towards socially, economically and environmentally sustainable systems it is important to have a clear understanding of the history of sanitation. This field has to date not been given sufficient attention, and the future of sanitation would clearly benefit from an examination of the past. Historical research questions could include the following:

- What sanitation systems were developed in different periods and cultures?
- How were these systems culturally, economically, technically and environmentally embedded in the given social context?
- Why has the end-of-pipe sewer system become so dominant today?
- How can previous, historical experience and philosophy of sanitation be collected and made useful and relevant in a modern context?
- What traditionally codified social knowledge, values and habits may prove to be of use when introducing innovative sanitation systems? Which taboos, reservations and social boundary conditions need to be considered?

Historical research is therefore being called upon to examine the route we have taken in addressing our sanitation problems and in so doing to provide inspiration fort he road we may take into the future.

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