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**WATER, SANITATION AND HYGIENE SERVICES BEYOND 2015:
IMPROVING ACCESS AND SUSTAINABILITY**

User perspectives to direct water reuse from the Nano Membrane toilet

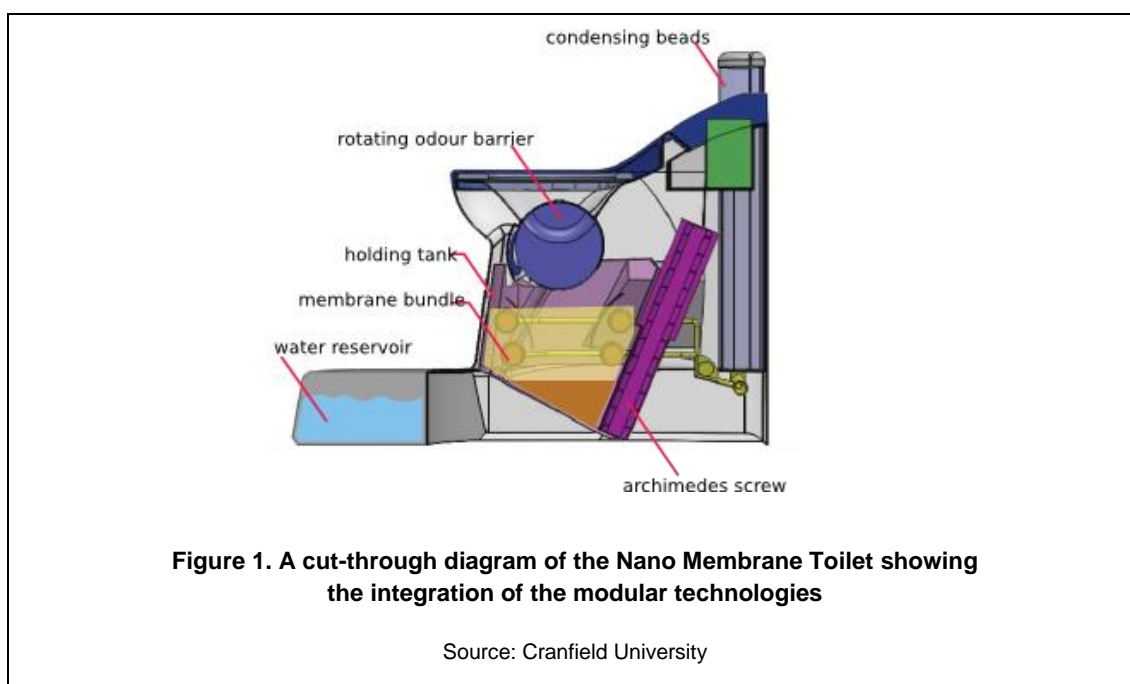
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BRIEFING PAPER 2251

The Nano Membrane toilet is a response to the Bill and Melinda Gates Foundation 'Re-invent the Toilet Challenge'. The Nano Membrane toilet has many design aspects that will involve interaction by the end-user, including water reuse from the membrane treatment system which produces treated water directly available to the user at household level. In order to maintain a user focused design development, a survey was carried out on potential end users in Kumasi, Ghana, in order to understand their attitudes to direct reuse of water from the toilet, and how the attitudes may be affected by aesthetic changes to the water. It was found that end users would be willing to use the product water for a wide range of household purposes, with cleaning being the most likely. Odour was found to have the greatest effect over taste and colour on user's willingness for all potential purposes, including drinking, cooking, and teeth cleaning.

Introduction

In 2011, the Water, Sanitation and Hygiene program of the Bill and Melinda Gates Foundation initiated the 'Reinvent the Toilet Challenge', as a response to the growing need for sustainable sanitation solutions. The challenge was to develop a new toilet design that could: treat human waste and recover resources such as water, energy and nutrients; operate 'off-grid', requiring no water, sewer, or power connections; cost less than US \$0.05 per user per day; promote sustainable and financially profitable sanitation services and business in poor, urban environments; provide an aspirational product attractive to both developing and developed nations. The Nano Membrane Toilet is being developed at Cranfield University to meet the Reinvent the Toilet Challenge requirements, providing a sanitation solution that is convenient, modern, hygienic, user-friendly, and affordable. The Nano Membrane Toilet incorporates a number of modular technologies that are integrated to meet the demands of treatment and resource recovery from both the solid and liquid components of human waste. Human waste that is collected in the rotating flush mechanism is then deposited in the holding tank, where odours are contained from the user by the constant maintenance of an air-tight seal. The liquids are extracted from the separation chamber and filtered through a dense membrane bundle, inducing pervaporation, a process that does not allow even dissolved contaminants to pass through the membrane structure, only water and ammonia in a partially vaporized state. The vapor is then condensed back to liquid form in a column filled with nano-coated beads, with ammonia removed in a second column containing ion-exchange beads for ammonia adsorption. The final treated water is collected in a water reservoir on the step of the toilet, where it is available for re-use in the household (Figure 1). Solids are collected from the bottom of the holding tank and dewatered through an Archimedes screw, which enables free water to drain by gravity back into the holding tank whilst also promoting further dewatering through compression as the spacing of the screw threads decreases. The dewatered solids will then be transferred to a briquette cutter, where they will be divided and dried before introduction to a small-scale gasifier unit.



Aside from the technological aspects of developing the Nano Membrane toilet, the project is committed to a user focused design, ensuring that the technology developed is both accessible and easy for the user, and also fulfils the objective to create an aspirational product that would be attractive to potential customers. Through the initial development of the various modular technologies, initial design questions were raised around user perspectives of the toilet and its resource recovery options. For this reason, it was decided to conduct an initial household questionnaire of potential end users in order to gauge reaction to the various components of the toilets that will have direct interface with the user. Of particular interest was the attitude of potential end users to direct water reuse. The Nano Membrane toilet has the potential to treat black water to high drinking water quality, but the uptake of this water would depend on the desirability of the end user to use this water. Using lower grade membranes and reducing the Nano bead columns would provide inferior water quality but also lower the overall cost and complexity of the system. Understanding the user perspectives to this direct water reuse can have implications on the development of the water treatment components of the toilet, as well as potentially wider reaching interest as part of the global discussion on water reuse attitudes.

Methods

A 43 question questionnaire was compiled to incorporate a number of aspects of the Nano Membrane toilet design that interfaced with the user, such as the gasifier, operation and maintenance, and technology acceptance, although this paper will review the section on the use of the product water from the toilet. The questionnaire was conducted in Kumasi, Ghana, with customers of the CleanTeam, a sanitation enterprise offering a branded portable toilet for household use supported by a service agreement to collect waste 2 to 3 times a week. A sample size of 103 households was selected as representative of the 664 CleanTeam toilets distributed at the time of study design. The questionnaires were delivered by Cranfield University researchers accompanied by various CleanTeam service staff, visiting households in their respective service areas to ensure familiarity for the respondents. The CleanTeam staff also served as translators where respondents did not speak English, and as such the staff were introduced to the questionnaire questions and purpose before visit.

Of the 103 respondents, 27 were male and 76 were female. The largest age bracket recorded was 35-49 years, with 42 respondents falling in this bracket, with two respondents' ages not recorded (Figure 2).

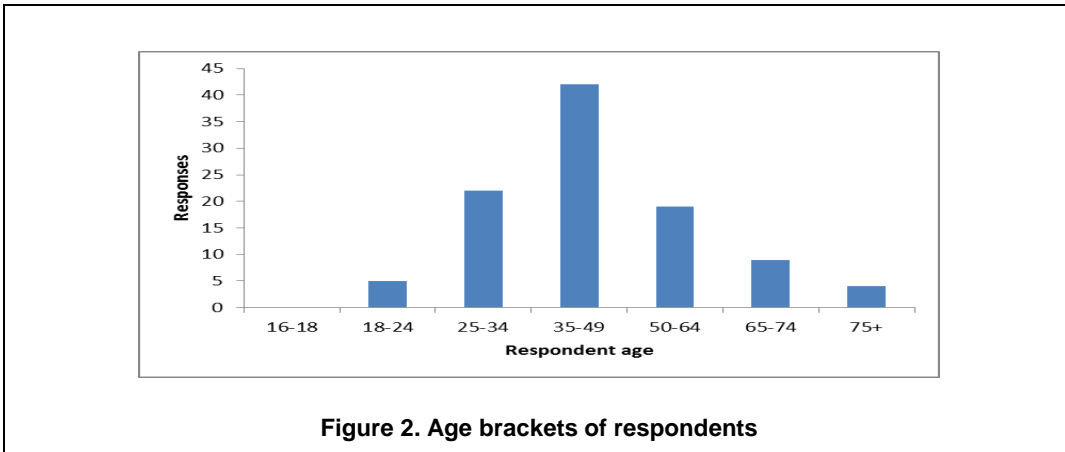


Figure 2. Age brackets of respondents

It must be noted that some bias should be attached the outputs of this questionnaire. The respondents, whilst a statistically representative sample of the CleanTeam customer base, had all chosen to join the CleanTeam enterprise and therefore pay for an improved household sanitation system, meaning they would not be a representative sample of the population of Kumasi or even the specific low income districts that were visited during surveying.

Results

Current water supply situation

The water supply, even in the low income districts of Kumasi, was found to be comprehensive and widely accepted. Piped water is common, with 82 % of respondents having piped water either directly to their house, or shared in a private courtyard with a small number of households. Of the remaining respondents without direct piped supply, none had to walk more than 5 minutes to collect water, either from a shared standpost or borehole. Water tariffs were found to vary greatly between districts, and even households, as water usage was metered in some areas: water prices paid by respondents ranged from 2 – 50 GHS (0.59 – 14.71 USD) a week, with a mean of 7.6 GHS (2.24 USD). Six respondents did not pay for their water. The water quality was perceived to be good, with 73 % of respondents stating they were satisfied with the quality (Figure 3). Of the remainder, the most commonly cited cause of dissatisfaction was turbidity at times during the rainy season.

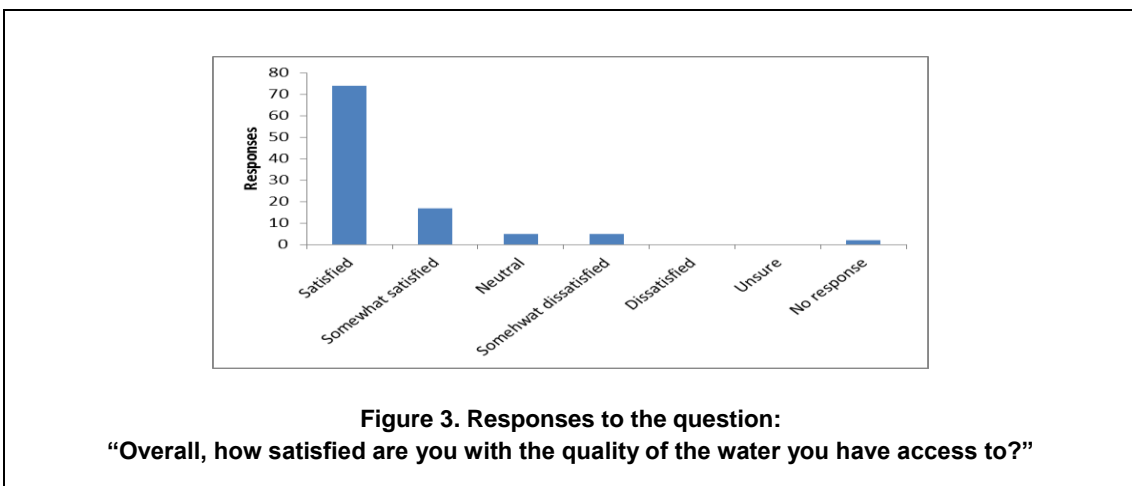


Figure 3. Responses to the question: "Overall, how satisfied are you with the quality of the water you have access to?"

Attitudes towards direct water reuse from the toilet

The concept of the Nano Membrane toilet was explained to respondents in layman’s terms, including the potential of the toilet to treat water to a high enough quality to make it safe for drinking. The majority of the respondents were willing to use the water from the toilet in some capacity, based on neutral smell, colour

and taste, with only 13 respondents stating they would not use the water at all (Figure 4). Of the respondents who would use the water, the lowest number was for irrigation – although few of the households grew produce – followed by drinking with 41 respondents.

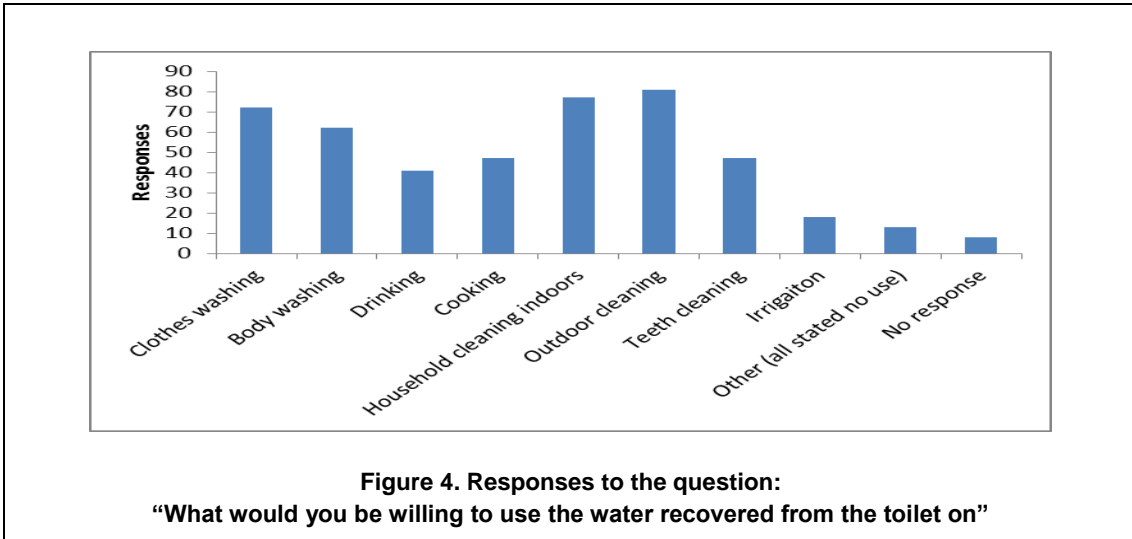


Figure 4. Responses to the question: "What would you be willing to use the water recovered from the toilet on"

However, attitudes changed significantly with aesthetic changes in the water. When asked whether a change in odour from neutral would affect respondent’s willingness to use the water, only 7 of the 41 original respondents who were willing to drink the product water stated a slight odour would have no influence on drinking the water (Figure 5), and only 2 people would drink the water happily if it had a strong odour (Figure 6). Outdoor cleaning was the option least affected by odour, with 60 of the original 81 respondents stating they were willing to use the water for this purpose saying an odour would have no effect on their willingness to use it, and 34 of those respondents saying they would still be uninfluenced by a strong odour.

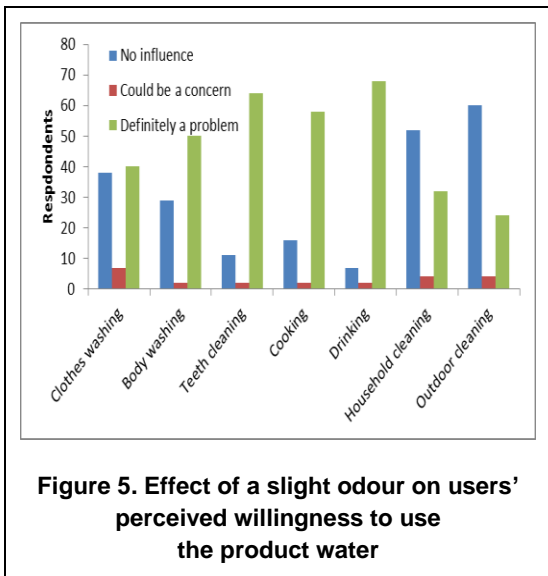


Figure 5. Effect of a slight odour on users' perceived willingness to use the product water

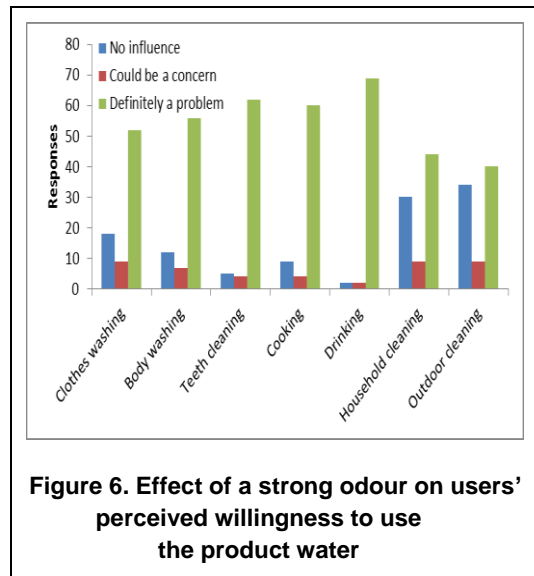
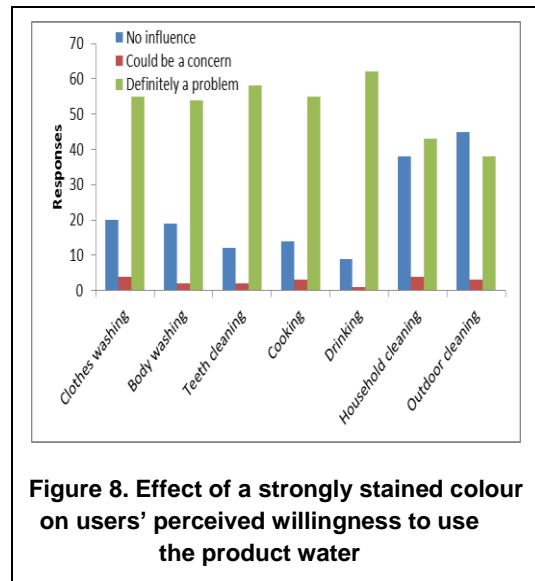
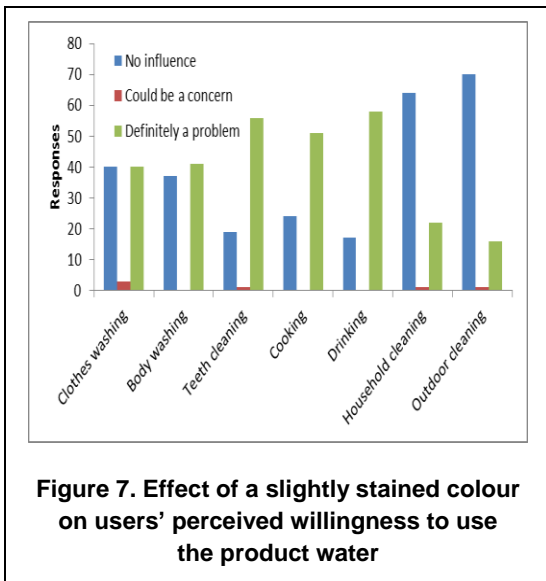
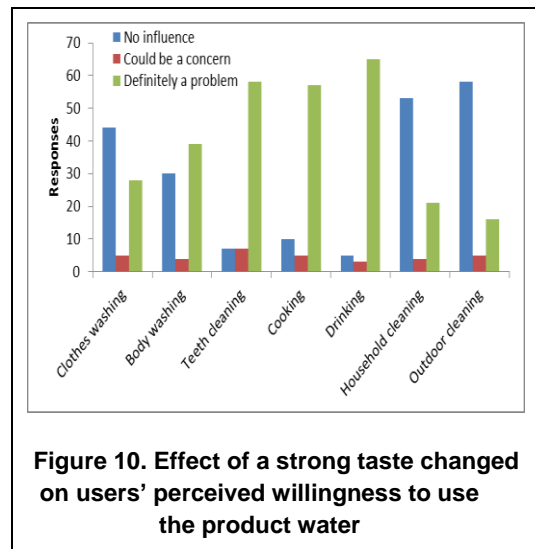
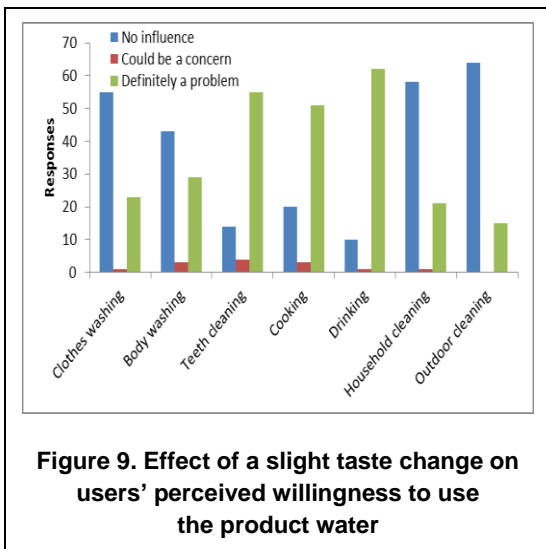


Figure 6. Effect of a strong odour on users' perceived willingness to use the product water

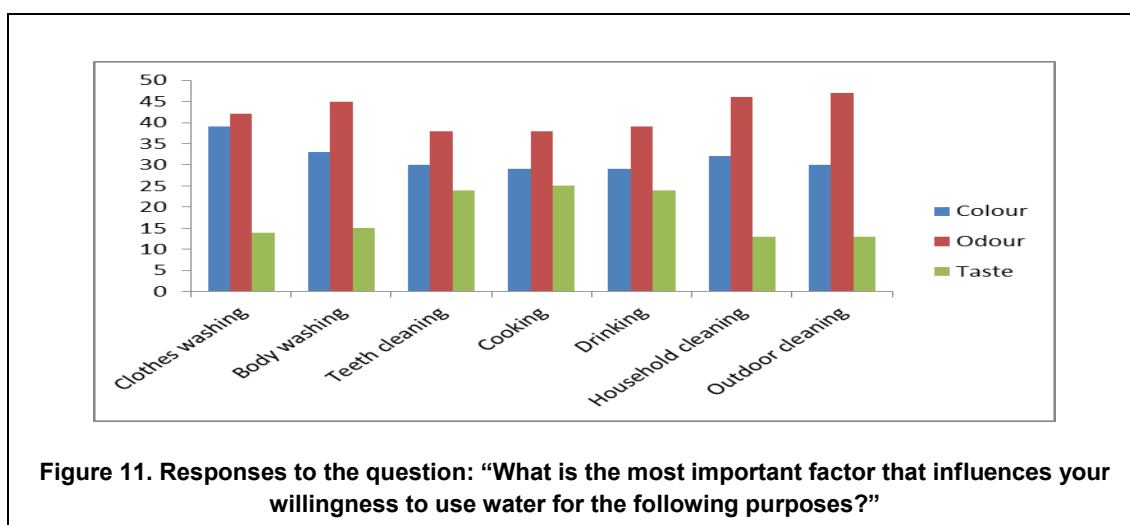
Colour appeared to be less of an issue, as 17 respondents said a slight stained colour to the water would have no influence on their willingness to drink the water (Figure 7), and 9 stated a strongly stained colour would still have no influence (Figure 8). Even with a strongly stained colour, more respondents would consider that aesthetic to have no influence in using the water for outdoor cleaning than would have a small or strong concern.



Interesting, whilst 68 respondents had stated a slight odour would ‘definitely be a problem’ for drinking water, only 62 stated that a slight change in taste would definitely be a problem (Figure 9). Taste and colour seemed to have a similar effect: for teeth cleaning, cooking, and drinking, the number of respondents that would have a definite problem with a slight colour were 56, 51, and 58 *cf.* 55, 51, and 62 for a slight change in taste. Intuitively, a strong change in taste did not have much of a difference on users’ willingness to use the water for cleaning purposes, with no increase in the number of respondents stating a strong taste to be a problem for household cleaning compared to the number stating a slight taste to be a problem, and only one additional respondent stating a strong taste would ‘definitely be a problem’ compared to the number giving the same response for a slight taste (Figure 10).



Respondents were also asked separately what the most important aspect of water aesthetics (odour, colour, taste) was to them in relation to their willingness to use water for the purposes stated above. For all water uses, odour was stated as the most important factor, followed by colour and then by taste. This was true even for drinking, where 39 respondents stated odour was the most important factor, followed by 29 stating colour and 24 stating taste. The most pronounced different was in outdoor cleaning, where 47 respondents stated odour as the most important factor, followed by 30 and 13 for colour and taste, respectively.



Discussion

The results of the potential end user survey yielded some important insights for the design development. From the respondents questioned, there was a general acceptance of the concept of direct water reuse, with the majority of the respondents willing to use the water for a range of household purposes, including drinking. This willingness quickly declined with any deterioration of the aesthetics. This strong decline may be due to the high quality and convenient availability of the piped water supply through Kumasi, and therefore these responses must be considered within that context. Additional surveys in locations where the water supply is not as close, or the standard is not as high, would likely yield different results. For application to Kumasi, however, the inclusion of treatment technologies within the Nano Membrane toilet to treat water to such a high standard would appear unnecessary – whilst users would be ‘willing’ to use the water from the toilet for many purposes, they would mostly use it for outdoor cleaning (Figure 4), for which purpose the quality of water, in terms of aesthetics, is not as important to their willingness to continue to use it.

The most important aesthetic factor with regards to water usage was found to be odour, regardless of the purpose the water was to be used for. This is most pronounced for the household and outdoor cleaning purposes, which were cited as the most likely use for the water. As ammonia can emit a distinct odour, the importance of the ion exchange nano-beads in ammonia removal must be recognised for end users to have a positive interface with the product water. In areas where irrigation is more commonplace, however, this may not be the case, as the value of the ammonia as a fertiliser may be more important than the odour.

Conclusions

From a survey of potential end users of the Nano Membrane toilet in Kumasi, odour was found to be the most important factor affecting their willingness to use treated water produced by the toilet. Whilst there was general high acceptance to use the water for a wide range of household purposes, outdoor and household cleaning were found to be the most likely uses. Potential changes in the aesthetics of the water were found to have an effect on user willingness, most notably a slight or strong odour.

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