SHORT COMMUNICATION

Safe drinking water and clean air: An experimental study evaluating the concept of combining household water treatment and indoor air improvement using the Water Disinfection Stove (WADIS)

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Abstract

Indoor air pollution and unsafe water remain two of the most important environmental risk factors for the global burden of infectious diseases. Improved stoves and household water treatment (HWT) methods represent two of the most effective interventions to fight respiratory and diarrhoeal illnesses at household level. Since new improved stoves are highly accepted and HWT methods have their drawbacks regarding sustained use, combining the two interventions in one technical solution could result in notable positive convenience and health benefits.

A WAter DIIsinfection Stove (WADIS) based on a Lorena-stove design with a simple flow-through boiling water-treatment system was developed and tested by a pilot experimental study in rural Bolivia. The results of a post-implementation evaluation of two WADIS and 27 Lorena-stoves indicate high social acceptance rather due to convenience gains of the stove than to perceived health improvements. The high efficacy of the WADIS-water treatment system, with a reduction of microbiological contamination load in the treated water from 87600 thermod tolerant coliform colony forming units per 100 mL (CFU/100 mL) to zero is indicative.

The WADIS concept unifies two interventions addressing two important global burdens of disease. WADIS’ simple design, relying on locally available materials and low manufacturing costs (approx. 6 US) indicates potential for spontaneous diffusion and scaling up.

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Introduction

Indoor air-pollution and unsafe water are considered to be amongst the most important global risk factors for lower respiratory infections and diarrhoeal illnesses (Prüss-Üstün et al., 2008). Burning coal and biomass fuels for use in unvented stoves is the domestic energy source for almost 3 billion people, and the resulting smoke contributes significantly to the global illness and disease burden, accounting for about 1.5 million of the 59 million deaths annually, mainly among children under 5 years of age and women (WHO, 2005; Ezzati and Kammen, 2002; Bruce et al., 2000; Smith et al., 2000). Unsafe water, inadequate sanitation and hygiene are among the three top health risk factors in developing countries.
Combining the two interventions at the household level – household water treatment (HWT) and vented stoves to improve indoor air quality (IAQ) – offers the potential to make considerable contributions toward the achievement of Millennium Development Goals1 (Gordon and Rehfuess, 2007). Implementations of improved stoves proved to be highly effective in removing smoke by means of chimneys, while evidence for improvement of health is inconclusive (Smith et al., 2004).

The two systematic reviews of Fewtrell et al. (2005) and Clasen et al. (2007) found that in controlled field trials HWT methods reduce the diarrhoeal burden by 20–35%. Despite these promising findings, only one study provides information on the sustainability of health improvements through HWT intervention after the immediate intervention period (Conroy et al., 1999), and behaviour-based methods may be difficult to sustain in non-trial conditions (Luby et al., 2008).

Simple, affordable HWT options such as disinfection with household bleach (sodium hypochlorite), ceramic filtration and solar disinfection have their advantages and disadvantages, and may be appropriate in different settings, but all depend on the effort and willingness of users to integrate the new technology into their daily life. Motivating such a behaviour change, which often adds work to the daily routine, can be complex when users do not perceive obvious health benefits that accrue from disinfecting water (Mäusezahl et al., 2008). Given such inherent barriers for adoption of HWT methods that are based on behaviour change, there is room for innovative water treatment technologies that do not create additional burdens for users. Tangible and immediate benefits will motivate their use.

The WADIS Device

The WADIS device is based on the Lorena adobe-stove design originally developed as a simple-to-build vented cooking stove for use in Central America by a group of volunteers in Guatemala (www.aprovecho.org). Lorena-design based stoves, which are widely used in Central and South America have shown to significantly reduce air particle concentrations and are highly adaptable to local needs and available materials (Household Energy and Health Project, 2006: Masera et al., 2005). The fully enclosed Lorena-based stove consists of rammed earth construction, features one combustion chamber with three pot holes and chimney ventilation (see Fig. 1).

For the WADIS a Lorena-stove was fitted with a locally available galvanised iron water conduit pipe of 2 cm internal diameter and 3 m length. It was coiled in three helix structures with different diameters of 25–18 cm around the three pot holes of the Lorena-stove. The coiled conduit pipe was directly exposed to the hottest zones in the combustion chambers creating a flow-through boiling water-treatment system (Fig. 1). A 20-litre plastic bucket served as a raw water reservoir. A commercially available hosepipe was used for connecting the raw water bucket to the flow-through boiling water-treatment system. The outlet of the conduit pipe of the water treatment system was equipped with a commercially available water tap that allows regulating the water flow-through speed. Manufacturing and material (conduit pipe, horse pipe, water tap, and plastic bucket) costs for the WADIS stove were approx. 6 US dollars.

1Millennium Development Goals: 1 (eradicate poverty), 4 (reduce child mortality), 5 (improve maternal health) and 7 (environmental sustainability).
Ascertaining socio-cultural acceptability

To assess the socio-cultural acceptability of the WADIS-stove two households from a rural community closest situated to the field base were asked to volunteer for testing the stove in their homes. The two households were selected because they were typical households of the rural population that are subsistence farmers, with low income and 4 years of formal education. Both had children >5 years, and relied on unsafe drinking water sources. The owners of the two experimental WADIS-stoves provided detailed information on their experience and impact on their daily lives using the new WADIS technology.

Fig. 1. Schematic diagrams of the Water Disinfection Stove (WADIS).
To enhance the view of the two WADIS, the perception of further 27 Lorena-stove owners were assessed as the Lorena-stove is the closest proxy for the WADIS. The Lorena-stoves were implemented 6 months previous to this study in two communities in the Totora district, by a local NGO development programme. Information on the Lorena-stove, its usage and handling, cooking performance, fuel consumption, reduction of indoor smoke, and perceived effect on health compared to previous cooking stoves in use, was obtained from 27 interviews. The structured questionnaire with non-leading questions was applied by trained, local field staff from the randomised controlled SODIS trial (Mäusezahl et al., 2008).

**Ascertaining efficacy**

To assess the efficacy of the WADIS to improve drinking water quality, one of the two WADIS implemented in two households in a community in the Totora district was used. The efficacy assessment was done by comparing microbiologically contaminated water samples before and after treatment by the WADIS. In total four tests were done from an initial water sample of 20 litres from a nearby microbiologically contaminated community drinking water source. The degree of faecal contamination of the 20-litre sample was analysed (sample A). The contaminated water was led to flow from an elevated plastic bucket through the cold conduit pipe in the WADIS in order to assess baseline disinfecting effects other than heat (sample B). The two subsequent tests (samples C and D) were done with altering flow-through rates (1 and 2 litres per minute) after the WADIS was heated as usual for cooking. Tests were conducted after waiting additional 30 min to allow WADIS to reach operating temperature. All water samples (B, C and D) were collected after passing the conduit pipe in 1-litre sterile sampling containers and microbiologically analysed at the national referral laboratory (Centro de Aguas y Saneamiento Ambiental (CASA)). Efficacy of the boiling flow-through water-treatment system to inactivate pathogens was assessed by measuring the number of colony forming units/100 mL (CFU/100 mL) for thermotolerant coliforms and the most probable number/100 mL (MPN/100 mL) for total coliforms and *E. coli* in the 1-litre water sample before and after treatment. The 1-litre samples were processed in the laboratory using standard membrane filtration techniques (Franson and Clesceri, 1998) for thermotolerant coliforms, and Colilert®-18 dehydrated media (IDEEX, Westbrook Maine, USA) for the identification of total coliforms and *E. coli* bacteria.

The potential efficacy of the WADIS to reduce indoor smoke was assessed qualitatively by interviewing the 27 owners of the improved Lorena-stoves (used as a surrogate vented stove for WADIS) to determine whether they perceived a notable indoor smoke reduction since the installation of the improved stove.

**Results**

**Socio-cultural acceptability**

Detailed information provided by the two WADIS owners revealed that in addition to valuing the indoor smoke reduction, they especially valued the provision of hot/warm water in a larger quantity than before and specifically for having this commodity available for many hours during the day. The provision of running, hot water in the home lead to previously unanticipated benefits including: preparing baths for small children, laundry with warm water, and connecting sprinklers for showers (Box 1). The WADIS owners did not comment on limitations or concerns regarding the new stove.

Of the 27 households owning the Lorena-stove (used as a surrogate stove for WADIS) 26 reported to be satisfied with the general cooking performance of the stove. Among the 27 Lorena-stove owners 23 (85.3%) reported that the new stove produced less indoor smoke, and 19 (73%) stated that reduced smoke was the most important reason why they were satisfied with the new stove. Comparing the frequencies of illnesses before and after installment of an improved stove, 60.9% of the Lorena-users perceived reductions in cough, 30.4% reported reductions in eye irritation, and 21.7% reported suffering less of headaches. Seven (26.9%)

**Box 1.** Selected statements from Beneficiaries indicating the potential of the new WADIS:

- “Now I have masses of warm water for the laundry, which is great!” (23 year old woman, Totora)
- “My daughter wants to have her face washed every morning before going to school because the warm water makes her beautiful, she says.” (31 year old woman, Totora)
- “I have connected a shower to the tap from the stove and everyone in the family wants to take a shower with warm water.” (32 year old man, Totora)
- “Since I can use this hot water it is much easier to clean the dishes because the fat is now better soluble” (31 year old woman, Totora).
Discussion

Efficacy tests

The WADIS-stove improved drinking water quality of two tested 1-litre water samples (samples C and D) from an initial contamination load of thermotolerant coliforms of 87,600–0 CFU/100 mL (Table 1). The complete elimination of thermotolerant coliforms in the contaminated drinking water by the flow-through boiling water-treatment system of the WADIS was confirmed in our tests of total coliforms and E. coli concentrations. Both indicators for faecal contamination were reduced to zero. Doubling of flow-through speed from 1 to 2 litres per minute did not influence efficacy of any measurement.

Table 1. Results of water analysis of faecally contaminated drinking water before and after treatment by the WADIS-stove.

<table>
<thead>
<tr>
<th>Water sample</th>
<th>Flow-through rate (L/min)</th>
<th>Thermotolerant coliforms (CFU/100 mL)</th>
<th>Total coliforms (MPN/100 mL)</th>
<th>E. coli (MPN/100 mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>–</td>
<td>87600</td>
<td>&gt;2419.2</td>
<td>221.1</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>84300</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

A = initial contaminated water sample; B = control water sample after flow-through cold stove; C and D = water samples after treatment by flow through hot stove with different flow through rates; CFU = Colony Forming Units; MPN = Most Probable Number.

users reported that the new stove required less fuel compared to their prior stove; the remaining users reported no change in their fuel use. Besides cooking the Lorena-stove is also used to boil water (25/27 or 92.6%). Provision of hot/warm water for personal hygiene (68%), washing the dishes (6%) and provision of safe drinking water (48%) were the main reasons mentioned for wanting to boil water.

Efficacy tests

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Discussion

This study provides preliminary results from testing a simple combined smoke-free cooking and water purification device (WADIS) based on the Lorena-stove. The microbiological analyses of water before and after treatment by the WADIS revealed that the simple technical supplement of the stove – a coiled iron pipe in the burning chamber – was highly efficacious in disinfecting faecally contaminated drinking water. Detailed information provided by the two WADIS owners confirmed that the main purpose of the combined interventions, namely the reduction of smoke and the provision of large quantities of hot/warm safe water were perceived as the main benefits of the technology. When prompted, owners of Lorena stoves, which were used as a surrogate-vented stove for the WADIS declared that illness symptoms related to indoor air pollution such as eye irritations, cough and headache decreased notably after using the new stoves. WADIS owners strongly valued the large quantity of hot/warm water generated by the stove and immediately incorporated their warm water use to previously unthought-of domains of household and personal hygiene such as dish washing, laundry, showering or baby bathing. Our findings from a small number of efficacy tests and interviews suggest that the users in rural Bolivia perceive immediate benefits from the combined stove/water treatment WADIS system and have little trouble integrating its use into their daily routine. These findings indicate potentially large benefits from combining improved stoves with a household water treatment concept represented by the WADIS.

For a household solution to have a positive public health impact an intervention needs to be scalable, i.e. easy to implement and people should desire it. The WADIS stove brings the basic prerequisites for being scalable and desirable by providing desired hot/warm water in large quantity for various household chores and by reducing spurious indoor smoke. The simple design, which relies on locally available materials and enables owners to maintain the stoves themselves, is additionally conducive for the scalability and self-driven diffusion of the technology. Manufacturing costs for a simple Lorena-based WADIS stove are approx. 6 US dollars. The production and sale of WADIS accessories, such as taps, showers and safe storage containers which are also widely available and affordable, can offer income-generating opportunities for local entrepreneurs. Recent progress in the social marketing of sodium hypochlorite for household-based water disinfection (Banerjee et al., 2007) and the commercial production and sale of various types of improved stoves (e.g. the ‘Rocket stove’ in Uganda (Habermehl, 2007), the ceramic Jiko in Kenya/Sudan (Ezzati et al., 2000)) provide some evidence of the demand for similar products even at full cost recovery.

The main limitations of this study are that only two experimental WADIS stoves could be built with the funds available and the low number of samples tested for assessing the efficacy. The short duration of follow up and the low number of WADIS built did not allow...
observing health effects on indoor air quality and water and hygiene related infectious diseases. The perceived benefits reported by the users of newly installed Lorena-stoves must be interpreted with care due to the lack of a comparison group (e.g. with a traditional stove). This applies particularly to the perceived smoke reduction since this was one of the main selling points of the Lorena-stove. In addition it should be mentioned that the views on WADIS of the two households testing the stove, might not be generalizable to the overall local population because they had established a close relationship with the study team.

In order to warrant the scalability and sustainability of the WADIS concept, it needs to be further developed and extensively evaluated in terms of choice of material for water heating coils, long-term durability and maintenance, functionality, safety and instruction for use. Mandatory for further tests is the development of preventive measures; for example against superheating and powerful discharge of hot vapour during the flow-through process in the water treatment system of the WADIS, which could potentially lead to injuries in adults and children standing close to the outlet of the WADIS conduit pipe. This issue could easily be addressed by simply preventing starting water flow into the empty coil of a pre-heated stove and using child and pressure-proof taps.

To reach the MDG and considering the moderate success of existing HWT methods especially when focusing on the provision of long-term solutions and sustainability in reducing the global burden of diarrhoeal disease an exigency for innovative, locally developed concepts continues to exist. The conceptual idea of integrating a simple flow-through boiling water treatment system in existing, effective and desirable improved stoves that reduce indoor air pollution and fuel consumption is a promising strategy for reducing common environmentally mediated diseases. The WADIS concept unifies two interventions addressing two important global burdens of disease at once (respiratory infections and waterborne gastrointestinal illness) and could contribute to the endeavours to help reach the MDGs.

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References


Household Energy and Health Project, 2006. Monitoring and Evaluation of Improved Cookstove Programs for Indoor
Air Quality and Stove Performance. Indoor Air Pollution Group, School of Public Health, University of California, Berkeley, 41pp.


