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on

Appropriate Water Supply, Sanitation and Hygiene (WASH) Solutions for Informal Settlements and Marginalized Communities

Proceedings

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Development of Appropriate Safe Drinking Water Supply and Sanitation System for Slums and Squatters in Nepal Project
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With the Partnership of

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Foreword

Nepal Engineering College (***nec***) has been offering various undergraduate and graduate programs in engineering and technical management since 1994. The programs and the associated curriculum confirm to the traditional syllabuses offered at national and international universities. The practical experience of ***nec***'s graduates and the faculty members engaged in research and consultancy works hinted towards a gap in the formal academic training and the ground reality. ***nec*** noticed that too many projects have failed to achieve their stated objectives, partly due to the university syllabus that are far removed from the reality. This realization led ***nec*** to develop new syllabuses based on field reality. In 1999, ***nec*** developed a curriculum on Farmer Managed Irrigation System (FMIS) based on a series of field visits and stakeholder meetings. In 2007, ***nec*** developed a completely new curriculum on M.Sc. Interdisciplinary Water Resources Management for a regional program, which is considered to be the best curriculum in this field in the South Asia region. These successes encouraged ***nec*** to develop a new curriculum on water supply engineering specifically targeting the informal settlements located in and around urban areas.

nec feels happy to be a part of the organizing team of this Regional Conference on Development of Appropriate Water Supply, Sanitation and Hygiene (WASH) Solutions for Informal Settlements and Marginalized Communities. This regional conference is a culmination of the three-years research project on Development of Appropriate Safe Drinking Water (SDW) Supply System for Slum Dwellers and Squatters in Nepal funded by the Development Partners for High Education (DelPHE), through the British Council, Kathmandu, Department for International Development, United Kingdom. The ***nec*** as the lead research institution for the project had the privilege of jointly working with its partner institutions, the Imperial College London (ICL) and Preston University, Pakistan. Together these three institutions identified four suitable research sites in Nepal, conducted a series of stakeholders' meeting, leadership trainings, WASH trainings and national conferences in the last three years. As stated by the local stakeholders, these activities enabled the local residents to express their feelings and needs openly and clearly. The undergraduate and graduate students from ***nec*** and ICL actively participated in the execution of the program, from stakeholders' training and design of appropriate solutions to pilot scale implementation (toilet constructions, rainwater harvesting, and water treatment plant) at the research sites. The experience for each of these activities and the inputs from the stakeholders, including the inhabitants of the selected communities, were incorporated in the selection and design of the appropriate solution to the problem of access to drinking water and sanitation at each location. The reaction of the local residents towards the implementation of the project is very promising and indicates towards the success of the project. Based on the outcome of this project, ***nec*** proposed a curriculum to this conference. The proposed curriculum will be finalized after intensive discussion among the experts. We are fully convinced that the right implementation of the final curriculums will result in production of technical human resources better capable to understand, appreciate and deal with the real issues of WASH in rural and informal settlements.

The overwhelming response to the Call for Papers for this conference challenged the editorial committee of this conference to select the best of the best. ***nec*** appreciates the interest shown by the academicians, researchers, and professionals involved in WASH in informal settlements. Finally, 19 papers from outside Nepal and 6 papers from Nepal were selected for presentation in the conference. The lessons learned from various studies and project implementations have been complied in the conference proceedings. The resolutions of the conference will be presented to the concerned line agencies, academic institutions, research organizations and the NGOs involved in WASH sectors. We hope that the institutions will consider these resolutions seriously and adopt them to suit their situations. ***nec*** will form a cell to follow up on the impact of the outcome of the project, and will inform the stakeholders in timely basis, so that the results of the project do not go in vain.

nec, the Imperial College London and the Preston University would like to thank all those who contributed directly and/or indirectly in the successful conclusion of the project and the success of the regional conference.

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May 19, 2010

AN INVESTIGATIONAL RESEARCH ON THE SYNERGY OF WATER PASTEURIZATION AND IMPROVED COOK STOVE FOR PROVIDING SAFE DRINKING WATER AND IMPROVED INDOOR AIR

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ABSTRACT

In Nepal, indoor smoke is responsible for 7,500 deaths per year, and drinking unsafe water is attributed for the mortality of 13,000 children. The prevalence of these two major causes of morbidity and mortality in many poor rural regions has created a need for both indoor smoke and water quality intervention. One of the popular smoke reducing technology in Nepal is the mud two-pot-hole Improved Cook Stove (ICS) promoted by Alternative Energy Promotion Centre/Energy Sector Assistance Programme. Likewise, various household drinking water treatment options are currently available in Nepal. The Chulli System, used in Bangladesh, reported the use of pasteurization to purify water using the heat in the combustion chamber of a traditional cooking stove. In this context, Environment and Public Health Organization designed a model for Water Pasteurization through Improved Cook Stove (WAPIC) to research on how effectively the heat content of smoke in the stove can inactivate thermo-tolerant coliform bacteria. A locally available hollow aluminum pipe (internal diameter 8 mm, length 3.7 m) was coiled into a spiral ovular helix of 10±1 cm in diameter. The coiled unit is placed inside the chimney of ICS. Thirty test units (n=30) of WAPIC were field installed in three geographical regions viz. inner terai, mid-hill and high-hill of Nepal. Two round of monitoring of the installed system resulted no E. coli in the treated water from initial raw count in the range of 2 to >1000cfu/100ml. Total water output from the two different models from the field units was *found in the range of 3.5 litres to 5.6 litres/per day and 10.2 -15.0 litres per day. Moreover, Indoor $PM_{2.5}$ measurement before and after the installation of WAPIC in 15 out of 30 households showed 67.5 % (P=0.001) reduction in the mean concentration of $PM_{2.5}$. Users' survey (n=25) showed positive responses about the efficacy of the system as a possible integrated technology. Consequently, WAPIC units can significantly reduce indicator water microbes as well improve indoor air pollution.*

Keywords: *Pasteurization, Coliform, Indoor air pollution, Improved cook stove*

1. INTRODUCTION

Unsafe water and indoor air pollution are two major environmental risk factors in the developing countries (Corvalán and Üstün, 2006). Globally, 1.6 million people die due to exposure to indoor smoke and 1.8 million people, mostly children, die from waterborne diarrheal disease annually (ITDG, 2004; Smith et al.,2004; WHO 2007a, 2007b). In Nepal, indoor smoke is responsible for 7,500 deaths per year, and drinking unsafe water is attributed to the mortality of 13,000 children (DWSS and UNICEF, 2006; WHO, 2007; UNICEF, 2005).

Solid biomass fuels such as wood, dung and agriculture residue are used by more than 85% of the Nepali population for daily cooking and heating activities (CBS, 2007). Use of these dirty fuels results in elevated levels of smoke, containing harmful suspended particulate matter and carbon monoxide (ENPHO, 2008; NHRC 2005; ITDG, 2002). One of the popular smoke alleviating technologies in Nepal is the two pothole Mud Improved Cook Stoves (ICS), promoted by the Alternative Energy Promotion Center's (AEPC) Energy Sector Assistance Programme (ESAP).

Similarly, various household water treatment systems (HWTs) are currently available in Nepal to treat unsafe water. Environment and Public Health Organization (ENPHO) has been a leading NGO in developing and promoting various HWTs technologies such as Solar Disinfection (SODIS); Solvaten; Boiling; Chlorination; and filtration options, including colloidal silver and sand filters.

The co-prevalence of these two major causes of morbidity and mortality in many poor rural regions of Nepal has created a need for both indoor smoke and water quality interventions. Because indoor smoke and water quality problems often occur together in rural settings, there is a need to develop an integrated technology that eliminates both risk factors at the same time.

ENPHO has initiated research in combining water pasteurization and two pothole mud improved cook stoves for water purification and reduction of indoor air pollution respectively. The Chulli System, used in Bangladesh, reported the use of pasteurization to purify water using the heat in the combustion chamber of a traditional cooking stove (Islam and Johnston, 2006). By retaining water at 70^{o} C for 45 seconds, the system completely inactivated thermo-tolerant coliform bacteria in water. Pasteurization is a popular bacterial inactivation process in the dairy, food and beverage industries.

Solar cookers promoted by Robert Metcalf in Kenya and Tanzania provide another example of the practical use of pasteurization to eliminate water borne pathogens. Metcalf's published data revealed that heating contaminated water to 65^0C result in pasteurization of the water and make it safe to drink (Metcalf and Ciochetti, 1983). Other research has also shown the effectiveness of heating water in the range of 55-65^0C, result in a 9 log reduction of many pathogenic protozoa (Giardia, Cryptosporidium, and Entameoba), bacteria (Enterococcus, Escherichia *coli*, Vibrio *cholera*, and Salmonella) and Rotavirus (Anthony et al., 2006; Charles et al., 1997; Jorgensen 1998; Metacalf, 1995). A critical design consideration for any water pasteurization unit is to ensure that the system achieves sufficiently high temperatures and retention times (UNICEF, 2008).

In Bolivia, a method similar to the Chulli System was combined with an improved cook stove. Dubbed the WADIS, or water disinfection stove, this stove was pilot tested for water purification at sub-boiling temperatures (Christen et al., 2009), using excess heat generated in the combustion chamber of the stove to heat and purify water.

The WAPIC system proposed in this paper differs from the WADIS and Chulli systems. The latter systems use the heat of the combustion chamber to purify water, while WAPIC uses waste heat in the chimney section of the ICS. When wood is burned as fuel in the ICS, much of the heat generated is lost in the form of smoke. This smoke is eventually vented through the chimney section of the ICS. WAPIC is designed to utilize this waste heat for the inactivation of thermo-tolerant coliforms.

2. MATERIALS AND METHODS

To create the WAPIC system, a locally available hollow aluminum pipe (internal diameter 8 mm, length 3.7 m), was coiled into a spiral ovular helix of 10±1 cm in diameter. The coiled unit is placed inside the chimney of ICS. The chimney has a cylindrical opening of 10 cm in diameter for the passage of smoke. In the WAPIC, the coil is positioned along the wall of the opening. The top end of the coil is connected to a 20 L plastic container of raw water; the other end of the coil releases pasteurized water (Figure 1: WAPIC Model).

2.1. How Does WAPIC Work?

When fuel is burnt in an ICS, heat from the fire directly heats Pothole 1. Additional heat – mainly from smoke – travels from Pothole 1 to Pothole 2 and escapes through the chimney (Figure 1). The pasteurizing coil is placed inside the chimney in order to utilize this excess heat from the smoke. In order for water to achieve adequate pasteurization, the flow rate of water through the coil must be controlled.

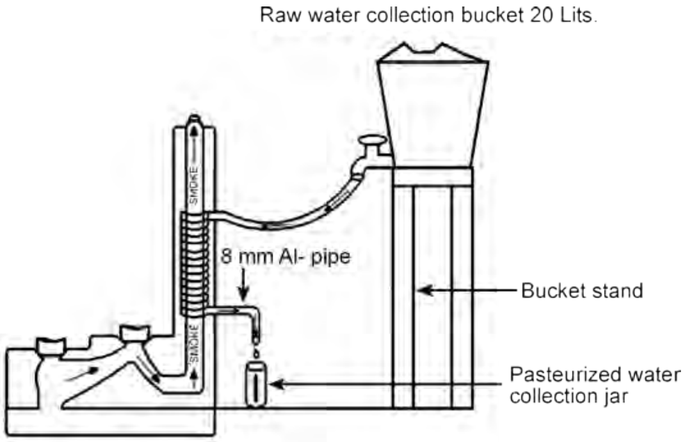

Figure 1: WAPIC model

2.2. Stages of Development of WAPIC and Parameters Tested

Evaluating the efficacy of WAPIC required two exploratory phases. The initial phase included the development of the WAPIC system in the laboratory setting (referred to as the bench model). The second phase involved refining the bench model for testing in a field setting.

2.2.1. Laboratory testing

The bench model was constructed at the ENPHO laboratory. The objective of the bench model was to determine the relationship between temperature and flow rate. We conducted repeated fuel combustion in the WAPIC to determine flow rate and temperature of the treated water from the system (data not shown). Trials gave a conservative estimate of the required flow rate at which treated water would achieve $>70^0$C at least. After ascertaining the flow for water pasteurization, microbial analyses were conducted to evaluate E. *coli* count.

2.2.2. Field testing

Thirty test WAPIC units were tested in the field. The parameters evaluated in the field units include the following: microbial removal efficiency (E.*coli),* physical parameters (temperature of treated water and flow rate in the field units, temperature profile of treated water in 20% of the households), indoor air pollution measurements, and social acceptance questionnaires. In all the 30 households, microbial, physical and social monitoring was conducted twice, once after 20-30days the installation of WAPIC and again after four to six weeks of household level WAPIC use.

Indoor air monitoring: Indoor air pollution measurements were taken to estimate the change in indoor $PM_{2.5}$ (particulate matter with an aerodynamic diameter less than 2.5 micrometer). Changes in the concentrations during the use of traditional cooking stove (TCS) and after the installation ICS with WAPIC system was carried out. This test used a portable UCB particle monitor for real-time $PM_{2.5}$ measurement recommended by Centre for Entrepreneurship, Health and Development, University of California, Berkeley (www.ehs.sph.berkeley.edu). $PM_{2.5}$ was sampled for 24 hours per test household. Out of the 30 selected households, 15 households were monitored twice, once during the TCS use and once 6 weeks after installation and use of ICS with WAPIC.

2.2.3. Social reaction/acceptance

The monitoring also involved questionnaire that included questions about mechanical problems, general impressions of the WAPIC system, and the user's interest in system for long term use. A total of 30 users were surveyed.

2.3. Field Installation and Site intervened

Two pothole mud ICS are distributed by the Energy Sector Assistance Program (ESAP), collaboration between the Nepali government and Alternative Energy Promotion Center (AEPC). Stoves are distributed across the three primary geographical regions of Nepal, the inner Terai , the mid-hill regions , and the high-hill regions.

In each region, AEPC/ESAP has a Regional Renewable Energy Service Centre (RRESC) through which stoves are promoted. Before WAPIC installations began, stove-makers in each region received orientation and training about the technology and its usage. Households were selected from the following regions / districts:

Inner Terai Region: Dang (ele. 600 m) was chosen for the study. A total of 10 household units were installed in Dang, at Rampur, Laxmipur Village Development Committee area.

Mid-Hill Region: Kakani, in Nuwakot district (ele. 1800 m) and Gundu in Bhaktapur district (ele. 1400 m) were chosen as the mid-hill region. Five units were installed at each of these locations.

High-Hill Region: Rakey, Ilam (ele.2100 m) was chosen as the high hill region. Ten units were installed.

Comparative data on the incidence of diarrheal disease and acute respiratory infection (ARI) in children age five and under in these districts shows the highest reported incidences in Bhaktapur (166 diarrhea, 311 ARI per 1000), followed by Nuwakot, Ilam and Dang (DOHS, 2006).

A total of 30 WAPIC units were installed in the field, which included 24 two-coil units and 6 one coil units. Two of the five units installed at both Gundu and Kakani are one-coil units. Three of the ten units installed in Dang were one-coil systems. All of the units installed in Ilam were two-coil systems.

3. RESULTS

3.1. Bench Model Results

Flow Rates: From the bench model, it was determined that a flow rate of 31.6 ml/min (stdev. ±3ml/min) was necessary to achieve adequate pasteurization of water. At this flow rate, the retention time of the water in the coil was 70 seconds. Considering the average household size of five to six people and three to four hours of stove use per day, the estimated amount of water output was expected to be insufficient.

Because of this, the bench model was modified. The only change in the system was the addition of a second coil, in essence doubling the length of the coil and increasing the retention time in the tube. After the addition of the second coil, treated water was adequately pasteurized at 70.0 ml/min (stdev.± 3 ml/min) with a retention time of 150 seconds in the system. The one coil system was still considered for field testing in households with less than five members.

Microbiological Monitoring: Raw water E. *coli* count ranging from 864 to 7000 cfu/100ml were tested in the one coil system (n=4) bench model. The pasteurization achieved 99.8 to 100% removal in the one coil system. E. *coli* removal in the treated water from two coil system was 100% with raw count ranging from 1000 to 7000 cfu/100ml (n=4).

3.2. Field Results

3.2.1. Round 1 result of microbial and physical parameters

Microbiological Monitoring: The results of the first round of microbial monitoring showed that the 25 WAPIC units installed in Dang, Ilam, and Kakani achieved 100% removal of E. *coli* (Table 1). Five units installed in Gundu achieved only between 61 and 93% removal.

Table 1: Result of microbial monitoring

Place	Raw E. *coli (*cfu/100)	Treated E. *coli* (cfu/100)
Kakani	80 to > 1000	0
Gundu	21-204	7-15
Dang	3-344	0
Ilam	2-98	0

Count of E. *coli* as high as >1000 cfu/100 ml were detected in the raw water of Kakani. Usage of the WAPIC system reduced these counts to 0 cfu/100ml. Regardless of whether the system contained one coil or two coils, the removal efficiency was determined to be 100% for E. *coli*.

Flow Rates: Flow rates of the two coil system were found in the range of 54.0 to 69.3 ml/min (Table 2). Flow rates of the one coil system were found in the range between 29.0 to 31.4 ml/min. Cooking times varied with different study sites. Higher stove use in Ilam and Dang were noted. Consequently, water output at these study sites was higher than other study sites (14.4 L, 15.0 L; Dang and Ilam).

Table 2: Result of physical monitoring

Place	Coil system	Flow rate (ml/min)(stdev)	Cooking hr/per day	Water out put (lts) per day(stdev)
Gundu	One coil (n=2)	29.0(±1.00)	2.0	3.5 (±0.1)
	Two coil(n=3)	54.0(±5.2)	2.7	8.7 (±1.7)
Kakani	One coil (n=2)	29.0(±0.7)	3.0	5.6(±0.3)
	Two coil(n=3)	54.0 (± 0.9)	3.2	10.2(±0.6)
Dang	One coil (n=3)	31.4 (±1.6)	2.5	4.7 (±0.7)
	Two coil (n=7)	63.4(±2.6)	3.8	14.4(±3.9)
Ilam	Two coil	69.3(±9.4)	3.6	15.0(±5.4)

3.2.2. Round 2 results of microbial and physical parameters

Microbiological Monitoring: The five units evaluated during the second field-monitoring phase at Kakani still functioned appropriately. The temperature of treated water surpassed 70^0C within 5-10 minutes of cooking. Initial E. *coli* counts as high as 321 to 1224 cfu/100ml in untreated water was reduced to 0 cfu/100ml.

Table 3: Result of microbial monitoring in second round

Place	No of Units (n)	Raw *E. coli (*cfu/100)	Treated *E.coli* (cfu/100)
Kakani	5	321 to > 1000	0
Gundu	3	10 to 34	2-5
Dang	10	12->1000	0
Ilam	10	NA	NA

The ten units evaluated during second-phase monitoring in Dang showed similar efficiencies in reducing pathogen load. The raw water count of E. *coli* was between 12->1000cfu/100ml. In the three households in Gundu, we noted inadequate temperatures for pasteurization, resulting in poor water purification.

Flow Rate: Physical monitoring during the second round of tests indicated that the flow rate did not vary between monitoring phases. Some users (n=3) reported problems with the flow of raw water into the system. This is primarily caused by high turbidity of the raw water and lack of cleaning of the raw water bucket.

3.2.3. Overall results of indoor air monitoring

Sixty seven percent (67.5%) reduction in $PM_{2.5}$ concentrations was estimated after installation of WAPIC stoves (Figure 2). Mean concentrations across all the monitored households were reduced from 1.91 (*stdev±0.9*) to 0.61(*stdev±0.3*) mg/m^3.

3.2.4. Survey results

56% of respondents reported using spring water as their main drinking water source and 34% thought their raw water was contaminated. 80% of respondents knew about the importance of treating household water and 73% use some form of HWT. Diarrhea cases in the past year were reported in 48% of surveyed households. Average cooking time reported was 3.50 hr/day (*min: 1.5 hrs, max: 7hrs*). While WAPIC was fairly new to users, 89% of respondents noted they were comfortable using the system.

Forty Eight percent (48%) of the users categorized WAPIC as a water purification technology. 36% of the users perceived WAPIC to be an integrated technology that cleans water, improves health and consumes less firewood. 18 respondents agreed this system represents a positive approach toward solving two major problems – indoor air pollution and water quality in the rural households.

WAPIC users noted that the system curbs the separate boiling of water for drinking because smoke heat is used for water pasteurization during cooking. This consequently reduces fuel wood consumption and smoke emission into the indoor environment.

4. DISCUSSION

In Nepal, water-induced diarrheal deaths and respiratory infection among children are the major health risks. The combination of water and air purification technologies in WAPIC has the potential to help many rural households. The testing showed that no E. *coli* survived in properly treated pasteurized water and indoor smoke was reduced by 65.5% after the installation of WAPIC. Users viewed the system and its dual benefits positively and had faced only minor problem operating it.

Treated water at Gundu did not achieve pasteurization temperature. We attribute this to usage of a different type of fuel. The prominent biomass available and used in Gundu for cooking is agricultural residues, mainly straw and small shrubs. Wood logs, twigs, and dung used as fuel in all other study sites emit relatively more heat for a longer duration. The temperature of treated water in the WAPIC systems in Gundu was measured in the range of 50-55^{0}C compared to >70^{0}C in the treated water in Kakani, Dang and Ilam. We believe that the WAPIC system may not be ideal in its current form for communities who rely on agricultural residues as a fuel source.

WAPIC field installations reveal that many hurdles still must be overcome in order to make this system user friendly and sustainable. The main problem is maintaining a standard stove design across districts. One installation in Ilam showed that the baffle slope and baffle gap were not appropriately built. Consequently, the natural draft of smoke from the first pothole to the second pothole and into chimney was reduced. Reduction of smoke draft, which is the source of heat for the coil, can result in unsuccessful pasteurization.

Users operation and maintenance of stove is another critical factor that can influence the efficacy of water pasteurization. Cooking habits and chimney cleaning intervals are also critical factors in achieving the complete benefit of WAPIC. Standard ICS installations [without WAPIC] require specific operation and maintenance behaviors required to prevent chimney blockage and promote complete combustion. Chimney promoters teach these behaviors to households. With WAPIC, proper operation and maintenance of the stove becomes more important. For example, lack of regular chimney cleaning could mask the coil with soot from the smoke, which reduces the transfer of heat from smoke to the coil.

5. CONCLUSION AND RECOMMENDATIONS

Further study of the WAPIC should focus on the following main objectives:

Evaluating potential upgrades to the system: Further research is needed to ensure consistent flow rates throughout cooking periods, determine the effect of turbid water on the system, determine the long term durability of the pasteurizing coil, and to ensure pasteurization of water during the whole cooking period. One of the learning from the research work, inverting the flow of the water through the coil also produces relatively consistence flow, which is to be tested in the field.

Behavioral gaps: The effective and appropriate use of the system depends upon changes in household behavior. Issues like handling of the system, firing and cooking habits, stove and chimney cleaning habits, perception about importance of safe water and clean indoor air are key areas of intervention. A more detailed social acceptance survey, coupled with time-activity data, would begin to explore these issues.

Exploring new areas of pasteurization within ICS: Based on models utilized in Bangladesh and Bolivia, it may be worth moving the pasteurizing coil to the combustion chamber. However, the large volume of heat in the chamber may require the pasteurizing coil to be made of a different material. It may also alter the efficiency of the entire stove system. Further evaluations are necessary to determine the ideal placement of the pasteurizing coil.

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REFERENCES

Anthony T S., Dunstan, R. H. Harrison, T., Coombes P. and Kuczera. G.,(2006). *Thermal Inactivation of Water-borne Pathogenic and Indicator Bacteria at Sub-boiling Temperatures,* 6, Callaghan : Water Research, Vol. 40.

Centre Bureau of Statistics, (2007). *Statistical Year Book 2007,* Kathmandu, Government of Nepal.

Charles P. C., Jame E. N., and Jeanetle T., (1997). *Evaluation of Microbial Removal/Inactivation by the Innowave 240 r,* Department of Soil, Water and Environmental Science, University of Arizona.

Christen, A., Navarro, C.M., Mausezahl. D., (2009). *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*), Bolivia, International Journal of Hygiene and Environmental Health, Vol. 212.

Corvalán, C. and Prüss-Üstün, (2006). *Preventing Disease Through Healthy Environment, Towards an Estimate of the Environmental Burden of Disease, Geneva,*WHO,92 4 159382 2.

Department of Health Services, (2006). *Annual Report 2005/06. Kathmandu*. Ministry of Health, Government of Nepal.

Department of Water Supply and Sewerage Nepal and UNICEF, (2006). *Guidelines on School Led Total Sanitation, Kathmandu,* Department of Water Supply and Sewerage and UNICEF, Nepal.

Environment and Public Health Organization (2008)., Nepal *Assessment of Effectiveness of Improved Cook Stove in Reducing Indoor Air and Improving Health,* Kathmandu.

Islam M. F. and Johnston, R. B.,(2006). *Household Pasteurization of Drinking-water : the Chulli Water-treatment System. 3, Dhaka* : Journal of Health, Population and Nutrition, Vol. 24. 1606-0997.

ITDG, (2004). *Smoke- The Killer in the Kitchen: Indoor Air Pollution in Developing Countries*, ITDG Press.

ITDG,(2002). *Smoke, Health and Household Energy*, ITDG Press.

Jorgensen, F.J.A. Nohr, K. Sorenson, Boisen F.,(1988). *Contamination of Drinking Water By Direct Solar Heating In Solar Panels*, Journal of Applied Microbiology, 1998, Vol. 85.

Metcalf, R. and Ciochetti, H.,(1983). *Pasteurization of Naturally Contaminated Water with Solar Energy*, 2, Sacromento, Applied And Environmental Microbiology, Vol. 47. 0099-2240/84/020223.

Nepal Health Research Council(2004). *Situation Analysis of Indoor Air Pollution and Development of Guidelines for Indoor Air Quality Assessment,* Kathmandu, Nepal.

Robert M., (1995). *The Micro-biology of Solar Water Pasteurization with Applications in East Africa,* Sacromento : California State University (Unpublished).

Smith K.R. S., Sumi M, Feuz. M.,(2004). *Indoor Smoke from Solid Fuels: Assessing the Environmental Burden of Disease in Developing Countries*, Geneva :World Health Organization Press, 2004.

United Nation for Chidren Education Fund, (2008). *Handbook on Water Quality,* NewYork : UNICEF Press.

United Nation for Chidren Education Fund, (2005). *Drinking Water Quality*. UNICEF Press.

World Health Organization, (2007). *Indoor Air Pollution: National Burden of Disease Estimates,* Geneva : World Health Organization Press.

World Health Organization, (2007). *Combating Waterborne Disease at the Household Level*, International Network to Promote Household Water Treatment and Safe Storage. Geneva : WHO, ISBN:978 92 4 159522 3.