Use of ash and mud for handwashing in low income communities
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Summary

Infectious and parasitic disease continues to exact a huge toll on the health and well-being of the global population. The WHO 2008 report assesses that, worldwide, infectious and parasitic diseases account for 9.5 million deaths a year (16.2% of all deaths). Epidemiological and microbiological data show that, in low income communities, as elsewhere, handwashing is particularly important in reducing the burden of infectious and parasitic diseases. The hands are the last line of defence against exposure to pathogens which can occur either directly from the hand to the mouth, eye, nose, or other area of the skin, or indirectly by “handling” of food or water.

Although there is relatively little systematic data available, these data suggest that the efficacy of the handwashing process itself has a significant impact on the risk of disease transmission. A key factor is the extent to which pathogens are detached from the skin surface, by rubbing with appropriate materials prior to rinsing. In low income communities in developing countries, soil, mud or ash are still frequently used as an alternative to soap. Some studies suggest that soil and ash are effective in reducing contamination on hands, but may be less effective than handwashing with soap. More data are needed to evaluate and optimise this key factor. Risks associated with entrapment of contaminated soil under the fingernails, which may not be removed by handwashing also require further consideration.

In the context of developing countries, it is important to weigh the potential benefits of using mud, soil or ash as an alternative to soap, against the fact that these materials can become contaminated with pathogens and helminths, and can themselves act as a vehicle and source of gastrointestinal, parasitic and other infections. This review brings together a substantial body of microbiological data which indicates the biological plausibility of infection transmission arising from residues of contaminated soil, mud or ash on the hands. The data show that infectious and parasitic agents are extensively found in soil and have the ability to persist for considerable periods of time. It also shows their potential to infect either via the oral route as a result of direct hand-to-mouth transmission during normal daily activities, or as a result of handling food, or via the skin, particularly where the skin has cuts or abrasions. Where ash is allowed to accumulate either in, or in the vicinity of the home, it has the potential to become contaminated from human or animal faeces or from wastewater. The amount of soil or ash in contact with the hands or under the fingernails during handwashing with ash or soil may be small, but in many cases these organisms have a very low infectious dose, particularly for people whose immunity is impaired as a result of underlying disease, age, malnutrition etc.

Although there is microbiological evidence indicating the potential for infection transmission by the use of contaminated soil, mud or ash for handwashing, there is little or no epidemiological evidence to suggest whether or to what extent this represents a risk. On the basis that intervention studies consistently show that, in communities that practice handwashing with soap the infection rate decreases, by the same logic, it can be argued that where contaminated soil, mud or ash is regularly applied to the skin for handwashing, this must in some measure increase the risk of infection, particularly where the material remains trapped under the fingernails.

Mud, soil or ash used for handwashing can also contain potential toxic heavy metals such as arsenic, lead and chromium, as well as pesticides. Although this could represent a toxic hazard when applied to the hands for handwashing, there are no epidemiological or risk assessment data to the magnitude of the risk, but again this is
likely to be small relative to other routes of exposure (i.e. due to drinking contaminated water). In the constantly changing social, economic and environmental situations in these countries, the situation needs to be kept under review.

In recent years there has been significant investment in the promotion of handwashing in low income communities, aimed at reducing the burden of diarrhoeal and parasitic diseases. In view of this, if the potential risks and benefits of mud, soil or ash versus soap were the only consideration, then perpetuating the use of soil, mud or ash is questionable, despite the fact that the toxicological and microbiological risks associated with use of these materials may be small. One of the key constraints is the affordability of soap. In extreme settings where people are poor, and at highest risk for morbidity and mortality from infectious disease, the greater need is for families to spend what little income they have on food. For these communities, the use of clean and dried soil and ash for handwashing is preferable to using water only, because it is more effective.

The situation in developing countries today, calls for wider use, rather than universal use, of soap. The need is to focus on programmes aimed at making low-cost soap and adequate safe water freely available to the increasing number of communities which can afford it. Within these communities there is a need to change the mindset, so that attitudes to using soap for handwashing, and thus behaviour, is dictated by their desire to enjoy the health benefits rather than being conditioned by age old knowledge, religious beliefs, social customs etc. We need to invest in hygiene promotion programmes, which focus on getting these communities to change their behaviour and adopt handwashing with soap as an accepted practice to maintain good health. In particular, we need to encourage the use of soap rather than mud, soil or ash before preparing food and before eating.

In public health, it is generally accepted that handwashing with soap should be preferred over mud, soil or ash, which in turn is preferable to using water only. All of these options are preferred over no handwashing at all. In developing handwashing promotion programmes, it is important to take account of local economic, cultural and political conditions. We need to develop programmes which reach all socioeconomic groups in developing countries, including those in extreme poverty, and communicate in a manner which achieves hand hygiene behaviour change which is most appropriate to their particular socio-economic situation.
1. INTRODUCTION

It is well accepted that one of the most effective things that people can do for themselves in their everyday lives to reduce the risks of contracting an infectious or parasitic disease is to practice good hand hygiene. The hands are particularly important since they are the last line of defence in the chain of transmission of gastrointestinal (GI) pathogens, either directly from hand-to-mouth, or indirectly by “handling” of food or water. Although respiratory tract (RT) infections such as colds and influenza are transmitted via contaminated aerosol particles of mucous, the hands can also play a part; where hands become contaminated with respiratory viruses, infection can be transferred by rubbing the conjunctiva of the eyes, or the nasal mucosa. The hands can also play a part in the transmission of skin, wound, eye and other infections.

Overall, the microbiological data, together with intervention study data provide consistent evidence of a strong causal link between hygiene and the spread of infection in the home and community, and suggests that the hands are one of the most important routes for the spread of infection. Data assessing the strength of the association between hand hygiene and prevention of diarrhoeal, respiratory and skin infections comes from a range of sources including epidemiological data (surveillance data, data from intervention studies, case control studies, etc) and microbiological/biological plausibility data (data showing how and to what extent infectious agents are introduced into the home, how and to what extent they survive and spread such that family members are exposed to an infectious dose). These data are reviewed in Appendix 1.

If the data from intervention studies are an accurate reflection of the true picture, it suggests that, for up to 60% of GI illnesses, the hands are the “sufficient”, or a “component” (i.e. hands together with hand, food contact or other environmental surfaces) cause of the spread of infection. For RT infections, intervention study data suggest that transmission via the hands could be a sufficient or component cause of up to 50% of illnesses. Although up to a 50-60% reduction in GI and RT infectious disease risk was observed in some intervention studies, in other studies the reduction was much less. This variability could be due to methodological issues, but could also be due to other factors.

The differences could, for example, be due to differences in the range of pathogens (with differing modes of spread) prevalent in different study communities, such that hand hygiene has greater impact in some groups than others. Alternatively, it could reflect differing levels of hand hygiene compliance between different intervention groups. Groups which receive “good” information are more likely to use an effective handwashing technique, and more likely to apply it at critical times. The efficacy of a handwashing process in removing pathogens from the hands depends on a number of factors including the use of soap or other material to facilitate detachment of microbes, parasites, organic soiling etc from the skin surface, the extent of the friction applied to the hands (the handrubbing technique), the amount and quality of water used to rinse the hands, and hand drying. Relatively little systematic data has been generated on the efficacy of handwashing processes, or the health benefits of promoting good handwashing techniques. However, although there are no intervention study data available, estimates using Quantitative Microbial Risk Assessment (QMRA) (see Appendix 2) indicate how even a relatively modest increase in the reduction of microbes on hands through, for example, improved handwashing techniques could produce a significant increase in the health impact of a hand hygiene promotion campaign.
One of the key factors which determine the efficacy of handwashing is the extent to which pathogens are detached from the skin surface, by rubbing the hands with appropriate materials prior to rinsing. Although relatively limited data is available, these data suggest that use of soap significantly increases the reduction of microbes on hands relative to that achieved by washing with water alone. In low income communities, in developing countries such as India, Bangladesh and sub-Saharan Africa, soil and mud are often used as zero cost alternatives to soap for handwashing. However, there are some concerns that the use of these materials may be associated with certain health risks, which may arise from contamination of these materials with microbial pathogens or other parasites. In addition, ash may contain materials which carry a toxicity risk.

The objective of this review is to bring together the available scientific data on the benefits, and the microbiological and chemical risks of using mud, soil and ash, as against soap, as against water only, for handwashing in low income communities, and to evaluate the factors which inform choice of the most appropriate agent in relation to the needs and constraints in different communities.

2. THE USE OF SOIL, MUD AND ASH FOR HANDWASHING

In low income communities, soil, mud or ash may be used as a zero cost alternative to soap for handwashing. In rural India and Bangladesh soap is often considered a beautifying agent or for the physical feeling of cleanliness which it gives, rather than being associated with the removal of microorganisms or health benefits.\cite{1,2,3} In city slums, ash is not easily available where gas or kerosene is used for cooking. It is also often considered less pleasant on the hands compared to soap or soil.\cite{2}

People in many Asian and African countries like India, Bangladesh, Pakistan, sub-Saharan countries etc, are accustomed to defecating in the open by the side of rivers, pond, lakes, also the railway tracks, highways, etc. Generally, they carry a pitcher of water for anal cleansing and post-defecation handwashing. In most cases they collect soil or mud from the ground nearby and rub their hands with the same prior to washing with water. In rural homes, where cow dung cakes, wood, dried leaves, along with coal is used for domestic cooking, the residual ash is collected from the bottom of the oven and stored in a corner of the house courtyard. The ash is often used by the rural community for cleaning teeth and also for post-defecation hand rubbing and handwashing. However, with more people taking to kerosene-based ovens, the use of ash is on the decline. Similarly, with the increase in the number of household toilets (both in India and Bangladesh the proportion of rural homes having household toilets is more than 60%) the number of people practising open defecation is reducing and the habit of rubbing of hands with soil and mud should also be declining.

According to Hoque et al,\cite{2,3} in rural Bangladesh, after anal cleansing following defecation rural people rub their left hand on the ground and rinse it with water, or scoop up a handful of soil which is used to rub the hands, which are then rinsed with water. A substantial proportion of women wash the left hand only. Hoque et al\cite{3} discuss how handwashing practices across Asia are strongly shaped by culturally learned patterns. Long-standing religious and secular patterns influence people’s ideas and behaviours regarding cleanliness, handwashing and other hygiene actions. Cleanliness has a central place in Islamic religious beliefs and practices, as well as in the religions in other Asian countries. Muslims, Buddhists and Hindus share strong traditional concepts concerning the separation of left and right hands, the left hand being used for anal cleansing and the right for eating. Many individuals however do
rub both hands together as prescribed by religious teachings, showing how hygiene
behaviours are shaped both by religious and secular ideas.

In rural Bangladesh (and in some regions of the sub-continent), mud or ash are only
used for hand cleansing after defecation. In all other situations such as before eating
or before preparing food, these materials are not used, but often, in this situation the
hands are washed with water only.4

In 1995 Hoque et al reported a study of women in randomly selected households in
rural Bangladesh evaluating different handwashing processes.3,5,6 Of 90 women
observed washing their hands after defecation, 38% used mud, 2% used ash, 19%
used soap, and 41% used water only without a rubbing agent. With the steady
economic growth that has occurred in Bangladesh, the proportion of households
using mud or ash to wash their hands has reduced from the time this study was
conducted.4 The Sanitation, Hygiene Education and Water Supply in Bangladesh
Programme (SHEWA-B) is a large scale intensive hygiene/sanitation and water
quality improvement program.4 The initial stage of this project involved structured
observations on handwashing practices during July-August 2007. Results identified
that hand washing with water alone before food preparation and eating was quite
common (47-76%), but washing both hands with soap or ash was observed <2% of
the time. Washing both hands with soap or ash was more common after defecation
(17-18%), after cleaning a child’s anus (22-24%) or after handling cow dung (12-
20%). Availability of handwashing materials such as soap, ash or mud at the site of
handwashing was low, with approximately 3.0% and <1% of households having the
specified material. Water availability was high. Hand drying was observed to take
place before preparing food, after defecation, after eating and before serving food. A
high proportion of females did not dry their hands after hand washing. Use of
hygienic toilet facilities was low (27% in intervention communities). The most
common method of disposal was throwing faeces in the jungle or bush (35%); only
9% of the time was faeces disposed in a toilet or specified pit.

2.1 THE CHEMICAL CONTENT OF ASH/MUD/SOIL

Natural constituents of soil and mud which are generally used for hand rubbing after
defecation with or without water include fine or coarse sand, sandy clay, loam,
humus and other decomposed organic materials. The moisture content of the soil or
mud that is used varies widely. If they are collected from the vicinity of pond, river or
canals etc, they are likely to be quite moist. However, dry soil consisting of fine sand,
clay, loam and humus are also used. Temperature in tropical countries varies
between 15-40°C. As discussed in section 5, moisture content and temperature are
important factors which determine the survival of microbial pathogens and helminths
in soil.

As mentioned earlier, ash is the resultant product of the burning of coal, wood fibre,
dry leaves, fodder, cow dung cakes, waste crops and various kinds of solid waste
matters discarded from the rural households. Depending on the source material the
ash could contain toxic metallic compounds, heavy metals like lead, mercury,
arSENic, chromium etc, and also polycyclic aromatic hydro-carbons. Toxicity of
various kinds of ashes resulting from the burning of municipal solid wastes has been
reported by various authors.7,8,9,10
2.2 RISK OF MICROBIAL AND CHEMICAL CONTAMINATION BY THE USE OF ASH/MUD/SOIL

The chemical constituents of ash, depending on its source material as mentioned above, indicate the potential for chemical and toxicological risks associated with its use as a handwashing agent. While natural soil consisting of sand, clay, loam, etc, does not generally contain toxic substances, it could acquire the same through various anthropogenic activities like disposal of industrial of wastes, bio-medical wastes, etc. In recent years, pesticides and heavy metal contamination of the water and soil of ponds, lakes, rivers and canals have been reported from various developing countries. In a recent study in Kolkata, the fish cultivated in the ponds and rivers in West Bengal, India, were found to have high concentrations of mercury, much above the WHO/FAO permissible limit.\(^{11}\) It could reasonably be concluded that the mud and soil collected from such contaminated ponds or rivers would contain varying levels of such toxic substances.

In recent years naturally-occurring geogenic arsenic and fluoride has been detected in groundwater and soil in large numbers of developing countries like India, Bangladesh, Myanmar, China, Vietnam and many other countries.\(^{12,13,14,15}\) In these countries, arsenic occurs in soils at an average concentration of about 5-6 mg/l, but mean arsenic contents in soils as high as 20 ppm in Italy, 14 ppm in Mexico, 11.2 ppm in China and 11 ppm in Japan have been reported.\(^{12}\) The average concentration of arsenic in alluvial sand and mud/clay has been reported to be 2.9 mg/kg and 6.5 mg/kg, respectively, in Bangladesh.\(^{12}\) Arsenic concentrations in soil as high as 51 mg/kg in Faridpur and 83 mg/kg in Comilla have been reported from Bangladesh.\(^{12}\) According to WHO, arsenic is a documented carcinogen.\(^{16}\)

Toxic metals and pesticides in contaminated soil applied to the hands can be ingested or absorbed either via the oral route as a result of direct hand-to-mouth transmission from soil, or a result of handling food, or via the skin, particularly where there are cuts or abrasions. Although the data indicate the presence of potentially toxic materials in soil, mud or ash used for handwashing, the data are insufficient to make any quantitative risk assessment. The risk to health depends both on the dose to which people are exposed and the toxicological properties (e.g. the LD\(_{50}\)) of the soil constituents. During handwashing with soil or ash, the extent of the exposure is likely to be relatively small since the hands are rinsed immediately after application and rubbing.

Although the ingestion of such substances has been/is being reduced, as the provision of improved water sources to the communities increases and the management of municipal, industrial and bio-medical waste improves, given the present eco-toxicological situations in the Asian and African countries, the use of ash/mud/soil for washing hands after defecation and particularly before food would always be associated with an element of toxicological risk and should be constantly monitored. However, exposure from groundwater used for drinking remains the most important source.

The microbiological issues and the issues related to persistence of helminths and other pathogens in soil and ash are discussed in detail in sections 4-7.

3. MICROBIOLOGICAL DATA ON EFFICACY OF ASH AND SOIL/MUD FOR HANDWASHING

The available data, although relatively limited, suggest that the efficacy of the handwashing process itself has a significant impact on the risk of disease transmission. The efficacy of handwashing depends on a number of factors including
the use of soap or other materials to facilitate detachment of microbes etc from the skin surface, the extent of the friction applied to the hands (the duration and technique of handrubbing), the amount and quality of the water used to rinse the hands, and hand drying.

In a study reported in 1991, Hoque and Briend evaluated the relative efficacy of handwashing using ash, soap, mud or plain water, in a group of 20 women living in a slum of Dhaka in Bangladesh. Each woman washed her hands using each of the washing agents and the efficacy of the process was assessed by comparing faecal coliform counts from post-washing hand samples. Results (Table 1) showed that, for 60% of women who did not wash their hands, the hands were contaminated with faecal coliforms. The proportion of positive counts was similar for ash, mud and soap, and slightly higher for water, but none of these differences were statistically significantly different from each other.

Table 1 – Hand contamination with faecal coliforms following handwashing with different agents (from Hoque and Briend)

<table>
<thead>
<tr>
<th></th>
<th>Number of contaminated hands (%)</th>
<th>P-values against control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control*</td>
<td>12 (60)</td>
<td>NS</td>
</tr>
<tr>
<td>Water</td>
<td>8 (40)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Soap</td>
<td>4 (20)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Ash</td>
<td>3 (15)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Mud</td>
<td>4 (20)</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

*women did not wash their hands.

In 1995 Hoque et al reported a further more extensive study of women in randomly selected households in rural Bangladesh evaluating different handwashing processes under controlled conditions. This study involved two phases, an observational phase and an experimental phase. In the observational phase, the women were observed and interviewed about handwashing. Bacteriological samples were also taken from the hands and the number of faecal coliform colony forming units (cfus) determined. Of 90 women observed washing their hands after defecation, 38% used mud, 2% used ash, 19% used soap, and 41% used water only without a rubbing agent. Those who used mud either rubbed their fingers and palms on the ground or scooped out a small amount of soil and rubbed it between their fingers and palms. Mud was taken from locations near the cooking area, defecation site or living quarters. Altogether, 81% of non-soap users stated that they might use soap, but were unable to afford it. A total of 44% of women washed both hands, while 56% washed only their left hands. Seventy-four per cent rinsed their hands with 0.7 litres of water or less, 48% used tube-well water and the rest used surface water. During 62% of all washing events, fingers were rubbed 3 times or more and the majority of women who used soap rubbed their fingers more than 3 times. About 78% of the women dried or wiped their hands on their clothes and the rest let them air dry. Faecal coliform counts on hands before handwashing were 8,511 and 977 cfus per hand for left and right hands, respectively. Although the counts of left hands were reduced significantly after their “usual” handwashing practice they were still high (geometric mean left hand 1,995 and right hands 1,318 faecal coliforms per hand).

In the experimental phase, the effectiveness of various components of handwashing (cleaning agent, rubbing frequencies, quality and quantity of water and drying technique) was systematically evaluated. Women were requested to wash their hands according to specific instructions. Samples were taken from the hands and the
number of faecal cfus determined. The results (Table 2) indicate that, when each of
the components of handwashing was adequately executed, they favourably
influenced the reduction of coliform counts. Under experimental conditions all the
washing agents – soil, soap and ash – showed similar results producing a greater
than 80% (of the order of 1-2 logs) reduction in coliforms on hands. In all cases, the
reduction was significantly greater than that due to “usual” handwashing in the
observational phase. Lower coliform counts were observed with increased hand
rubbing frequency and when rinsing was performed using 2 litres compared with
only 0.5 litres of water. Compared with tube-well water, use of pond water showed
significantly higher counts for right hands (geometric mean of the count of tube-well
water was 32 faecal coliforms/100 ml and that of pond water was 17,330 faecal
coliforms/100 ml). The practice of drying of hands on clothing tended to contaminate
the hands.

Faecal coliform counts in soil were significant, but varied according to location
(geometric mean counts in soil near the cooking area, soil near the latrine and wet
soil near the latrine were 3,877, 4,000 and 7,010 cfu/g of soil, respectively). Not
surprisingly, counts on hands after cleaning hands by rubbing them on the
ground were significantly higher than those after handwashing. It was found however
that the level of contamination in the soil used for handwashing did not significantly
affect the efficiency of handwashing. Hoque et al concluded that the trend towards
better results from handwashing with both hands, increased frequency of rubbing,
and an increased volume of rinsing water all support the prime importance of
scrubbing/frictional motion and consequent washing out of loosened bacteria with
water. Although the results suggest that the use of a rubbing agent is important, they
suggest that the nature of the agent is a less important factor. Hoque et al have
suggested that the key component of the handwashing process is the mechanical
rubbing of the hands and that soap is more effective than soil and ash because soap
users tend to rub their hands more and use more water to rinse away the soapy
feeling on their hands.3

Table 2 – Comparison of faecal coliform counts on hands under various
experimental conditions (from Hoque et al5)

<table>
<thead>
<tr>
<th>Experimental conditions</th>
<th>Left hand: geometric mean (P values, 95% CI)</th>
<th>Right hand: geometric mean (P values 95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Reference washing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil (near kitchen), 6 rubbings and rinsing with 2 litres of tube-well water (N = 83)</td>
<td>129 (P = 0.5; 0.33-1.74)</td>
<td>89 (P = 0.23; 0.26-1.38)</td>
</tr>
<tr>
<td>(A) Washing agent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash (n = 84)</td>
<td>98 (P = 0.25; 0.74-3.02)</td>
<td>54 (P = 0.52; 0.63-2.45)</td>
</tr>
<tr>
<td>Soap (n = 60)</td>
<td>195 (P = 0.23; 0.62-1.38)</td>
<td>112 (P = 0.52; 0.63-2.45)</td>
</tr>
<tr>
<td>(B) Testing of soil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil (near latrine) (n = 75)</td>
<td>132 (P = 0.97; 0.48-2.19)</td>
<td>110 (P = 0.57; 0.6-2.45)</td>
</tr>
<tr>
<td>Soil (wet)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Anuradha et al. carried out a similar study in 2 villages in Andhra Pradesh, India. Twenty households belonging to a high income group (HIG) and 20 households belonging to a low income group (LIG) having children 1-2 years of age were studied. Handwashing practices of mothers before feeding the child were observed. Bacteriological samples were then taken from the hands and the total number of cfus determined. Results (Table 3) suggest, as found by Hoque et al., that all the washing agents, i.e. ash and soap were more or less equally effective in reducing faecal coliform hand contamination. Although soap appeared to be more effective, the difference was not significant. Set against that, however, the sample size was small. Washing hands with plain water reduced contamination on the hands but was less effective than washing with agents, but again the result was not significant. Mothers of HIG and LIG families who used soap to wash their hands had total bacterial counts of 55±32.52 and 61.6±70.63, whereas families who used only water to wash their hands had total bacterial counts of 529±189.23 and 655±351.0 for HIG and LIG families, respectively. Total bacterial counts were even higher for mothers who did not wash their hands at all (972.25±109.07 in HIG and 1224.6±251.06 in LIG families). These differences were not significant between the two groups. Mothers of HIG families who did not wash their hands before feeding the child had lower bacterial counts than mothers of LIG families, but this difference was not significant.

### Table 3 – Bacterial contamination of hands of mothers in high income group (HIG) and low income group (LIG) families

<table>
<thead>
<tr>
<th>Agents</th>
<th>No</th>
<th>Total # bacterial counts of handwashing</th>
<th>‘t’ value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soap</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HIG</td>
<td>6 (30)</td>
<td>55±32.52</td>
<td>0.124NS</td>
</tr>
<tr>
<td>LIG</td>
<td>2 (10)</td>
<td>61.6±70.63</td>
<td></td>
</tr>
<tr>
<td><strong>Ash</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HIG</td>
<td>0 (0)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>LIG</td>
<td>8 (40)</td>
<td>219.62±87.37</td>
<td></td>
</tr>
</tbody>
</table>
Plain water

<table>
<thead>
<tr>
<th>Group</th>
<th>Sample Size</th>
<th>Total Bacterial Count (CFU per ml)</th>
<th>Log Reduction of E. coli</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIG</td>
<td>10 (50)</td>
<td>529.00±181.23</td>
<td>0.9330&lt;sup&gt;NS&lt;/sup&gt;</td>
</tr>
<tr>
<td>LIG</td>
<td>3 (15)</td>
<td>655.00±351.0</td>
<td></td>
</tr>
</tbody>
</table>

Did not wash hands

<table>
<thead>
<tr>
<th>Group</th>
<th>Sample Size</th>
<th>Total Bacterial Count (CFU per ml)</th>
<th>Log Reduction of E. coli</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIG</td>
<td>4 (20)</td>
<td>972.25±109.07</td>
<td>1.8730&lt;sup&gt;NS&lt;/sup&gt;</td>
</tr>
<tr>
<td>LIG</td>
<td>7 (35)</td>
<td>1224.0±251.06</td>
<td></td>
</tr>
</tbody>
</table>

Values in parenthesis are percentages; NA – Not applicable; NS – Not significant

# Total bacterial counts of handwashing per ml or CFU per ml

The conclusions of Hoque et al and Anuradha et al are supported by studies by Khan<sup>18</sup> and Alam et al<sup>19</sup>. Khan carried out a study in Dacca, Bangladesh, of confirmed cases of shigellosis and their families, who were followed up for 10 days. A group of 50 families were given 2-4 pieces of soap (soap only) while a second group of 50 families were given 1-3 earthenware pitchers for storing water (water only). Families were advised to wash their hands with soap and water after defecation and before meals. Rates of secondary infection in families provided with water only were significantly higher than those for the soap only group (p=<0.01). The secondary infection rate (contacts yielding the same types of isolates as the index case) was 10.1% in the study group and 32.4% in the control group. The secondary case rate (contacts with secondary infections had 3 or more episodes of diarrhoea/dysentery in 24 hours) was 2.2% in the study group and 14.2% in the control group. The study by Alam et al<sup>19</sup> examined the effect of maternal personal and domestic hygiene on the incidence of diarrhoea in children aged 6-23 months from rural areas in Bangladesh. The intervention area received augmented water supply through handpumps and health education, while the control area received no inputs. Diarrhoea incidence was recorded weekly while the mothers' personal and domestic hygiene was observed yearly. Results (Table 4) show that, in the intervention area (but not in the control area) use of mud or ash decreased yearly diarrhoea incidence in children by more than that for families who used water only for handwashing (p=<0.01).

Table 4 – Diarrhoea incidence per child-year by mothers’ handwashing practices

<table>
<thead>
<tr>
<th>Handwashing Practice</th>
<th>Intervention area</th>
<th>Control area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>Use ash/mud</td>
<td>215</td>
<td>3.0</td>
</tr>
<tr>
<td>Use water only</td>
<td>174</td>
<td>4.0</td>
</tr>
</tbody>
</table>

*P=<0.01 for use of mud/ash compared with use of water only

In a new study (Schmidt, London School of Hygiene, in press) 480 samples were collected from 20 volunteers who were asked to contaminate their hands purposely by wiping them over surfaces in public places (British Museum and Buses). Handwashing with water only reduced the total level of faecal bacteria present by 49%. Handwashing with soap and water reduced the total level of faecal bacteria by 81%. Statistical testing revealed a highly significant relationship between the handwashing method and contamination levels. The effect appeared to be similar for different faecal bacteria.

Also of relevance to this review are studies based on standard European and US panel testing methodologies for determining the efficacy of handwashing with soap under differing conditions (reviewed by Bloomfield et al).<sup>20</sup> Data suggest (in agreement with the findings of Hoque et al) that the log reduction of <i>Escherichia coli</i>
(E. coli) on hands achieved after a 15 second handwash was 0.6-1.1 log increasing to 1.8-2.8 for a 30 second handwash. Extending the washing time to 1 minute produces a reduction of 2.6-3.23 log, but increasing the process for more than 1 minute did not appear to gain any additional reduction. Other studies have shown that the amount of water,21 and proper hand drying after handwashing (although there is some disagreement about the importance of drying) are also important factors.22,23,24,25 Data on the importance of using a rubbing agent comes from some studies carried out by Sattar et al using the US standard “fingerpad” method.26 Data on the effectiveness of handwashing with soap-based formulations, compared with water alone, in the removal of bacteria and viruses27,28 suggests that, in most (but not all) cases, liquid soap-based formulations were more effective than water alone, but the authors concluded that the differences were not statistically significant. Schurmann and Eggers concluded that enteric viruses, particularly poliovirus, may be more strongly bound to the skin, and that the inclusion of an abrasive substance (aluminium hydroxide or sand) in handwash preparations is needed to achieve effective removal.29 There is also some concern that soap bars have the potential to spread contamination from person-to-person via the hands.30,31

Although the field studies as described above indicate the importance of hand rubbing using appropriate agents during handwashing, it is important to bear in mind that all of these studies evaluated only the impact of handwashing on enteric pathogens and diarrhoeal diseases. There are no data available to determine the relative effectiveness of different handwashing processes on the removal of helminths or other microbial agents such as viruses and protozoa. In addition, these studies evaluated only contamination of the hands themselves and did not consider contamination which can occur under the fingernails. The risks of infection from using soil or ash for handwashing are likely to increase where soil or ash particles become trapped under the fingernails and are not removed by rinsing the hands. A number of studies have evaluated the extent to which pathogens can persist under the fingernails. Compared to other parts of the hand, the area beneath the fingernails harbours the most microorganisms and is most difficult to clean.32 This is particularly important for infectious agents and parasites such as hookworms and leptospiroses which can infect via the skin.

A number of studies have shown the presence of ova, larvae, and cysts of intestinal parasites under the fingernails of study participants.33,34,35 In 1988, Okubaghiizi reported a study of 569 participants in Gondar, Ethiopia.33 Among 569 subjects, ova, larva and cysts were found in the fingernail dirt of 149 subjects. The most frequently isolated (Table 5) were ova of Ascaris lumbricoides (A. lumbricoides), but ova of Taeniahynchus saginatus, Strongyloides stercoralis larva and Entamoeba histolytica (E. histolytica) cysts were also found. In 2001, Sahlemariam et al35 carried out a study of foodhandlers in the cafeterias of three university and training colleges, in Jimma, Ethiopia. In this study, out of 101 fingernail contents examined, 11 (10.9%) were positive for one or more parasites which included A. lumbricoides, Taenia species, Giardia lamblia (G. lamblia) and E. histolytica. Of 101 stool specimens examined from these subjects 59 (58.4%) were positive for any one parasite and multiple isolates were found in 17.8% of positive cases. A. lumbricoides, 24 (23.8%) was found to be the most prevalent parasite followed by Trichuris trichiura (T. trichiura), 17 (16.8%), E histolytica, 10 (9.9%) hookworm, 3 (2.9%), Taenia species, 3 (2.9%) and G. lamblia, 2 (1.6%). Statistical analysis showed that there was no significant difference between the findings in the three institutions.
Table 5 – Presence of protozoa and helminths under fingernails and in stools in 569 subjects studies in Gondar, Ethiopia (from Okubhagzi)

<table>
<thead>
<tr>
<th></th>
<th>Under fingernails</th>
<th>In stool</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right hand</td>
<td>Left hand</td>
</tr>
<tr>
<td>Ascaris lumbricoides (ova)</td>
<td>45 (33.58%)</td>
<td>57 (42.54%)</td>
</tr>
<tr>
<td>Taeniarhynchus saginatus (ova)</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Strongyloides stercoralis (larva)</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Entamoeba histolytica (cysts)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>53</td>
<td>63</td>
</tr>
</tbody>
</table>

Studies by Lin et al. show how bacteria and viruses can be retained under the fingernails after handwashing. In this study, the fingernails of volunteers were artificially contaminated with ground beef containing E. coli or artificial faeces containing feline calicivirus (FCV). Volunteers then washed their hands with tap water, liquid soap, or liquid soap with a nailbrush. Results, as shown in Table 6 suggest that up to 2.5 log cfu E. coli or TCID FCV were retained under the fingernails after contact with the ground beef or faecal material (the amount of bacteria or virus particles released by scrubbing with a nail brush), but handwashing with tap water or soap released only around 1.2 log from fingernails leaving a residual of around 1.4 log trapped under the nail.

In a more recent study carried out in Ethiopia, Andarghie et al determined the prevalence of bacteria and intestinal parasites in fingernails contents among 127 food-handlers working in the cafeterias of a university and teachers training college, in Gondar. In this study none of the fingernail contents of the foodhandlers was positive for intestinal parasites, or Shigella species. This was despite the fact that these agents were detected in stool samples. Intestinal parasites detected in the stools included A. lumbricoides (18.11%), S. stercoralis (5.5%), E. histolytica/dispar (1.6%), T. trichiura (1.6%), hookworm species (0.8%) and G. lamblia (0.8%). Shigella species were isolated from stool samples of four food-handlers. The predominant species isolated from fingernails contents were coagulase-negative staphylococci (41.7%), followed by Staphylococcus aureus (16.5%), Klebsiella species (5.5%), E. coli (3.1%) and other enteric strains.

Table 6 – Reduction of E. coli (log cfu) and feline calicivirus (log TCID<sub>50</sub>) beneath fingernails by different handwashing methods (15 second handwash) (from Lin et al)

<table>
<thead>
<tr>
<th></th>
<th>Tap water</th>
<th>Soap</th>
<th>Soap plus nailbrush</th>
</tr>
</thead>
<tbody>
<tr>
<td>E. coli</td>
<td>1.18±0.14</td>
<td>1.18±0.24</td>
<td>2.54±0.54</td>
</tr>
<tr>
<td>Feline calicivirus</td>
<td>1.97±0.68</td>
<td>1.82±0.46</td>
<td>2.54±0.57</td>
</tr>
</tbody>
</table>

The data presented in this section suggest that much more systematic work is needed to determine the efficacy of hand hygiene procedures (both under controlled conditions and under practical conditions) and investigate how hand hygiene procedures could be optimised through the use of appropriate washing agents together with rubbing, rinsing and drying protocols in order to maximise the release of bacteria, viruses and parasites from the hands.
4. INFECTIOUS DISEASES ARISING FROM SOIL-BORNE PATHOGENS AND HELMINTHS

It is well accepted that soil can become contaminated with pathogens and helminths in high concentrations, and that it can act as a vehicle and source of disease. In their everyday lives, humans can be exposed to GI pathogens in soil, either directly (e.g. by hand-to-mouth) or indirectly via food, water and air. Some parasites infect by penetrating the skin including the surfaces of the hands, arms, legs feet etc. On the one hand, handwashing (and bathing) is important for the removal of these agents from the hands and other areas of the body, but where contaminated soil is used as an alternative to soap for handwashing, this has the potential to increase the risk of exposure to pathogens or parasites in the soil, particularly where soil remains trapped under the fingernails and is not removed by rinsing. Diseases associated with soil can be classified according to the origin of the etiological agent:

(1) Soil-borne diseases caused by enteric pathogens which get into the soil via human or animal excreta. Enteric pathogens transmitted by the fecal:oral route are bacteria, viruses, protozoa and helminths.

(2) Soil-associated diseases which are caused by opportunistic or emerging pathogens that belong to the normal soil microbiota (e.g. *Aspergillus fumigatus* is a very common fungus occurring in soils and can infect the lungs via inhalation of spores).

(3) Soil-based diseases caused by pathogens indigenous to soil (which include *C. tetani, B. anthracis, and C. perfringens*).

(4) Soil-related diseases, which result in intoxication from the ingestion of food contaminated with entero- or neurotoxins (e.g. *Clostridium botulinum, C. perfrigens, Bacillus cereus*).

Infections associated with soil-borne pathogens include GI infections caused by a range of bacteria, viruses and protozoa. Other infections include those caused by helminths (soil-transmitted helminths (STHs) and schistosomiasis. There are also a number of other non-enteric infections caused by other microbial species which can persist in soil. In this section we briefly review infections associated with soil-borne pathogens and their known routes of transmission.

4.1 GASTROINTESTINAL INFECTIONS

GI infections are caused by a range of organisms, including bacteria, viruses, protozoa and helminths which can be found in contaminated soil. Bacterial infections include salmonellosis (*Salmonella* sp.), cholera (*Vibrio cholerae*), dysentery (*Shigella* sp.) and infections caused by *Campylobacter jejuni, Yersinia* sp. and *E. coli* O157:H7 and many other strains.

Diarrhoeal diseases remain a principal cause of preventable morbidity and death in developing countries. One estimate suggests that residents of developing nations may experience between 5 and 20 episodes of diarrhoea per year. The 2008 WHO report on the global burden of disease reports a total of 2.16 million deaths per year calculated for data gathered in 2004. Table 7 shows that the highest levels of diarrhoeal disease occur in Africa and the eastern Mediterranean region.
Table 7 – Disease burden from diarrhoeal disease: total deaths and DALYs for 2002 and 2004 (from WHO\textsuperscript{39})

<table>
<thead>
<tr>
<th></th>
<th>Global</th>
<th>Africa</th>
<th>Americas</th>
<th>South East Asia</th>
<th>Europe</th>
<th>Eastern Mediterranean</th>
<th>W. Pacific</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of total deaths due to diarrhoeal diseases</td>
<td>2002</td>
<td>3.2%</td>
<td>6.6%</td>
<td>0.9%</td>
<td>4.1%</td>
<td>0.2%</td>
<td>6.2%</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>3.7%</td>
<td>8.9%</td>
<td>1.1%</td>
<td>4.4%</td>
<td>0.4%</td>
<td>5.9%</td>
</tr>
<tr>
<td>% of total DALYs lost due to diarrhoeal diseases</td>
<td>2002</td>
<td>4.2%</td>
<td>6.4%</td>
<td>1.6%</td>
<td>4.8%</td>
<td>0.49%</td>
<td>6.2%</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>4.8%</td>
<td>8.5%</td>
<td>1.8%</td>
<td>5.2%</td>
<td>0.9%</td>
<td>5.8%</td>
</tr>
</tbody>
</table>

According to Graham,\textsuperscript{40} over 21 million cases of \textit{S. typhi} were estimated (in 2000) worldwide, mostly in developing countries. Typhoid fever is particularly common in South and South East Asia. Campylobacter are generally regarded as one of the most common bacterial causes of gastroenteritis worldwide and one of the most frequently isolated bacteria from stools of people infected with diarrhoea in developing countries. Approximately 5-14\% of all diarrhoea worldwide is thought to be caused by Campylobacter. In both developed and developing countries, Campylobacter cause more cases of diarrhoea than Salmonella bacteria. Coker et al\textsuperscript{41} report that the major sources of Campylobacter are not only food but also environmental contamination. The global cholera report for 2005\textsuperscript{42} documents a total of 131,943 cases, including 2,272 deaths, notified from 52 countries. The total number of countries reporting cases has declined slightly, but there were a number of countries where cholera re-emerged after having been absent for several years. Globally, the actual number of cholera cases is known to be much higher.

Enteric viruses are also a significant cause of infectious disease worldwide. Hepatitis A, enteric adenoviruses, poliovirus types 1 and 2, multiple strains of echoviruses and coxsackievirus are enteric viruses associated with human wastewater, most particularly including sewage.\textsuperscript{37,43,44} Hepatitis A is found worldwide. Hepatitis A is particularly frequent in countries with poor sanitary and hygienic conditions (Africa, Asia, and Central and South America). Countries with economies in transition and some regions of industrialised countries where sanitary conditions are sub-standard are also highly affected.\textsuperscript{45}

The most commonly detected protozoa in sewage include \textit{E. histolytica}, \textit{Giardia intestinalis} and \textit{Cryptosporidium parvum}. These pathogens cause diarrhoea and the illness can result from the ingestion of just 10 cysts/oocysts or less.\textsuperscript{46} The infective stage is the fully formed oocysts of the parasite, which are passed in the faeces and transmitted to a second individual via the faecal:oral route. In developing countries virtually 100\% of children are infected by 2 years of age and, following infection, cyst excretion may persist for months.\textsuperscript{47} Asymptomatic infection is quite common. \textit{C. parvum} and \textit{C. andersoni} are known to exist among calves in India and its association with diarrhoea in children from some states of India has also been established and is a growing paediatric problem.\textsuperscript{48} Human incidence of 1.0-9.8\% was reported from Kolkata and southern India. The possibility of zoonotic transmission is of considerable significance, especially in rural areas depending on the sanitary conditions. Hygienic precautions recommended to prevent transmission include washing hands after working in the soil, using toilets and handling pets, and drinking protected water or pasteurised dairy products. Prevalence rates for giardiasis range from 2-7\% in developed countries and 20-30\% in most developing countries.\textsuperscript{49}
4.2 SOIL-TRANSMITTED HELMINTHS

Infections caused by STHs and schistosomiasis are among the most prevalent diseases in low income communities in the developing world. The four most common STHs are roundworms (A. lumbricoides), whipworms (T. trichiura), hookworms (Necatur americanus and Ancylostoma duodenale) and S. stercoralis. The incidence, prevalence and epidemiology of STHs is reviewed in detail by Hotez et al. and Brooker et al.

For all the major human STH infections, whereas most individuals harbour just a few worms in their intestines, others hosts harbour disproportionately large worm burdens. As a rule, 20% of the host population harbours approximately 80% of the worm population. The adult stages of Ascaris, trichuris and hookworm inhabit the GI tract, and produce eggs that are passed in human faeces into the environment. T. trichiura and A. lumbricoides eggs infect via the oral route. Hookworm transmission occurs by skin contact with infective third-stage larvae (L3) that have the ability to penetrate through the skin, frequently entering the body through the hands, feet, arms, or legs. A. duodenale L3 also can be ingested. Morbidity caused by STHs is mostly associated with infections of heavy intensity. It usually peaks in school age years and is then reduced by lower exposure and increased immune response.

STH infections rarely cause death. Instead, the burden of disease is related to the chronic and insidious effects on the hosts' health and nutritional status. For hookworm infections, high intensity is generally reached in adulthood, aggravating iron-deficiency anaemia in women of reproductive age. High intensity of infection is associated with the risk of severe complications, such as intestinal obstruction. Hookworms are recognised as an important cause of intestinal blood loss leading to iron deficiency and protein malnutrition. Studies in young pre-school children with low intensity of infection show that anthelmintic treatment has an effect on anaemia and mild wasting malnutrition. This suggests that, in young children, even subclinical intestinal nematode infections can cause wasting malnutrition and anaemia. Chronic STH infections resulting from Ascaris, Trichuris, and hookworm can dramatically affect physical and mental development in children (WHO 2002). Iron deficiency anaemia during pregnancy has been linked to maternal-fetal consequences, including prematurity, low birthweight, and impaired lactation (WHO 2002).

According to Hotez 2006, A. lumbricoides infects around 1.221 billion people worldwide, T. trichiuris 795 million, and hookworms 740 million (de Silvia et al.). WHO report that 130 countries/territories worldwide are endemic for STHs. The greatest numbers of STH infections occur in the Americas, China, East Asia and sub-Saharan Africa. S. stercoralis is also a common STH in some of these regions, although detailed information on the prevalence of Strongyloidiasis is lacking.

4.3 OTHER NON-ENTERIC INFECTIONS ACQUIRED THROUGH CONTACT WITH WATER AND SOIL

Although contaminated water and soil is an obvious vehicle of GI illness, there is increasing data showing that a variety of non enteric infections may be acquired through non enteric, physical contact with water. Pitlik et al. carried out a comprehensive review of infectious diseases acquired through occupational, recreational (and also therapeutic) contact. Such infections are of two types: superficial, involving damaged or previously intact mucosae and skin; and systemic, often serious infections that may occur in the setting of depressed immunity. Pitlik et
show how a broad spectrum of aquatic organisms, many commonly found in soil, including viruses, bacteria, fungi, algae, and parasites, may invade the host through such extra-intestinal routes as the conjunctivae, respiratory mucosae, skin, mucosae of the rectum or genitalia. The exact mode of bacterial penetration into a given body site may depend on a number of factors.

Leptospirosis is caused by pathogenic strains of the spirochaete leptospira. Human infection occurs through direct contact with the urine of infected animals (the causative organisms have been found in a variety of both wild and domestic animals, including rodents, insectivores, dogs, cattle, pigs and horses) or by contact with a urine-contaminated environment, such as surface water, soil and plants. Leptospires can gain entry through cuts and abrasions in the skin and through mucous membranes of the eyes, nose and mouth. Leptospirosis occurs worldwide, in both rural and urban areas and in temperate and tropical climates. The number of human cases worldwide probably ranges from 0.1 to 1 per 100 000 per year in temperate climates to 10 or more per 100 000 per year in the humid tropics although it is likely that leptospirosis is underreported in many areas of the world.

Leptospirosis may follow either ingestion of, or skin contact with, contaminated water. Pathogenic leptospires are found in a variety of surface waters, and infection has followed bathing in rivers. Ponds and streams contiguous to livestock pastures are particularly hazardous in this regard. The ecology and epidemiology of waterborne leptospirosis has been extensively reviewed by Crawford et al. In temperate regions, leptospira can survive in surface water at pH 7 for more than 3 weeks during the summer and autumn. The organisms are killed by salinity, drying, chemical pollution, or exposure to pH <6.2 or >8.0. Organisms are thought to accumulate in the soil of livestock breeding areas and are washed into bodies of water by rainfall. Other soil-borne pathogens include Rhodococcus equi, Erysipelothrix rhusiopathiae, Burkholderia pseudomallei, and Clostridium tetani (Cl. tetani).

Melioidosis is an infectious disease (symptoms include pain in the chest, bones, or joints, cough, skin infections and pneumonia) caused by Burkholderia pseudomallei, found in soil and water. It is of importance in endemic areas, particularly in Thailand and northern Australia. It exists in acute and chronic forms. According to Sheehy et al., melioidosis was a common problem among soldiers in Southeast Asia; acquisition of Burkholderia pseudomallei may have been related to exposure of wounds to contaminated marshes and rice paddies. This species is commonly isolated from soil and surface waters in endemic areas.

Skin infections caused by E. rhusiopathiae are reviewed by Reboli and Farrar. Soil and surface water become contaminated with the organism which can originate from the faeces of a variety of species including pigs, sheep, cattle, horses and dogs and rodents, fresh water and salt water fish. The organism enters through minor cuts and abrasions in the skin and causes local cellulitis. In rare cases disease extends to joint and heart involvement. E. rhusiopathiae, and infections due to this organism are worldwide in distribution and mainly affects workers of fish and poultry industry or agriculture based occupations, but has been reported in housewives and foodhandlers. The organism is not able to exist indefinitely in soil, but may live long enough to cause infection weeks or months after initial soil contamination.

In neonates, the freshly cut umbilical cord is a prime site of bacterial colonisation. In a study of mortality rates and risk factors in Loralai District Pakistan, Quddus et al found that the unhygienic practice which contributed most to the high infant mortality
rate in the area was the use of soil as a delivery surface. The authors noted that most of the houses in the study area were made of mud with the floor plastered with a layer of mud and hay. Prior to delivery a layer of soil was typically spread on the floor as a soaking agent. *Cl. tetani* is ubiquitous in the soil in areas such as Pakistan and agricultural soil is heavily contaminated with *Cl. tetani* spores. This situation increases the risk of infection via the umbilical cord which occurs either directly or indirectly via the hands of the birth attendant.71

5. PERSISTENCE OF BACTERIA, VIRUSES, PROTOZOA AND HELMINTHS IN SOIL

Soil, in developing countries becomes contaminated with pathogens from a number of sources which include untreated domestic wastewater, the use of human and animal excreta as manure and the inadequate disposal of human excreta. The risks of exposure to pathogens from infected soil depend upon their ability to survive within the soil. Survival times in soil are affected by soil moisture, pH, type of soil, temperature, sunlight and organic matter. Among the physical and chemical properties of soil, soil moisture is a major factor determining bacterial survival. Greater survival is often associated with moist soils, thus rainfall is a factor that favours survival. Reductions in bacterial and viral population densities are observed under dry soil conditions. Thus, the rates of enteric pathogen survival are lower in sandy soils with a low water-holding capacity. Soluble organics increase survival and, in the case of bacteria, may favour their regrowth when degradable organic matter is present. Lower temperatures favour bacterial and viral survival. Ultraviolet from sunlight inactivates viruses on the surface of the soil but viruses in deeper layers are not affected.72 Data on the survival of specific pathogens in soil is reviewed by Guan and Holley,73 Jenkins,74 Brooker et al51 and Feachem et al.75

Data from Guan and Holley,73 as summarised in Table 8 shows that *Salmonella* is relatively persistent in soil. Guo et al76 found that, when inoculated at 8 log_{10} cfu/g into moist soil, which was then stored at 20°C, less than 2 log reductions were observed after 45 days. These findings are consistent with the findings of Zibilske and Weaver,77 who reported the survival of *Salmonella enterica* Typhimurium in soil for 42 days at 22°C. Under natural environmental conditions, *Salmonella enterica* Typhimurium was isolated up to 14 days from agricultural soil contaminated with *Salmonella*-contaminated manure.76 The authors also cited unpublished data showing that, under controlled conditions in terrestrial ecosystems, *Salmonella enterica* Typhimurium DT 104 and DT 12 could survive up to 299 days. In the laboratory, *Y. enterocolitica* survived for 7 days in soil at 30°C.78 In an early study, *Campylobacter intestinalis* survived in non-sterilised soil for 10 days at 20-37°C.80

*E. coli* O157:H7 can survive in soil for long periods depending on the soil type. In the laboratory, the organism survived for at least 8 weeks. Under fluctuating environmental temperatures (6.5-19.6°C), the organism can be detected for up to 99 days.81 Jones82 states that *E. coli* O157 can remain viable in soil for more than 4 months. While most human *E. coli* O157 cases have been associated with the consumption of contaminated meat and dairy products, there is also evidence that human infection has occurred through the ingestion of contaminated soil, fruit and vegetables and drinking water.
### Table 8 – Survival (days) of enteric pathogens in soil (from Guan and Holley\textsuperscript{73})

<table>
<thead>
<tr>
<th>Temp</th>
<th>Escherichia coli O157:H7</th>
<th>Salmonella</th>
<th>Yersinia enterocolitica</th>
<th>Campylobacter</th>
<th>Giardia</th>
<th>Cryptosporidium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold 4-6°C</td>
<td>99</td>
<td>63</td>
<td>10*</td>
<td>20</td>
<td>49</td>
<td>56</td>
</tr>
<tr>
<td>Warm 20-30°C</td>
<td>56</td>
<td>&gt;45</td>
<td>10</td>
<td>10</td>
<td>7</td>
<td>28</td>
</tr>
</tbody>
</table>

\*predicted value based on existing values from other environments

The survival of enteric viruses in soil is reviewed by Hurst et al.\textsuperscript{83} They conclude that enteric viruses can survive in soil for prolonged periods of time, which vary according to the strain and the environmental conditions, but can be as long as 3 months or more. Olson et al.\textsuperscript{84} reported that at 25°C Giardia cysts were inactivated at 1 week in soil whereas Cryptosporidium oocysts survived and were infective for 4 weeks. Cryptosporidium oocysts were degraded more rapidly in soil containing natural microorganisms than in sterile soil. Data from Brooker et al.\textsuperscript{51} shows that the eggs of A. lumbricoides and T. trichiura can survive for 28-84 and 10-30 days, respectively in appropriate conditions, and hookworms can survive for 3-10 days. Other reports\textsuperscript{50,85} suggest that eggs can remain viable in soil for months or years. Leptospires can survive for long periods of time in a range of environmental conditions including soil and water, thus increasing the probability of infecting a susceptible host.\textsuperscript{62} This facilitates indirect transmission of disease from animals to humans. Viscosity and salt concentration are reported as critical for the survival in fresh water with survival for 110 days observed in distilled water, and up to 347 days in more viscous solutions.\textsuperscript{86}

Feachem et al.\textsuperscript{87} also present information on the survival times of excreted pathogens in soil and on crop surfaces. Their data suggests that enteroviruses can survive in soil for periods varying between 15 and 70 days. The survival time for E. histolytica in soil was 42 hours to 10 days depending on conditions. For leptospira and S. typhii survival times were quoted at 12 hours to 15 days and 2-400 days, respectively. Depending on conditions, hookworm larvae may survive in soil for up to 17 weeks, while helminth eggs may persist for several months.

### 6. Soil-borne Infectious Diseases – The Link Between Contaminated Soil, Infectious Disease and Hand Hygiene

It is well accepted that soil, contaminated with pathogenic microorganisms and parasites, can act as a vehicle and source of disease. Figure 1 illustrates a model of the routes of transmission of diarrhoeal disease agents which indicates that soil and hands are key components in the chain of transmission of these agents. The model suggests that the main sources of microbial pathogens and parasites in soil are from human and animal excreta, although municipal solid waste can also be a source of soil-borne enteric pathogens. It also shows how humans can be exposed to pathogens in soil, which can occur either directly (e.g. by hand-to-mouth) or indirectly via contaminated food and drinking water.

Microbiological contamination of soil and mud is widespread in the developing countries of Asia and Africa, due to large scale practice of open defecation. Another practice which adds to the risk is the sewage irrigation of crops and soil. Though it is expected that, with the total sanitation campaign gathering momentum in countries like India, Bangladesh, etc, the number of people practising open defecation will significantly decline, human excreta will continue to be disposed into pits in the soil and as such contamination of soil with helminths and pathogens will continue. On the
other hand, both flooding and also population growth increase the spread of pathogens and parasites around the environment.

**Figure 1** – Sources and routes of transmission of soil-borne pathogens and parasites (from Prüss-Üstün et al)\(^8\)

As shown in Figure 1, transmission of bacteria, viruses, protozoa and parasites from human and animal excreta to a new human host involves a complex system of interrelated pathways, involving sewage, groundwater etc, as well as soil and hands. According to Santamaria and Toranzos,\(^3\) although many of the diseases associated with soils have been well characterised and studied, enteric diseases and their link to soil have been understudied and possibly underestimated. In assessing the exposure risks associated with soil and hands including those which might result from using contaminated soil, mud or ash as a handwashing agent, what is not known is the extent to which transmission from soil via the hands is a component factor in disease transmission, and its importance relative to the other pathways depicted in Figure 1. Although there is substantial microbiological evidence, as presented in this review, which supports the biological plausibility of this transmission route, there is little or no epidemiological data, which specifically examines the role of soil and hands. Handwashing intervention studies as reviewed in Appendix 1 allow some assessment of the impact of handwashing *per se* relative to other interventions, but give no indication of the extent to which the intervention may have prevented transmission of soil-borne pathogens relative to contamination from other sources, for example, direct hand contact with contaminated faecal material. None of these studies addresses the infection risks from application of contaminated soil, mud or ash to the hands.

The potential for transmission of infectious and parasitic diseases via the soil and hands is indicated by reports of outbreaks of infectious and parasitic diseases, traced to contaminated groundwater sources.\(^3\)^7 According to Santamaria and Toranzos,\(^3\) one of the first cases of infection with *E. coli* O157:H7 linked to the use of animal excreta as manure was with an ovovegetarian woman who consumed almost exclusively the food produced in her garden, in which she used the manure from her own cow as a fertiliser. In 1970, an outbreak occurred as a result of the ingestion of vegetables irrigated with wastewater. Further studies indicated that *V.*
*cholerae* was present in the irrigated soils. There are also data showing that infection risks are greater in populations which have increased direct contact with soil, for example, through occupational exposure. Blum and Feachem reviewed the existing epidemiological evidence and concluded that crop fertilisation with untreated excreta causes significant infections with intestinal nematodes and bacteria in consumers and field workers. Pitlik et al reviewed outbreaks of non-enteric infections acquired through direct contact (occupational or recreational) with water.

More direct evidence comes from a study of the prevalence of cryptosporidiosis in a community in Venezuela. It was found that 34 of 67 (50.7%) cases of cryptosporidiosis clustered in two sectors with extreme poverty. Variables strongly associated with a higher risk for infection (p<0.01) were residing in these sectors versus the remainder, living in a hut or small residence versus a brick or larger house, using an area of backyard rather than a toilet or latrine for defecation, and having contact with soil contaminated with human faeces.

Data suggesting that poor hygiene plays a role in the transmission of soil-borne pathogens comes from a number of sources, although again it is not possible from these data to determine the importance of hand contamination and hand hygiene relative to other factors. Since STHs depend for transmission on environments contaminated with egg-carrying faeces, these infections are associated with poverty, lack of sanitation and clean water, poor hygiene and overpopulation. Specific occupations, household clustering, and behaviours influence the prevalence and intensity of helminth infections, particularly for hookworm, in which the highest intensities occur among adults. Engagement in agricultural pursuits, for example, is a risk factor for hookworm infection indicating the importance of skin exposure. In an epidemiological survey of STH infections in 236 schoolchildren aged 5-15 years from an urban area (group A) and an indigenous reserve (group B), in Parana, Brazil, it was found that the prevalence of STH infections was significantly higher in group B (93%) than in group A (22%) (p<0.001). Heavy infections were detected in 2.9% and 23% of the children in group A and group B, respectively (p<0.001). Housing/hygienic indicators were significantly poorer in group B. A statistically significant correlation was observed between the prevalence of STH infections with most housing/hygienic variables. To promote the control of STH infections, a non-governmental organisation in Korea was founded in 1964, and mass faecal examination followed by selective mass chemotherapy with anthelmintics was performed twice a year from 1969-1995 targeting schoolchildren nationwide. In 1971, the overall intestinal helminth egg positive rate was 84.3% which was reduced to 63.2% in 1976, 41.1% in 1981, 12.9% in 1986, 3.8% in 1992, 2.4% in 1997, and 4.3% in 2004. During this period, the national economy rapidly developed, and living standards including environment, sanitation, and agricultural technology greatly improved. It was concluded that mass chemotherapy, together with the improvement of the environment and sanitation, is important for initiating and achieving STH control in a developing community.

In addition to the routes of faecal:oral transmission shown in Figure 1, as discussed in section 4, some soil-borne pathogens such as hookworms and leptospires are known to infect via the skin surface, rather than the oral route. For these agents, it is difficult to assess the extent of any risk from hand contamination following contact with contaminated soil, including the application of contaminated soil, mud or ash to the hands during handwashing. It is mostly stated that hookworm infection occurs “often or generally through the feet” (which in poor communities are in constant contact with the soil) but WHO state that “Hookworm transmission occurs by skin contact with infective larvae that have the ability to penetrate through the skin, frequently entering the body through the hands, feet, arms, or legs.” For these agents, not only the frequency but also the duration of exposure must be an
important factor which determines the risk of infection by this route. However, where infective larvae remain trapped under the fingernails, after hand rinsing this is likely to increase the risk of infection.

**The infectious dose**

An important factor which determines the risk associated with consumption of, or exposure to, soil-borne pathogens or parasites is the infectious dose, i.e. the number of organisms or parasites required to cause an infection. The infectious dose can vary significantly according to pathogenicity of the disease agent. The available data as summarised in Table 9 indicates that many of the soil-borne pathogens and parasites have a relatively low “infectious dose”, which means that exposure to relatively small quantities of contaminated soil on the hands may be sufficient to cause infection.

**Table 9 – Infectious doses for pathogens (from Bloomfield et al,\(^98\) Jenkins\(^74\))**

<table>
<thead>
<tr>
<th>Organism</th>
<th>Infectious dose</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Salmonella</em> spp</td>
<td>Up to $10^6$, but could be as low as 10-100 cells(^99)</td>
</tr>
<tr>
<td><em>Campylobacter</em> spp</td>
<td>500 organisms can result in human illness(^100)</td>
</tr>
<tr>
<td><em>E. coli</em></td>
<td>$10^3$-$10^7$ cells</td>
</tr>
<tr>
<td><em>E. coli</em> 0157</td>
<td>Oral dose for <em>E. coli</em> 0157 may be as little as 10 cells.(^101) In one outbreak a median dose of &lt;100 organisms per hamburger was reported.(^102)</td>
</tr>
<tr>
<td><em>Shigella</em></td>
<td>10-100 cells(^74)</td>
</tr>
<tr>
<td><em>Vibrio cholera</em></td>
<td>1000 cells(^74)</td>
</tr>
<tr>
<td>Norovirus</td>
<td>10-100 units or even less(^103)</td>
</tr>
<tr>
<td>Rotavirus</td>
<td>May be as few as 10 particles.(^104) Ward et al showed that 13/14 adults became infected after consuming rotavirus ($10^3$ particles) picked up from a contaminated surface via the hands(^104)</td>
</tr>
<tr>
<td><em>Hepatitis A</em> virus</td>
<td>1-10 plaque forming units(^74)</td>
</tr>
<tr>
<td><em>Giardia Lamblia</em></td>
<td>10-100 cysts(^74)</td>
</tr>
<tr>
<td><em>Cryptosporidium</em></td>
<td>10 cysts(^74)</td>
</tr>
<tr>
<td><em>Ascaris</em></td>
<td>1-10 eggs(^74)</td>
</tr>
</tbody>
</table>

The infectious dose is determined not only by the pathogenicity of the organism, but also the immune status of the community, and can be much lower for people who are “at special risk” than for healthy individuals. People who are at increased risk from exposure to infectious disease agents and parasites are the elderly, who have generally reduced immunity to infection which is often exacerbated by other basic illnesses. It also includes the very young, and people whose immuno-competence is impaired, either as a result of chronic and degenerative illness, including those who are infected with HIV/AIDS. Globally, the number of people living with HIV/AIDS is now 40 million, the majority living in developing countries. In sub-Saharan Africa alone there are 25 million cases; 11 million children are AIDS orphans of which 90% are infected. An area of growing concern is the possibility of a link between STHs, and other diseases. This is particularly relevant where HIV/AIDS epidemics have developed in low income communities where helminthiasis is hyperendemic. A review of 109 research papers\(^105\) revealed increasing evidence that this relationship may have created an opportunity for more rapid infection by the human immunodeficiency virus (HIV), as well as quicker progression to AIDS.

Malnutrition is also an important contributor to increased population susceptibility to infection. While accurate data on the prevalence of malnutrition are difficult to obtain,
problems are accentuated in developing countries, in areas of political unrest, and among marginalised populations.\textsuperscript{106}

Although the data presented in this section shows that soil and hands are an important component in the transmission of infectious diseases in low income communities, this does not necessarily mean that using mud/soil or ash for handwashing is a significant infection risk. However, in the same way that the process of handwashing to remove pathogens from the hands is associated with a decrease in the risk of infection, regular application of contaminated soil, mud and ash to the hands must in some measure increase the risks. This is discussed in more detail in section 9.

7. INFECTION RISKS ASSOCIATED WITH ASH

Wood ash, when freshly produced through the burning of wood, must be sterile. However, where ash is allowed to accumulate either in, or in the vicinity of the home, it has the potential to become contaminated with enteric pathogens, either from human or animal faeces or from wastewater discarded around the home. There is however no data to show whether and to what extent ash, used for handwashing, may be contaminated with pathogens and may be a source of infection.

8. SOCIO-ECONOMIC CONSIDERATIONS

In developing handwashing promotion strategies, there is a whole range of social, educational, cultural, religious and economic factors, which shape people’s attitudes, beliefs and actions in relation to hygiene, which need to be taken into consideration. In recent years a number of studies have been carried out, which show that the factors which determine people’s hygiene behaviours are extremely complex.\textsuperscript{107,108,109} These factors impact not only on people’s attitudes and behaviour in relation to handwashing per se (whether and when they wash their hands), it also determines, as discussed in section 2, the way in which they wash their hands (use of left or right hand, choice of agent, rubbing technique etc).

The data presented in this review suggests that the use of contaminated soil, mud or ash as an alternative to soap for handwashing in low income communities has potential microbiological and toxicological risks. If this were the only consideration then, it would seem logical to recommend consistently the use of soap in preference to these agents, despite the fact that the toxicological and microbiological risks may be very small. One of the key constraints to this course of action is the question of the affordability of soap. In extreme circumstances where people are poor, and at highest risk for infectious disease morbidity and mortality, the need for food and clean water is the highest priority. For these communities the data presented in section 3 indicates that the promotion of clean and dried soil and ash is preferable to using no agent at all, in that it is more effective in achieving the removal of organisms from the hands.

In the current fast-changing economic situation in developing countries, making a decision as to which communities can or cannot afford soap is difficult. Whereas soap may not be affordable for communities in extreme poverty, other low income communities may have the available income to buy soap, but may choose to purchase other consumer items, or, if they do buy soap, it is reserved solely for other purposes such as beautifying the skin or washing clothes.
This means that, to be successful, handwashing promotion activities must always take account of local issues. The need is to find the way to reach both those populations which can, and those which cannot afford soap for hand washing, and communicate with them in a manner which achieves hand hygiene behaviour change which is most appropriate to their situation.

9. DISCUSSION AND CONCLUSIONS

Infectious and parasitic disease continues to exact a huge toll on the health and well-being of the global population. The IFH recently published a report showing that a significant proportion of the global communicable disease burden is caused by diarrhoeal, respiratory and skin diseases, which could be significantly reduced by adequate water and sanitation combined with good hygiene practice. The 2008 WHO report on the global burden of disease, based on data for 2004, assesses that, worldwide, infectious and parasitic diseases account for 9.5 million deaths a year (16.2% of all deaths). A 2008 report prepared for WHO by Prüss-Üstün et al estimates that improving water, sanitation and hygiene has the potential to prevent at least 9.1% of the global disease burden (in disability-adjusted life years (DALYs)), or 6.3% of all deaths. Children, particularly those in developing countries, suffer a disproportionate share (up to 20%) of this burden. Although a substantial proportion of the estimated reduction derives from malnutrition, malaria, lymphatic filariasis and other causes, Prüss-Üstün et al estimate that diarrhoeal disease, intestinal nematode infections and shistosomiasis account for up to 39%, 2% and 1%, respectively, of the reduction in DALYs attributable to inadequate water, sanitation and hygiene. They concluded that, for diarrhoea, 80% of cases worldwide are attributable to unsafe water, inadequate sanitation or insufficient hygiene and that these cases result in 1.5 million deaths each year.

Epidemiological and microbiological data show that, in low income communities, as elsewhere, handwashing is particularly important in reducing the burden of infectious and parasitic diseases, since the hands are the last line of defence against exposure to microbes and parasites. This exposure can occur either directly from the hands to the mouth, eyes, nose, or other area of the body’s skin surface, or indirectly by “handling” of food or water.

As reviewed in section 3, although there is relatively little systematic data on the handwashing process itself, the existing data suggests that the efficacy of the process (the log reduction in contamination) has a significant impact on the risk of disease transmission. One of the key factors is the extent to which pathogens are detached from the skin surface, by rubbing the hands with appropriate materials prior to rinsing. In low income communities in developing countries, soil, mud or ash are still frequently used as alternatives to soap. Very few studies have evaluated the relative effectiveness of different surfactants and other rubbing agents, or the mechanical processes involved in adsorption and detachment of bacteria, viruses and helminths from the hands. Although the data (as reviewed in section 6) is rather limited, it suggests that soil and ash are effective in reducing contamination on hands and are more effective than using water alone, but may be less effective than handwashing with soap. It has been suggested that the key component of the handwashing process is the mechanical rubbing of the hands, and that soap is more effective than soil and ash because soap users tend to rub their hands more and use more water to rinse away the soapy feeling on their hands. The entrapment of contaminated soil under the fingernails, which may not be removed by handwashing, also requires further consideration.
In the context of developing countries, as discussed in section 4, it is important that the potential benefits of using soil, mud or ash as an alternative handwashing agent are weighed against the fact that these materials can become contaminated with pathogens and helminths in high concentrations, and can act as a vehicle and source of GI, parasitic and other infections. This review brings together a substantial body of data which indicates that the application of contaminated soil, mud or ash has the potential to increase the risk of transmission of infection from soil via the hands. The microbiological evidence, as presented in this review, demonstrates the biological plausibility of this route of transmission. These data show that microbial and parasitic agents are extensively found in soil in developing countries and have the ability to persist in the soil for considerable periods of time. It also shows their potential to infect either via the oral route as a result of direct hand contact during normal daily activities, or a result of handling food, or via the skin, particularly where there are cuts or abrasions. Whereas wood ash, when freshly produced through the burning of wood, is sterile, where ash is allowed to accumulate either in, or in the vicinity of the home, it also has the potential to become contaminated with pathogens from human or animal faeces or from wastewater. Although the amount of soil or mud and ash in contact with the hands or under the fingernails during handwashing may be small, the data show that, in many cases these organisms have a very low infectious dose, particularly for individuals or populations with lowered immunity to infection.

Although there is substantial microbiological evidence indicating the potential for transmission of infection by the use of contaminated soil, mud or ash for handwashing, there is little or no epidemiological evidence to indicate the magnitude of the risk. Intervention studies show that, in communities that practice handwashing with soap in order to remove pathogens from the hands, this reduces the risks, i.e. there is significant reduction in infectious disease rates. By the same logic, it can be argued that where contaminated soil, mud or ash is regularly applied to the skin for handwashing, this must in some measure increase the risk of exposure to infection, particularly where the material remains trapped under the fingernails and is not removed by rinsing. It is likely that the extent of the risk is relatively small compared to that associated with occupational or “normal daily life” contact with soil since the hands are immediately rinsed after application of the material. Nevertheless, although the risk to the individual is likely to be small, within a large population who regularly use contaminated mud, soil or ash for handwashing, it is possible that this could contribute in some measure to the disease burden. The QMRA data in Appendix 2 shows how a decrease (through the use of a more effective rubbing agent) or increase (through the application of contaminated soil mud or ash to the hands) in residual contamination on the hands can translate into a measurable increase in disease burden within a large population.

Section 2 shows that mud, soil or ash used for handwashing can also contain potentially toxic heavy metals such as arsenic, lead and chromium, as well as pesticides. This could represent a toxic hazard when applied to the hands for handwashing, although there are no epidemiological or risk assessment data to indicate the magnitude of the risk. As discussed in section 2 the risks are likely to be small relative to the exposure to these materials via other routes (i.e. as a result of drinking contaminated water), but nevertheless in the constantly changing social, economic and environmental situations in these countries, the situation needs to be kept under review.

The data presented in this review suggests that although the separate toxicological and microbiological risk from exposure to contaminated soil are likely to be small, taken together, perpetuating the use of these materials is questionable, particularly
since an alternative material is available. The reality however is not so simple, as discussed below.

In recent years there has been significant investment in the promotion of handwashing in low income communities, aimed at reducing the burden of diarrhoeal diseases. Handwashing promotion programmes include the Global Public Private Partnership on Handwashing supported by the World Bank, the Gates Foundation and the private sector. Promotion of handwashing is also a large component of the “WASH in Schools” programme. The WHO, World Bank and other United Nations agencies and bilaterals and civil society are also investing significantly to achieve STH control, through programmes of anthelmintic drug treatment, improved sanitation, and health education. These are aimed at reducing contamination of soil and water by promoting the use of latrines and hygienic behaviour.

In view of the significant investments that are currently in place to control the spread of diarrhoeal and parasitic infections in developing countries, if the health risks and benefits were the only consideration, then perpetuating the use of soil, mud or ash, as against soap is questionable, despite the fact that the toxicological and microbiological risks associated with soil, mud or ash may be small. One of the key constraints is the affordability of soap. In extreme settings where people are poor, and at highest risk for enteric disease morbidity and mortality from infectious disease, the greater need is for families to spend what little income they have on food. Currently, for example, according to the most recent Bangladesh demographic survey, 46% of children have stunted growth. For these communities the data presented in section 3 indicates that the promotion of clean and dried soil and ash is preferable to using water only for handwashing, because it is more effective. There is also the possibility that, if washing hands with soil, mud, or ash, is actively discouraged, this may discourage people from using any hand hygiene at all.

The situation in developing countries today, calls for wider use rather than the universal use of soap. The need is to focus on programmes aimed at making low-cost soap and adequate safe water freely available to communities which can afford it. The number of people in this socio-economic group is fast rising in countries like India and Bangladesh. Within these communities there is a need to change the mindset, so that attitudes to using soap for handwashing, and thus behaviour, is dictated by their desire to enjoy the health benefits (i.e. disease reduction) rather than being conditioned by age old knowledge, religious beliefs, social customs etc. We need to invest in hygiene promotion programmes, which focus on getting these communities to change their behaviour and adopt handwashing as an accepted practice to maintain good health, and the use of soap as an integral part of making hands germ free. In particular, we need to encourage the use of soap rather than mud, soil or ash before preparing food and before eating.

In recent years, a significant amount of research has been done to identify strategies for changing hygiene behaviour. One of the lessons that has been learnt, is that traditional approaches can raise awareness, but do not necessarily achieve the desired effects. If practices such as handwashing with soap are to become a universal norm, multi-dimensional promotion which engages the community is needed to persuade people to change their behaviour. In developing handwashing promotion programmes, it is important to take account of local economic, cultural and political conditions. We need to develop programmes which reach all socio-economic groups in developing countries including those in extreme poverty, and communicate in a manner which achieves hand hygiene behaviour change which is most appropriate to their particular situation.
To an extent this review raises more questions than it answers. It also identifies a number of research questions which need to be answered if the health benefits achieved from handwashing programmes are to be optimised. Further research is also needed to make a more informed assessment of the potential risks associated with use of soil, mud or ash for handwashing:

- Further work, involving both laboratory and intervention studies, is needed to understand better and optimise the efficacy of the handwashing process. In particular we need to identify the processes which best facilitate detachment of organisms from the hands during handwashing. These studies should involve not only bacterial, but also viruses, protozoa and helminths.
- Further epidemiological studies are need to understand better the relative importance of the different routes of transmission of infectious and parasitic agents, both via the faecal:oral route and via the skin, eyes etc including the role and importance of soil and hands as a component in the chain of transmission.
- More data, particularly epidemiological data is needed to assess the infection risks associated with using contaminated soil, mud and ash for handwashing. There is a need to understand better the extent to which soil, mud or ash used for handwashing is contaminated with infectious and parasitic agents.
- More data is needed to assess the toxicological risks associated with using contaminated soil, mud and ash. There is a need to understand better the extent to which soil, mud or ash actually used for handwashing is contaminated with heavy metal or pesticide residues.
APPENDIX 1 THE ASSOCIATION BETWEEN HAND HYGIENE AND THE PREVENTION OF DIARRHOEAL, RESPIRATORY AND SKIN INFECTIONS

Indications are that the hands are a key route for transmission of intestinal pathogens in the home and community. From a systematic review of handwashing intervention studies carried out in 2007 (Table 10), Bloomfield et al estimated that the reduction in the incidence of GI infections was between -13% to 79% for developing countries and between -10% and 57% for developed countries. Of the studies that were statistically significant (7/11 and 3/5), reductions in GI infections ranged from 26-79% and 48-57% for developing and developed countries, respectively.

Table 10 – Summary of data from intervention studies on the impact of hand hygiene on respiratory and GI infections (from Bloomfield et al)

<table>
<thead>
<tr>
<th>Type of infection</th>
<th>Area of study</th>
<th>Risk reduction from hand washing with soap</th>
<th>Range</th>
<th>No of statistically significant studies (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastrointestinal</td>
<td>Developed</td>
<td>-10% to 57%</td>
<td>3/5 studies (48% to 57%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Developing</td>
<td>-13% to 79%</td>
<td>7/11 (26% to 79%)</td>
<td></td>
</tr>
<tr>
<td>Respiratory</td>
<td>Developed and developing</td>
<td>5% to 53%</td>
<td>2/6 studies (20%-51%)</td>
<td></td>
</tr>
</tbody>
</table>

The strong causal relationship between hand hygiene and GI disease risk has also been demonstrated by meta-analysis studies of community-based interventions. Curtis and Cairncross estimated a 42-47% reduction in diarrhoeal diseases associated with handwashing. Fewtrell et al showed a 44% reduction in diarrhoeal illness associated with handwashing. In a more recent 2008 study, Aiello et al, estimated that handwashing with soap combined with education could produce a 39% reduction in GI illness. All three of these meta-analyses were carried out using data from studies conducted in both developed and developing countries. The link between poor hand hygiene and the spread of GI diseases is supported not only by epidemiological data, but also by a whole range of microbiological studies, many related specifically to the home and community. The microbiological data are summarised in various IFH reviews and reviews by other researchers.

For respiratory diseases the link between poor hygiene and spread of disease is also supported by both epidemiological and microbiological data. A range of intervention studies have been carried indicating a significant link between handwashing and transmission of respiratory infections. In 2007 Bloomfield et al carried out a systematic review of handwashing intervention studies assessing the impact on respiratory diseases. Based on these studies, Table 10 summarises the results of community-based interventions (excluding healthcare-related and military settings) on RT illnesses. Most studies were conducted in economically developed countries (83%, 5/6). The range of reduction in illness was 5-53%, but only 33% (2/6) of the studies were statistically significant. Rabie and Curtis in 2006 also published a review of hand hygiene studies involving RT infections. They reported that hand hygiene (handwashing, education, and waterless hand sanitisers) can reduce the risk of respiratory infection by 16% (95% CI: 11-21%). These investigators have now updated their estimate with two further, more recent, studies which, when all studies are taken together, give a pooled impact on respiratory infection of 23%. In a more recent 2008 study, Aiello et al, estimated that the reduction in respiratory illness associated with the pooled effects of hand hygiene (handwashing with soap, use of alcohol handrubs) was 21%.
The link between poor hygiene and spread of respiratory diseases is also supported by microbiological studies, many related specifically to the home. These data are summarised in various IFH\textsuperscript{98,120,121} and other reviews.\textsuperscript{123} These data show that although the commonly held belief is that colds are spread by particles of infected mucous generated by coughs and sneezes, increasingly, there is evidence that infection can spread when fingers become contaminated by contact with the infected nose, or when surfaces such as handkerchiefs or tap and door handles become contaminated by droplets of infected mucous shed from the nose. The virus is passed onto another person either by handshaking or when contaminated surfaces are touched by that person. Individuals then infect themselves by touching their nose or eyes with contaminated hands.

Globally, acute lower respiratory infections (ALRIs) such as pneumonia, bronchiolitis and bronchitis cause up to 4 million deaths annually, mostly in children, the major burden of ALRI disease is falling in developing countries. There is little data to show whether hygiene plays any significant role in the spread of ALRIs. Data from intervention studies as discussed above suggest that handwashing can produce a significant reduction in the risks of transmission of respiratory infections, but most of these studies were carried out in developed countries and concerned upper RT infections such as colds and flu. However, in 2005 Luby et al reported a study of the impact of handwashing with soap on pneumonia in children under 5, in squatter settlements in Karachi, Pakistan.\textsuperscript{126} The results indicated a 50% reduction in pneumonia in the intervention compared with the control group. Luby et al assess that a link between handwashing and the prevention of pneumonia in developing countries is plausible on the basis that, in developing countries it is known that viruses commonly cause pneumonias. It is also known that some of the viruses that infect the respiratory tract are transmitted from person-to-person via the hands. Additionally, several viruses that cause RT infections predispose children to bacterial pneumonia.
APPENDIX 2. THE USE OF QUANTITATIVE MICROBIAL RISK ASSESSMENT (QMRA) TO EVALUATE THE EFFECTIVENESS OF HAND HYGIENE IN PREVENTING THE TRANSMISSION OF INFECTION

Although intervention studies yield quantitative data on health impact, the reliability of estimates is difficult to confirm. Data from in vivo and in vitro tests is also limited because it gives no assessment of how the contamination reduction on hands correlates with health impact. In an attempt to overcome these problems, Haas et al have applied QMRA to estimate the relative health benefits resulting from the use of hand hygiene procedures with different efficacies. This involves using microbiological data from the published literature, related to each stage of the infection transmission cycle to calculate infection risk. These investigators used this approach to study the relative impact of different hand hygiene procedures in preventing transference of E. coli and E. coli O157:H7 from hand-to-mouth following hand contact with ground beef during food preparation. To perform the risk assessment, data on the density of pathogens in ground beef, transference from beef to hands, removal by handwashing or alcohol hand sanitiser (AHS), rate of transfer from hand-to-mouth and infectivity of ingested pathogens were obtained from the literature, and, after screening for data quality, used to develop probability distributions. With some plausible assumptions, it was assessed that, assuming that there are 100 million individuals in the United States each of whom handles ground beef once per month, this results in $1.2 \times 10^9$ contacts per year. Assuming that 10% of these individuals contact hand-to-mouth after handling ground beef, this amounts to $1.2 \times 10^8$ incidents per year. For E. coli O157:H7, it was assessed (Table 11) that if no handwashing is done this would result in $0.7$ infections per year. By contrast, if all individuals washed their hands with soap following contact with ground beef, producing a 0.3 log reduction on hands, this would result in an estimated $0.014$ infections per year, equating to a 98% median risk reduction compared with no handwashing. If all individuals used a hand hygiene process, following contact with ground beef, producing a 4.3 log reduction on hands (i.e. they used an AHS, this would then result in an estimated $0.00005$ infections per year, equating to a 99.9996% median risk reduction for use of the sanitiser compared with handwashing.

<table>
<thead>
<tr>
<th>Log reduction on hands</th>
<th>No handwashing</th>
<th>Handwashing</th>
<th>Use of alcohol hand rub</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.39 x $10^{-2}$</td>
<td>1.25 x $10^{-2}$</td>
<td>1.15 x $10^{-2}$</td>
</tr>
<tr>
<td>Mean</td>
<td>5.98 x $10^{-9}$</td>
<td>1.18 x $10^{-10}$</td>
<td>3.71 x $10^{-13}$</td>
</tr>
<tr>
<td>Median</td>
<td>7.79 x $10^{-2}$</td>
<td>7.52 x $10^{-2}$</td>
<td>7.26 x $10^{-2}$</td>
</tr>
</tbody>
</table>

Risk modelling is a promising approach, but has limitations because of the multifactorial nature of infection transmission and paucity of data to specify model parameters. Although the data used in the modelling study is not specifically relevant to the transmission of soil-borne pathogens via the hands, what the data shows is how a quantifiable increase in the log reduction on hands, for example, an increase from a 2.5 to a 3.5 log reduction on hands can translate into a significant decrease in the risk of infection transmission, whereas a very small decrease in the efficacy of handwashing by use of a sub-optimal handwashing agent may produce no measurable increase in risk to the individual, within a large population who regularly use contaminated mud, soil or ash for handwashing, it can produce a measurable increase in the disease burden of the community.
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