HOME-BASED DRINKING WATER PURIFICATION THROUGH SUNLIGHT: FROM PROMOTION TO HEALTH EFFECTIVENESS

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Dedico este trabajo

a

mi familia

&

a

***Luz Maria**,*

mi amor eterno,
que se unió a mi camino
de una forma guiada por el destino

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EXECUTIVE SUMMARY

Diarrhoeal diseases constitute a significant illness burden for children living in low-income countries. Children under the age of five years suffer about four billion diarrhoea episodes per year, 90% of which occur in developing countries. Diarrhoeal illness accounts for more than four percent of the “disability adjusted life years" lost to the worldwide illness burden. ‘Unsafe water, sanitation and hygiene’ are the main global risk factors for diarrhoeal diseases.

Current strategies for providing safe water to more than one billion people are being reshaped. Since the formulation of the seventh Millennium Development Goal (MDG), the focus is on large-scale and sustainable approaches. Target 10 of the MDGs includes halving the number of people without access to safe water and sanitation facilities by 2015. Solar water disinfection (SODIS) is a home-based – or ‘point-of-use’ – water purification and safe storage method that could support the achievement of this goal, by providing safe drinking water to populations in need. The method consists of exposing water-filled, transparent PET bottles to full sunlight for about one day.

Our main objective of this project was to measure the effectiveness of solar water disinfection on the health of children under the age of five years. Based on a Latin American dissemination programme and further pilot studies in Bolivia (2001) and Bangladesh (1999/2000) on need assessment approaches in the domain of household water management, we decided to carry out the research in 10 rural Bolivian communities situated in the district of Mizque (Department of Cochabamba) from 2001 until 2003.

A case-control study was embedded in a morbidity surveillance scheme and complemented with cross-sectional surveys, in order to comprehensively describe the outcome: the impact of the SODIS method on the frequency of childhood diarrhoea. We developed three SODIS promotion strategies that used various communication channels to reach the target population: i) monthly community-based workshops; ii) monthly household visits; and iii) a school campaign in 11 school centres of the district. During four months of weekly diarrhoea monitoring we interviewed 100 cases, as well as 171 controls; the latter were randomly selected from the entire population. One-hour semi-structured interviews with mothers of selected study children were carried out to assess relevant risk factors for child diarrhoea.

We then compared the diarrhoea incidence rates in study children between families who applied the SODIS method with different intensities, and adjusted the results for major known confounding factors (e.g. age, sex, hand washing). In addition, the quality of household drinking water was analysed repeatedly, which enabled us to calculate the efficacy of the SODIS method under natural conditions representing daily Bolivian life in rural areas. We also repeatedly examined stool samples from community children for the presence of protozoa and helminths, to identify the main transmission pathways of these potentially diarrhoea-causing parasites.

The implementation of the SODIS method was challenging, as the target population did not immediately recognise benefits of using the new method. About 20% drank SODIS purified water on more than five days per week, and about 40% consumed the SODIS water less frequently. The individual promotion strategies affected the population in different ways: e.g. household visits increased adoption of the SODIS method and the school campaign enhanced awareness about germs and diseases. Such extensive promotion strategies may not be suitable for large-scale promotion of the SODIS method. The assessment of motivational messages directed towards *tangible* benefits for the population may prove essential to increase compliance.

Once the population was introduced to the SODIS method, we assessed its effect on the study childrens' health. The use of the SODIS method averted up to 75% of the diarrhoea episodes in a rural Bolivian child under five years of age. The impact was less, when families used the method less frequently (60%), indicating a dose-response relationship between the intensity of use (or compliance to the SODIS method) and reduction in diarrhoeal illness. In order to translate individual risk reductions to an impact measure at population level, we employed population-attributable fraction estimates using an uptake rate of the SODIS method of 20% in the community. Those calculations indicated that 15% of all child diarrhoeal illnesses in the population could be averted if the SODIS method would be consistently used.

The high diarrhoea incidences in children under the age of five (about 6 episodes per year) were not reflected in the infection data. It may therefore be assumed that bacteria and viruses (which we did not investigate in this study) caused most diarrhoea episodes in this setting.

We found that children would be re-infected rapidly after treatment for protozoa or helminth infection – 50% of the children were re-infected in the elapse of two month, mainly through *Giardia lamblia* and *Entamoeba hist/disp*. The age of the child, socio-economic status and hygiene indicators in the household were main risk factors for re-infection. Water-borne transmission of these protozoa was not dominant in this setting.

The high efficacy of the SODIS method in producing pathogen-free drinking water in the field is the foundation for a high effectiveness on people's health. SODIS-purified drinking water contained 90% less faecal coliform contamination than untreated drinking water. Families that left their water exposed for at least *two* days, achieved a significantly better purification effect, almost reaching the WHO recommendations of zero-tolerance of indicator bacteria in drinking water. These results support our findings of a high effectiveness of the SODIS method on child health due to the purification of their drinking water. Increased purification efficacy of SODIS due to prolonged exposure time further indicates that SODIS user instructions could be further revised to guarantee best efficacy under field conditions.

In rural Bangladesh, people were forced to switch from arsenic- to microbiologically contaminated drinking water sources. Diarrhoea rates were similar between intervention families that switched water sources, with people drinking groundwater, indicating that the SODIS method was efficacious enough to maintain water quality. We also learnt important aspects on the use (e.g. bottle scarcity in rural areas) and determinants for uptake and possible sustainable use of the method (e.g. acceptable alternative water source). Specific community selection criteria, including normative and perceived needs, were formulated for a subsequent need assessment in the Bolivian setting.

Since the start of our activities, we were challenged with developing and validating indicators to classify families according to their use of the SODIS method, as no standards existed. In Bolivia, the combination of three indicators for the uptake of SODIS may best estimate the use of the method in families during a one-time evaluation visit: reported use (sensitivity: 73%), observed use (specificity: 82%) and frequency of drinking SODIS water in the last week (positive predictive value: 85%). The indicators can be measured rapidly and easily through especially appointed staff during programme evaluation.

The most precise indicator is the repeated observation of SODIS purified water at the home during unannounced visits.

The finding of a significant impact of the SODIS method on child health is consistent with our other findings of a dose-response relationship, high efficacy under field conditions and the efficacious protection from diarrhoeal diseases in Bangladesh.

Future research should confirm these findings under a multitude of environmental, geographical and cultural settings and study designs, to produce reliable evidence of the methods' effectiveness in improving the health of populations. The current research raised issues regarding the implementation of and compliance of the population to the SODIS method in combination with the possibility to guarantee its water-purification ability. This also raised questions on the costs in relation to the benefits of the SODIS method from the individual to the programme – and planners' level; and the likelihood that the planner may no longer perceive the method as an intermediate but rather as a permanent solution to provide safe drinking water.

In the future, investigations should:

(i) define tangible benefits for target populations, that can later also be applied in social marketing strategies for the broader promotion and higher acceptance of the method in the population. In this context, user instructions should be adapted to guarantee water quality during large-scale promotion activities,

(ii) assess the costs of the SODIS method at individual-, programme- and planners' level. This will allow decision making at regional level, and comparison with other point-of-use methods at policy level,

(iii) consider in the planning process with the local people that the SODIS method should not replace future permanent and durable solutions for drinking water ("SODIS is only a valuable means to the end").

This is the first research that evaluated various levels of the solar disinfection method (efficacy, promotion, compliance, use, health effect) in different settings. Also, this study estimated the effectiveness of the method on the health of young children at population level applying an innovative population-based approach.

It demonstrated with confidence that the method is efficacious in reducing the diarrhoea burden in a child population. Due to its simplicity and almost ubiquitous applicability, solar disinfection is applicable in various settings, but the long-term use of the method also depends on the political will and the availability of subsidies (e.g. for motivational campaigns, or bottle provision). This project, with its multiplicity of findings served to inform and support a randomised control trial on the effectiveness of solar water disinfection in a rural area of Bolivia, and current endeavours in the national SODIS dissemination programme. At regional level, we mostly increased awareness about the application of the SODIS method that we hope will stimulate regional development. The ultimate decision-maker will always be the consumer and potential beneficiary.

ZUSAMMENFASSUNG

Durchfallerkrankungen sind ein beträchtliches Gesundheitsproblem für Kinder in Entwicklungsländern. Weltweit leiden Kinder im Alter von unter fünf Jahren an ca. vier Milliarden Durchfallepisoden pro Jahr, und etwa 90% dieser Krankheitslast entfällt auf die Entwicklungsländer. Vier Prozent der weltweit verlorenen Lebensjahre (DALYs) gehen auf Kosten von Durchfallerkrankungen. Die mangelnde Versorgung mit sauberem Trinkwasser sowie die fehlende Infrastruktur zur Entsorgung von Fäkalien sind die Ursachen für die meisten Durchfallerkrankungen.

Die aktuellen Strategien zur Verbesserung der Versorgung von einer Milliarde Menschen mit sauberem Trinkwasser werden zur Zeit neu entwickelt. Seit der Formulierung der Millenniumsziele zur Entwicklung und Armutsbekämpfung (MDG) ist das Augenmerk auf weitreichende und nachhaltige Planung gerichtet. Im siebten Millenniumsziel wird erwähnt, dass die Zahl der Menschen, die über keinen nachhaltigen Zugang zu sicherem Trinkwasser verfügen, bis zum Jahr 2015 um die Hälfte gesenkt werden soll. Solare Wasserdesinfektion (SODIS) ist eine der möglichen Methoden zur Aufbereitung und Aufbewahrung von Wasser auf Haushaltsebene, welche die Bevölkerung nach Bedarf mit sauberem Trinkwasser versorgt. Dieses System könnte somit zur Erreichung des siebten Millenniumszieles nachhaltig beitragen. Das Grundprinzip von SODIS liegt in der Sonnenexposition und damit der natürlichen UV-Lichtbestrahlung des aufzubereitenden Wassers in PET-Flaschen für die Dauer eines Tages.

Das Hauptziel der vorliegenden Studie war die Messung des Effekts der solaren Desinfektionsmethode auf die Gesundheit von Kindern unter fünf Jahren, auf Individuen- und Populationsebene. Basierend auf ein lateinamerikanisches Promotionsprogramm und auf Pilotstudien in Bangladesh (1999/2000) und Bolivien (2001) zur Erforschung von Bedarfseinschätzung und Bereitwilligkeit, wurde entschieden diese Studie in zehn bolivianischen Dörfern im ländlichen Distrikt von Mizque (Departement von Cochabamba) im Zeitraum von 2001 bis 2003 durchzuführen.

Um die Wirksamkeit der Methode umfassend zu messen, wurde eine Fall-Kontrollstudie in eine Langzeiterhebung der Kindermorbidität eingebettet, und mit zusätzlichen Querschnittstudien ergänzt.

Wir haben drei Promotionsstrategien für die Verbreitung der SODIS-Methode in der Zielbevölkerung entwickelt, welche verschiedene Kommunikationskanäle benutzten: monatliche Hausbesuche, monatliche Dorfaktivitäten mit aktiver Beteiligung der Bewohner, sowie eine breit angelegte Schulkampagne. Während einer viermonatigen Erhebung der Durchfallhäufigkeit in den Studiendörfern befragten wir Mütter von 100 Kindern mit und 171 Kindern ohne Durchfall; letztere wurden zufällig aus der gesunden Gesamtbevölkerung ausgewählt. Die Befragungen der Mütter der ausgewählten Studienkinder dienten dem Erkennen der Hauptrisikofaktoren für Durchfallerkrankungen bei Kindern. Wir verglichen das Durchfallvorkommen bei Studienkindern zwischen den Familien, die ihr Trinkwasser mit der SODIS-Methode aufbereiteten (mit unterschiedlichen Benutzerhäufigkeiten) und Familien, die anderes Wasser tranken. Bekannte Faktoren, welche das Resultat beeinflussen konnten, wie zum Beispiel das Alter, das Geschlecht und das Waschen der Hände, wurden berücksichtigt. Zusätzlich wurden Trinkwasserproben aus den Haushalten untersucht, um die Wirksamkeit der Methode hinsichtlich der Wasserkontamination unter alltäglichen Bedingungen zu prüfen. Wiederholt wurden auch Stuhlproben von allen beteiligten Kindern unter fünf Jahren auf Infektionen durch Protozoen und Helminthen analysiert, um die Hauptübertragungswege dieser potentiell durchfall-verursachenden Parasiten zu identifizieren.

Die Einführung der SODIS-Methode bei der Zielbevölkerung war eine Herausforderung, da die meisten Leute die Vorteile der Methode nicht erkannten. Etwa 20% der Zielbevölkerung trank durch SODIS aufbereitetes Wasser an über 5 Tagen in der Woche. Hingegen konsumierten etwa 40% der Bevölkerung das SODIS-Wasser weniger häufig. Die angewandten Promotionsstrategien beeinflussten die Bevölkerung auf unterschiedlichen Ebenen: die Hausbesuche beeinflussten die Anwendung und die Schulkampagne erhöhte das Bewusstsein in bezug auf Wasser, Erreger und deren Krankheiten. Solch umfangreiche und dadurch teure Strategien sind jedoch kaum geeignet für eine weitreichende Promotion der SODIS-Methode. Ein entscheidender Faktor ist es überzeugende und motivierende Argumente zu finden, welche die Bevölkerung auf verständliche und direkte Vorteile der Methode hinweisen. Dies könnte die Anzahl der Benutzer der Methode beträchtlich erhöhen.

Nachdem die Methode eingeführt war, wurde deren Auswirkung auf die Durchfallrate der Studienkinder untersucht. Die häufige Anwendung der SODIS-Methode reduzierte die Durchfallhäufigkeit in den Studienkindern um etwa 75%. Die Reduktion der Durchfallhäufigkeit war geringer, wenn die Familien die Methode weniger oft anwendeten (60%). Die erhöhte Reduktion der Durchfallhäufigkeit mit steigendem Konsum von SODIS aufbereitetem Trinkwasser schliesst auf eine Dosis-Wirkung-Beziehung und erhärtet somit unseren Befund. Wird die auf individueller Ebene eruierten Verbesserung gastrointestinaler Krankheitslasten, bei einer Anwendungshäufigkeit der SODIS Methode von 20%, auf Bevölkerungsniveau umgerechnet, so kann durch die Anwendung der solaren Trinkwasseraufbereitung 15% aller Durchfälle bei Kindern in dieser Bevölkerung verhindert werden.

Die hohe Durchfallrate bei den Studienkindern (etwa sechs Episoden pro Jahr) konnte meist nicht durch die Präsenz von Protozoen und/oder Helminthen in den Stuhlproben der Kinder erklärt werden. Somit darf angenommen werden, dass bakterielle und virale Erreger, welche nicht untersucht wurden, die Hauptursache der Durchfallerkrankungen in dieser Bevölkerungsgruppe waren. Fünfzig Prozent der Studienkinder infizierten sich erneut innerhalb von zwei Monaten nach der letzten Behandlung, und dies hauptsächlich durch die Protozoen *Giardia lamblia* und *Entamoeba histolytica/dispar*. Das sozioökonomische Umfeld und das Hygieneverhalten waren neben dem Alter der Kinder die Hauptrisikofaktoren für eine Reinfektion. Die Wasserübertragung der Protozoen kann in der Umgebung als niedrig eingeschätzt werden.

Die Wirksamkeit der SODIS-Methode, die Wasserkontamination mit Durchfallerregern auch unter Feldbedingungen zu reduzieren, muss gewährleistet sein, um die Durchfallrate in der Bevölkerung zu verringern. Das Trinkwasser, das mit der SODIS-Methode desinfiziert wurde, war um 90% weniger kontaminiert als ungereinigtes Trinkwasser oder das Wasser, das direkt aus Dorfquellen stammte. Die Familien, die ihr Wasser für mindestens zwei Tage an der Sonne liessen, erreichten Qualitätswerte, die den Richtlinien für Trinkwasserqualität der WHO fast entsprachen (keine nachweisbaren Indikatorbakterien). Diese Resultate unterstützen die gemessene Wirksamkeit in bezug auf die Gesundheit und zeigen weiter an, dass neue Instruktionen zum Gebrauch der SODIS-Methode formuliert werden könnten, um eine hohe Wasserqualität auch unter unkontrollierten Feldbedingungen zu garantieren (z.B. Verlängerung der expositionsyeit von 6 Stunden auf 2 Tage).

Im ländlichen Projektgebiet in Bangladesh war ein Teil der Bevölkerung mangels Alternativen gezwungen, von arsenhaltigen zu mikrobiologisch kontaminierten Wasserquellen zu wechseln. Die vergleichbaren Durchfallraten zwischen den Familien, die über die SODIS-Methode unterrichtet wurden, als sie ihre Wasserquellen wechseln mussten, und jenen Familien, die weiterhin Grundwasser tranken, zeigten, dass die SODIS-Methode die Wasserqualität effektiv verbesserte. Zusätzlich konnten bedeutende Aspekte der Anwendbarkeit beobachtet werden wie zum Beispiel die Verfügbarkeit von PET Flaschen in ländlichen Gebieten. Ausserdem identifizierten wir Faktoren, die zur Akzeptanz der Methode in der Bevölkerung beitrugen und auch deren nachhaltige Benutzung beeinflussten, wie zum Beispiel die Nutzung von alternativen Wasserquellen, die von der Bevölkerung ebenfalls akzeptiert waren. Spezifische Kriterien zur Auswahl von in Frage kommenden Dörfern (einschließlich normative und wahrgenommene Bedürfnisse) wurden formuliert und später in Bolivien angewandt.

Da bisher geeignete Standards fehlten, nach denen die Familien je nach Benutzungsgrad der SODIS-Methode klassifiziert werden konnten, war es von Anfang an notwendig, neue Indikatoren zu entwickeln und zu prüfen. In Bolivien konnte der Benutzungsgrad der SODIS-Methode in einer Familie am genauesten durch eine Kombination von drei Indikatoren, bestimmt werden: (i) Nutzungshäufigkeit gemäss Selbstdeklaration (Sensitivität: 73%), (ii) die beobachtete Anwendung (Spezifizität: 82%) und (iii) die Häufigkeit des Konsums von SODIS gereinigtes Wasser in der vorangegangenen Woche (positiver Voraussagewert: 85%). Alle drei Indikatoren konnten schnell und einfach während der Programmevaluationen durch eine Querschnittsstudie gemessen werden, am besten durch projektexternes Personal vor Ort. Als genauester Indikator für den Konsum von SODIS-gereinigtem Wasser in einer Familie wurde die wiederholte Beobachtung der Anwendung der SODIS-Methode anlässlich wiederholter unangemeldeter Hausbesuche eruiert.

Das Resultat eines signifikanten Gesundheitseffekts der SODIS-Methode ist konsistent mit anderen vorliegenden Ergebnissen: namentlich der Abhängigkeit des Effektes von der Häufigkeit des Konsums, der beobachteten hohen Wirksamkeit der solaren Wasserdesinfektion unter Feldbedingungen, und der wirksamen Prävention von Durchfallerkrankungen in Bangladesh.

Zukünftige Forschungsarbeiten sollten diese Ergebnisse unter unterschiedlichen Bedingungen und mit verschiedenen Studienprotokollen prüfen, um weitere zuverlässige Evidenzen für einen positiven Effekt der SODIS-Methode auf die Gesundheit zu liefern.

Diese Studie konnte auch Faktoren identifizieren, die mit der Promotion und nachhaltigen Anwendung der Methode zusammenhängen und aufzeigen, wie die Wirksamkeit unter Feldbedingungen garantiert werden könnte. Weitere Fragen betreffen die Kosten der SODIS-Methode in Verbindung mit deren Vorteilen für das Individuum bis hin zum Distrikt-, oder Gesundheits-Planer; und der Wahrscheinlichkeit, dass Planer die SODIS-Methode nicht mehr als Übergangslösung, sondern als eine längerfristige Lösung anerkennen.

Zukünftige Studien sollten:

(i) die für die Bevölkerung greifbaren und wahrnehmbaren Vorteile der SODIS-Methode definieren, und diese später in Strategien zum sozialen Marketing der Methode verwenden, um eine höhere Benutzerrate zu erreichen – in diesem Kontext könnten überarbeitete Benutzerinstruktionen dazu dienen, die Wasserqualität während der erweiterten Promotionsaktivitäten zu garantieren,

(ii) die Kosten der SODIS-Methode auf individueller, Programm- und Planungsebene abschätzen. Dies würde erlauben, Entscheidungen zur Entwicklung der Region zu treffen, und Vergleiche mit ähnlichen Wasseraufbereitungsmethoden auf globalem Niveau durchzuführen,

(iii) bereits im Planungsprozess zusammen mit der Zielbevölkerung bedenken, dass die SODIS-Methode die Einrichtungen zur Wasseraufbereitung und Auslieferung nicht ersetzt („SODIS“ ist nur ein wertvoller Weg zum Ziel).

Die vorliegende Arbeit ist eine erste Evaluation der SODIS-Methode, die verschiedene Aspekte (Wirksamkeit, Promotion, Befolgung, Anwendung und Gesundheitseffekt) in verschiedenen Regionen untersuchte. Die Evaluation konnte zuversichtlich aufzeigen, dass die SODIS-Methode Durchfallerkrankungen bei Kindern reduziert. Aufgrund der Einfachheit und Anpassungsfähigkeit ist die solare Wasserdesinfektion unter verschiedenen Bedingungen anwendbar. Ob jedoch eine Zielbevölkerung die Methode nachhaltig nutzten wird, hängt auch vom politischen Willen und den verfügbaren Subventionen ab (z.B. für Motivationskampagnen oder Bereitstellung von PET-Flaschen).

Die zahlreichen Erfahrungen und Ergebnisse dieses Projektes dienten zur Vorbereitung einer „randomisierten und kontrollierten Studie“ zur Erfassung des Gesundheitseffektes der Methode auf Bevölkerungsniveau in Bolivien („BoliviaWET“) und unterstützten ausserdem das nationale SODIS-Promotionsprogramm in seinen Aktivitäten. In der Region konnten vor allem das Bewusstsein über die Anwendbarkeit der SODIS-Methode geweckt werden. Dies kann und wird hoffentlich die regionale Entwicklung stimulieren. Die wichtigsten Entscheidungsträger bleiben schlussendlich die Konsumenten und potentiellen Nutzniesser der solaren Wasserdesinfektion.

RESUMEN EJECUTIVO

Las enfermedades diarreicas constituyen una significante causa de muerte infantil de niños que viven en países en vías de desarrollo. Los niños menores de cinco años sufren alrededor de 4 billones de episodios diarreicos por año, de los cuales el 90% ocurren en países en vías de desarrollo. La carga de las enfermedades diarreicas (a nivel mundial) están responsables para más del 4% de la pérdida de años de vida ajustados a la inhabilidad (QALYs) a nivel mundial. Agua contaminada y insuficiente seguro saneamiento e higiene son los principales factores de riesgo de enfermedades diarreicas a nivel mundial.

Las estrategias actuales para proveer agua segura a más de un billón de personas están siendo reformadas. Desde la formulación de la séptima Meta de Desarrollo para el Milenio (Millennium Development Goal, MDG) intervenciones sostenibles y a larga escala están siendo enfocadas. La décima meta de los MDG incluye reducir a la mitad el número de personas sin acceso a agua y facilidades de saneamiento segura hasta el 2015. El método domiciliario de la Desinfección Solar de Agua (Solar Water Disinfection, SODIS) – o “punto de uso” – es un método de purificación y almacenamiento de agua seguro que podría apoyar al alcance de esta meta, proveyendo agua segura a las poblaciones necesitadas. El método consiste en exponer botellas transparentes de plástico PET llenas de agua al sol durante aproximadamente un día.

Nuestro principal objetivo en este proyecto fue medir la efectividad de la Desinfección Solar del Agua en la salud de niños menores de 5 años. En base a un programa Latino Americano de diseminación y estudios pilotos en Bolivia (2001) y Bangladesh (1999/2000), investigando las necesidades domiciliarios al respeto a manejo de agua en los hogares, decidimos llevar a cabo la investigación en 10 comunidades rurales de Bolivia situadas en el distrito de Mizque (Departamento de Cochabamba) del 2001 al 2003.

Un estudio de ‘casos y controles’ fue incluido en un esquema de vigilancia de morbilidad infantil y fue complementado con investigaciones transversales, para describir el resultado de manera comprensible: el impacto del método SODIS en la frecuencia de diarreas infantiles.

Desarrollamos tres estrategias de promoción de SODIS que se disiparon a través de varios canales de comunicación para llegar a la población participando en el estudio: i) talleres mensuales comunitarios, ii) visitas domiciliarias mensuales, iii) una campaña escolar en 11 establecimientos educativos del distrito. Durante cuatro meses de monitoreo semanal de la diarrea infantil en los niños del estudio, entrevistamos 100 casos y 171 controles; los últimos fueron seleccionados al azar de todos los niños incluidos en el estudio. Las entrevistas semi-estructuradas de una hora con madres de niños (casos y controles), fueron llevadas a cabo para investigar los factores de riesgo más relevantes causando la diarrea infantil en esta población.

Comparamos los tasas de incidencia de diarrea de los niños participantes entre las familias que aplicaron el método SODIS con diferentes intensidades, tomando en cuenta factores conocidos que pueden confundir el resultado (por ejemplo, edad, sexo, lavado de manos). Adicionalmente, la calidad del agua de consumo en los hogares fue analizada mensualmente (3 meses), lo cual nos permitió calcular la eficacia del método SODIS bajo condiciones naturales que representan la vida diaria de los bolivianos en las áreas rurales. Hemos examinado repetidamente también, muestras de heces de niños de las comunidades, para identificar la presencia de protozoarios y helmintos, con el objetivo de investigar las principales vías de transmisión de estos parásitos que pueden causar enfermedades diarreicas.

La implementación del método SODIS fue desafiante porque la población meta no reconoció inmediatamente los beneficios de la aplicación de éste nuevo método. Alrededor del 20% bebió agua purificada SODIS durante más de cinco días por semana y alrededor del 40% consumió el agua purificada SODIS con menos frecuencia. Las estrategias de promoción individuales afectaron a la población de diferentes maneras: las visitas domiciliarias, por ejemplo, aumentaron la adopción del método SODIS, mientras que la campaña escolar ayudó a aumentar el conocimiento acerca de los gérmenes y las enfermedades. Este tipo de estrategias de promoción tan extensas no serian muy apropiadas para una promoción del método SODIS a larga escala. La formulación de mensajes de motivación dirigidos a beneficios tangibles para la población podría ser esencial para incrementar la aceptación del método.

Una vez que la población estudiada fue introducida al método, determinamos el efecto de SODIS en la salud de los niños participantes del estudio. El uso del método SODIS disminuyó hasta el 75% de episodios diarreicos en un niño menor de cinco años perteneciente a las comunidades rurales del estudio. El impacto fue menos cuando las familias usaron el método con menor frecuencia (60%), indicando una relación entre la dosis y la respuesta, es decir, entre la intensidad de uso (o aceptación del método SODIS) y la reducción de enfermedades diarreicas. Para aplicar la reducción del riesgo individual a nivel de la población, empleamos fracciones estimadas de la población, usando una adopción del método SODIS del 20% en el área. Estos cálculos indicaron que el 15% de todos los casos de diarrea infantil podrían ser reducidos si el método SODIS fuese usado constantemente y frecuentemente.

Los altos incidencias de diarrea en los niños menores de cinco años (alrededor de 6 episodios por año) no fueron reflejados en los datos de infección. Por tanto se puede asumir que las bacterias y virus (los cuales nosotros no investigamos en este estudio) causaron la mayor cantidad de enfermedades diarreicas en este contexto. Encontramos que los niños podrían ser rápidamente reinfectados protozoos o helmintos después del tratamiento contra estos infecciones – 50% de los niños fueron reinfectados en un lapso de 2 meses, principalmente con *Giardia lamblia* y *Entoameba hist/disp.* La edad del niño, el estado socio económico y las condiciones higiénicas en las viviendas fueron los principales factores de riesgo para una reinfección. La transmisión de estos protozoos a través del agua no fue dominante en este contexto.

Una alta eficacia del método SODIS en la producción de agua sin patógenos en el campo, es la base para una alta efectividad en la salud de los usuarios. El agua purificada por el método SODIS contiene 90% menos de coliformes fecales que el agua para consumo no tratada. Las familias que dejaron las botellas con agua expuestas por al menos dos días lograron un efecto de purificación significativamente mejor, casi alcanzando las recomendaciones de agua para consumo de la OMS: cero-tolerancia de bacterias indicadoras. Estos resultados avalan nuestros descubrimientos sobre la alta efectividad del método SODIS en la salud de los niños.

El aumento de la purificación con respecto a la prolongación de tiempo de exposición al sol indica que las instrucciones del SODIS podrían ser revisadas para garantizar la mejor eficacia en las concisiones específicas del área.

En una zona rural de Bangladesh, las personas fueron forzadas a cambiar de fuentes de agua contaminadas con arsénico a fuentes contaminadas con patógenos. Los tasas de incidencia de diarrea fueron iguales cuando se compararon las familias introducidos al método SODIS que cambiaron sus fuentes de agua, con las familias que seguían tomando agua subterránea (libre de patógenos y arsénico), indicando que el método SODIS fue eficaz para mantener la calidad del agua. También aprendimos aspectos importantes acerca del uso del método (por ejemplo, la escasez de botellas en el área rural) y determinantes para la adopción y posible sostenibilidad del uso del método (ej. fuentes alternativas de agua que sean aceptables para la población). Criterios específicos de selección de comunidades, incluyendo necesidades normativas y percibidas, fueron formulados para subsecuentemente adaptarles e investigar las necesidades comunitarias en el contexto boliviano.

Desde el inicio de nuestras actividades, fuimos desafiados con el desarrollo y validación de indicadores para clasificar las familias de acuerdo al uso del método SODIS, pues no existía ninguna norma estándar. En Bolivia, la combinación de tres indicadores para la adopción de SODIS podría estimar el uso del método durante una única evaluación de la mejor forma: uso reportado (sensibilidad: 73%), uso observado (especificidad: 82%) y la frecuencia de agua SODIS bebida en la última semana (valor predictivo positivo: 85%). Los indicadores pueden ser medidos de forma rápida y fácil a través de un equipo de trabajo especialmente escogidos durante la evaluación del programa. El indicador más preciso es la observación repetida del agua purificada SODIS en los hogares durante visitas no anticipadas.

El encuentro de un impacto significativo del método SODIS en la salud de los niños es consistente con respecto a nuestros descubrimientos de una relación entre la dosis y la respuesta, alta eficacia bajo condiciones rurales y la protección eficaz de las enfermedades diarreicas en Bangladesh.

Futuras investigaciones pueden confirmar estos hechos bajo diferentes condiciones culturales, ambientales y geográficas y diseños experimentales para producir evidencias confiables de la efectividad del método en la salud de las poblaciones. Esta investigación levantó temas respecto a la implementación y la conformidad de la población con respecto al método SODIS en combinación con la posibilidad de garantizar su habilidad de purificar agua de consumo.

Esto también levantó interrogantes sobre los costos en relación a los beneficios del método SODIS desde el nivel individual hasta el nivel del programa – a nivel de los planificadores; y la probabilidad de que el planificador no perciba el método como un intermediario, pero más bien como una solución permanente para proveer agua segura.

En el futuro las investigaciones deberían:

(iv) definir beneficios tangibles para las poblaciones, que puedan también ser usadas en el futuro en estrategias de mercadeo social para la amplia promoción y mayor aceptación del método en la población. En este contexto, las instrucciones para los usuarios deberían ser adaptadas para garantizar la calidad del agua durante las actividades de promoción a larga escala

(v) determinar los costos del método SODIS a nivel individual, del programa y de los planificadores. Esto permitirá tomar decisiones a nivel regional, y compararlas con otros tipos de métodos de 'punto-de-uso' a nivel de políticas

(vi) considerar en el proceso de planificación con las personas locales que el uso del método SODIS no debería reemplazar futuras soluciones permanentes y durables para el agua de consumo (SODIS es un medio para llegar al fin).

Este es la primera investigación que evaluó varios aspectos del método de desinfección solar (eficacia, promoción, conformidad, uso y efectos en la salud) en diferentes ambientes y que estimó la efectividad del método en la salud de niños a nivel de la población. Debido a su simplicidad y adaptabilidad, SODIS es aplicable en varios contextos, pero el uso a largo plazo del método también depende de la voluntad política y de los subsidios disponibles (por ejemplo, para campañas de motivación, o provisión de botellas).

Este proyecto, con sus múltiples descubrimientos, sirvió para informar y apoyar un ensayo aleatorizado de control sobre la efectividad de la desinfección solar del agua en un área rural de Bolivia, y actuales esfuerzos en la diseminación del programa SODIS a nivel nacional. A nivel regional, incrementamos la atención dada al uso del método SODIS que esperamos estimule el desarrollo regional. La última decisión siempre será la del consumidor y beneficiario potencial.

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1 BACKGROUND AND INTRODUCTION

1.1. Global burden of diarrhoeal diseases

Communicable diseases were responsible for 41% of the global disease burden in the year 2002 according to the World Health Report's estimates (2004). More than four percent of the global DALYs (Disability Adjusted Life Years) were ascribed to diarrhoeal diseases, which ranked fourth among the most important contributors to the global illness burden, after lower respiratory infections (6.1% of total), HIV/AIDS (5.7%) and unipolar depressive disorders (4.5%).

Africa and the "high-mortality" developing regions of South East Asia, the Eastern Mediterranean and the Eastern Pacific share over 90% of the world-wide loss of life years due to diarrhoeal diseases. These areas also account for a large proportion of the world's population and their inhabitants usually have low life expectancy at birth (Table 1.1). Young children, often under five years of age (Schirnding von, 2003), account for 99% of the diarrhoeal burden.

Children aged from 6 – 11 months living in developing countries, suffer a median of 4.8 diarrhoea episodes per year. This number declines with age, and a median of 3.2 diarrhoea episodes per year and child under five years of age is estimated.

A recent review confirmed that child mortality from diarrhoeal diseases fell by more than 40% over last four decades, whereas child morbidity from diarrhoeal diseases remained constant. Nevertheless, diarrhoeal diseases still account for about 21% of all child deaths (Kosek *et al.*, 2003).

The observed decrease in mortality during the last four decades seems to point towards a substantial improvement in access to and use of health care (Kosek *et al.*, 2003). Steady morbidity rates, however, show that preventive measures could not keep pace with population growth, migration and impoverishment. Persistently high rates of morbidity are of concern, because early and frequent childhood diarrhoea may have a long-term effect on linear growth and development (Kosek *et al.*, 2003).

Diarrhoeal diseases remain a significant burden, primarily affecting young children and infants in the poorest countries of the world. Most of the burden of diarrhoeal diseases can be considered as preventable. This is indicated by the inequity of the geographical and age distribution of the disease, as well as by the nature of the illness and its major risk factors.

Table 1.1: The burden of diarrhoeal diseases in selected countries from WHO regions (2002).

Country (WHO-Area)	*Total Population (10^3)*	*% Population >60y*	*Life Expectancy at birth (years)*	*Fertility rate*	*% Death (DD death/tot death)*	*DALYS due to DD (10^3)*	*% of total DALYS (regional)*	*% of total DALYS (global DD)*
*Sierra Leone**	4764	4.7	34.0	6.5	7.5	11548	7.2	18.6
Sudan	32878	5.6	57.1	4.4	7.1	8093	7.0	13.1
United Republic of Tanzania	36276	3.9	46.5	5.2	5.9	11689	5.8	18.9
*Bangladesh**	143809	5.1	62.6	3.5	4.5	18817	5.2	30.4
*Bolivia**	8645	6.6	63.2	3.9	3.9	750	4.4	1.2
China	1302307	10.0	71.1	1.8	1.4	6641	2.7	10.7
Indonesia	217131	7.9	66.4	2.4	1.9	1482	2.4	2.4
Iran, Islamic Republic of	68070	6.4	68.9	2.4	2.1	568	2.4	0.9
Brazil	176257	8.1	68.9	2.2	1.2	1494	1.8	2.4
Turkey	70318	8.2	70.0	2.5	0.7	485	1.3	0.2
Japan	127478	24.4	81.9	1.3	0.1	46	0.3	0.1
Russian Federation	144082	18.3	64.6	1.2	0.0	97	0.2	0.8
United States of America	291038	16.2	77.3	2.1	0.1	106	0.2	0.2
*Switzerland***	7171	22.1	80.6	1.4	0.1	110	0.2	0.2

Legend*: Selected countries from WHO regions defined by their overall adult and child mortality status. *high child and high adult mortality;**Very low child and very low adult mortality. According to WHO classification. DD: diarrhoeal diseases. Adopted from the World Health Report 2004*.

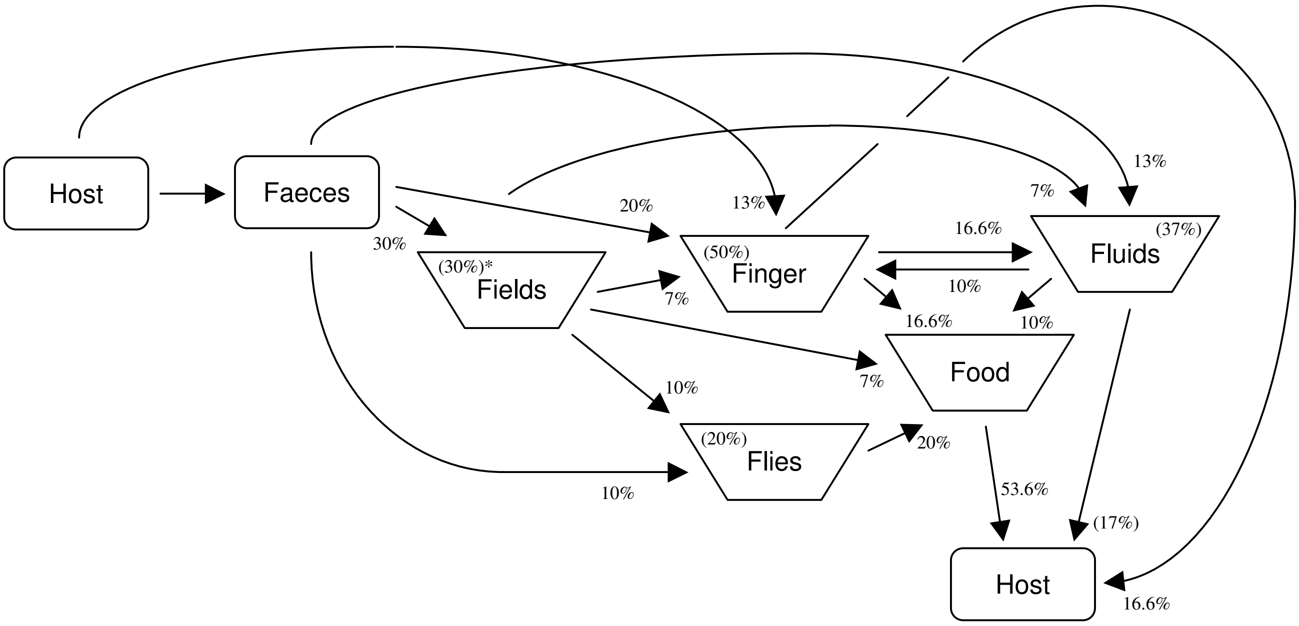
1.2. Diarrhoeal diseases prevention

Efforts directed towards diarrhoea prevention have not achieved the expected relief at global level, pointing to necessary changes in intervention strategies. Principal causes and risks of diarrhoeal diseases must be identified before preventive actions can be effective.

Pathogens and health conditions that can cause diarrhoeal diseases are many: Infections, allergies, malnutrition, immune disorders, drugs or poisons, enzyme effects and intestinal tract disorders (Thapar and Sanderson, 2004). The majority of diarrhoeal diseases are caused by infections transmitted via the faecal-oral route. In more than 65% of examined stool specimens from diarrhoea-sick individuals, at least one pathogen can be identified (Zikri *et al.*, 2000).

Many pathogens pass undetected by laboratory methods (especially viruses). The effective number of pathogen-caused diarrhoea can therefore be assumed higher.
Human and animal excreta can affect human health through drinking water, sewage, indirect contact and food along various pathways (Figure 1.1).

Figure 1.1: Relative contributions of faecal-oral diarrhoea transmission pathways



***Legend**: Percentages represent the proportional, potential burden of diarrhoea that may be transmitted to the host through the specified pathway. Numbers in brackets are based on the literature (see in text). Other numbers represent interpolated proportional contributions. After Wagner and Lanoix (Wagner and Lanoix, 1958)*

Figure 1.1 illustrates the possible, complex interactions among major transmission pathways, using the existing evidence (see below) and interpolating the proportional diarrhoea load where necessary. The risk of contracting diarrhoea is highest through the consumption of "food", as this is potentially contaminated from all other sources and affects the host directly. Furthermore, the figure explains why control measures targeting hand hygiene (e.g. hand washing with soap) can result in higher diarrhoea reduction rates than fly control under general circumstances.

Water (or "fluids") plays a dual role by putting people at risk through insufficient supply – leading to less food- and personal hygiene –, and through bad quality – by direct consumption.

‘Unsafe water, sanitation and hygiene’ (see transmission pathways in Figure 1.1) are considered to be the most important global risk factors for diarrhoeal illnesses; they are also among the three top risk factors for all illnesses in developing countries (Pruess *et al.*, 2003). Eliminating the risk of diarrhoeal diseases through unsafe water, sanitation and hygiene could relieve developing countries of 4-5% of their entire disease burden (WHO, 2002).

Huttly *et al.* commented that a larger reduction of the risk of diarrhoeal diseases can be achieved through single, targeted and effective interventions among the target population (Huttly *et al.*, 1997). Hand-washing, breast-feeding, food supplements and improved access to water supplies and sanitation rank among the key interventions for preventing diarrhoea mortality and morbidity in children under five years of age.

A recent review reported that the risk of diarrhoea in children under the age of five could be reduced by almost one half through just improving hand-washing behaviour (Curtis and Cairncross, 2003). About one third of diarrhoea morbidity and mortality in children under six months can be reduced by exclusive breastfeeding (Feachem and Koblinsky, 1984). Vitamin A supplementation was mostly seen to reduce diarrhoea mortality by about 33%, but a preventive effect on diarrhoea morbidity could not be conclusively found, indicating that Vitamin A supplementation affects the severity of the diarrhoea episodes but may not protect significantly from the illness itself (Huttly *et al.*, 1997). Flies can also contribute substantially to the transmission of faeces and diarrhoeal diseases. Recent studies showed that 20% of diarrhoeal morbidity in children aged under five years could be prevented through effective fly control (Chavasse *et al.*, 1999, Emerson *et al.*, 1999).

The health impact of improving water and/or sanitation can be high, but attributing the impact to one or the other type of intervention has been challenging. *Esrey et al.* calculated that the risk of diarrhoeal diseases could be reduced by 26% through the improvement of water and sanitation facilities, and that diarrhoea-specific mortality could be reduced by 65% (Esrey *et al.*, 1991).

As in the previous reviews, the same author emphasises that interventions to improve excreta disposal and to increase water quantity produce greater health impacts than improvements in water quality alone (Esrey *et al.*, 1985, Esrey *et al.*, 1991, Gundry *et al.*, 2004). This was also confirmed by a multi-country review of data from DHS (Demographic and Health Surveys), evaluating the effect of improved infrastructure on diarrhoea risk reduction (Esrey, 1996).

Further preventive measures refer to child immunisation and mothers' nutrition, as well as the control of animal reservoirs and epidemics. While the latter are not less important, they may not influence the incidence of diarrhoea as much as the former factors; their long-term impact on mortality and child development, however, might be considerable.

Targeting major risk factors for diarrhoeal diseases also has positive effects on child growth and development (Black *et al.*, 1984, Checkley *et al.*, 2004, Merchant *et al.*, 2003, Moore *et al.*, 2001), and even some impact on other diseases, such as acute respiratory illnesses (Cairncross, 2003, Roberts *et al.*, 2000, Ryan *et al.*, 2001). The expectation that at least two of the major disease burdens can be reduced considerably through a single preventive hygiene measure (e.g. hand washing), underlines the importance of ensuring basic hygiene services and access to safe water in under-served populations; these basic improvements represent a precondition for health and success against poverty.

In conclusion, simple and specific hygiene behaviours (e.g. hand-washing), control of human excreta, improvement of access to and quality of water and fly control can already block major transmission pathways associated with contracting diarrhoea in developing countries.

Their relative importance will depend on the dominant transmission pathways present in each setting, thus pointing to an in-depth "need assessment", before planning specific interventions.

1.3. Safe water and sanitation

About 1.1 billion people lack access to an improved water supply, and 2.6 billion lack access to improved sanitation (WHO/UNICEF, 2004). Rapid population growth, migration into urban areas and sustainability issues represent major challenges that impede the rapid development of the needed basic infrastructure.

In light of the urgency of the situation, Millennium Development Goals (MDGs) were formulated by 189 member states during the UN Millennium Summit (Appendix 1). Access to safe drinking water and basic sanitation need to be provided to half of the population in need by 2015 (goal 7, target 10 /*www.developmentgoals.org*).

Essentially, about 150 people per minute need to be supported in order to receive access to safe drinking water during the next 10 years; and almost 500 people per minute would need to be provided with access to basic sanitation facilities. Access to improved water sources has improved by almost 10% in the last decade in Sub-Saharan Africa alone, but recent calculations show that at the current coverage rate, the MDG target date of 2015 will be missed if not more people benefit from the already extensive efforts (WHO/UNICEF, 2004).

Providing all people with piped water in their home requires considerable investment and continuing input of financial and human resources. Capital investment for such systems commonly ranges between US$100 and US$150 per person served. It is not realistic to expect such large investments to occur in the foreseeable future (Reiff *et al.*, 1996). The Copenhagen Consensus Project – a commission of eight expert economists – recently ranked three proposals, to spend more of the development budget on water and sanitation, with the second highest rank according to their cost-effective strategy: Focussing on low-cost technologies in urban areas reduced costs, and strengthening local management increased sustainability.

The most urgent issues relating to target 10 of the MDGs are the development of new strategies for scaling up the provision of basic services, assuring their sustainability, safety and environmental compatibility. Promising experiences are currently made with partnerships between the public and the private sector and committed local governments.

This strategy closely relates to the eighth MDG, to build a global partnership for development. It also demonstrates the associations between the individual MDGs, and points towards the necessity for trans- and interdisciplinary actions to achieve them.

Present indicators for measuring progress towards the achievement of MDGs may still miss a considerable proportion of people that have access to improved water sources, but drink heavily contaminated water and therefore remain at high risk of water-borne diarrhoea. The WHO and UNICEF regularly evaluate the number of people having access to improved services. Under “improved” services, WHO/UNICEF defined specific indicators on the assumption that “improved technologies” are those that are more likely to provide safe services (see Appendix 3). For example, a household connection, a protected well or spring as well as rainwater collection are classified as “improved drinking water sources”. On the other hand, bottled water is considered “unimproved” as the water quantity – not quality – remains limited. The sustainable access to water may improve hygienic conditions in the household. However, water-borne diseases are not eliminated by the provision of improved access to water alone. Recurring cholera epidemics show best how critical the access to unsafe water can be. Such epidemics account for about 120’000 lives per year out of 18 million cases in the world (Global Task Force on Cholera Control, 2003).

1.4. Improving access to safe water sources

The primary objective is to provide sufficient water to the population in need for their basic requirements. As a secondary objective, the quality of drinking water must be guaranteed. The achievement of both objectives would reduce hygiene related and water-borne diseases considerably and be in line with target 10 of the MDGs: to not only provide *access*, but also guarantee the *safety* of the supplied water (Appendix 1).

The realisation, that also the poorest people would pay for good quality and essential services, was crucial for the development of new strategies to provide water and sanitation services.

A promising and feasible way forward is currently seen in (a) carrying out local promotional campaigns for basic services, (b) establishing and supporting the local, private sector that provides the services, and (c) ensuring the availability of services through a strong public sector. In addition, such a strategy would create new jobs and income opportunities and can be supported with comparatively low subsidies.

A seven-year Zimbabwean rural water and sanitation supply programme (1984 – 91) that relied on the enthusiastic support of target communities recorded that national coverage of basic water supplies had increased from 33% to 55% and with adequate sanitation from 7.5% to 21% (Mäusezahl, 1996). In Bangladesh, subsidised latrines were not successful until a "social mobilisation" campaign was launched, aimed at positioning latrines as desirable products, that increased the prestige and privacy of potential costumers: The result was a 25% increase of latrine coverage in rural areas (SDC, 2004). Valuable experience was obtained with public-private partnerships on hand-washing campaigns in Central America, and important lessons were drawn with respect to collaborative approaches and sustainability (Clasen, 2002). The project triggered a global hand-washing campaign, starting in Ghana and India, that is now expanding to Senegal, Peru, China and Nepal (Saadé *et al.*, 2001, SDC, 2004). A public-private partnership project provided access to water and sanitation in El Alto, Bolivia. Here, a large, private, water provider was interested in building the necessary infrastructure to immigrating rural Aymara people, recognising that in the long run, such people would become good and reliable customers (SDC, 2004).

The applicability and feasibility of such strategies for the provision of access to water seems promising, since it takes place locally where the market is driven by demand and quality of service. Water remains a public good and in developing countries, governments could take over responsibility (i.e. set regulations or become providers) to guarantee sufficient water of safe quality to all inhabitants.

Potential difficulties can arise from the fact that the public and private sector follow different objectives and priorities in such programmes. The Swiss Agency for Development and Cooperation (SDC), the Swiss Secretariat of Economic Affairs (Seco) and a global re-insurer (SwissRe) are currently establishing a ‘code of conduct’ (renamed “Policy Principles and Implementation Guidelines”) for public-private partnerships in development aid. The initiative combines the policy principles, the guidelines and the tool kit.

Public-private partnerships for the provision of water are more easily established in urban and peri-urban areas than in rural areas. However, six rural people lack access to improved water facilities, compared to one urban person (WHO/UNICEF, 2004). Small-scale water providers are generally not existent, and markets are unlikely to develop where population density is low and environmental conditions make difficult the installation of sustainable infrastructure. Yet, the development of infrastructure and of economic opportunities in rural areas is crucial, in order to decrease migration of people into urban areas. Subsidised installation of infrastructure with community participation is often the only way for the local population to obtain access to improved water sources.

Where water is available in sufficient quantities (improved or unimproved), water quality is often not guaranteed. The MDGs, however, emphasise the safety of the services provided. Current reports from improved water and sanitation coverage surveys (conducted by WHO/UNICEF) do not identify the water quality component, and the proportion of the population using *safe* drinking water can be assumed lower than the percentage using *improved* water sources (WHO/UNICEF, 2004). In the meantime, more people than reported drink contaminated water on a daily basis; and in addition to contamination at the water source, inaccurate water handling in the home leads to secondary contamination of drinking water that places consumers at higher risk of contracting diarrhoeal diseases (Figure 1.1).

Home-based water disinfection methods were proclaimed as decentralised – and therefore promising – options for populations that cannot be reached by water systems in the near future, or continue drinking contaminated water after access is provided (Mintz *et al.*, 2001).

The World Health Organisation evaluated several home-based water disinfection systems with the purpose to identify the most promising methods (Sobsey, 2002). The reviewer concluded that solar disinfection and chlorination with safe storage were the water purification methods with most encouraging evidence of efficacy. In-home water disinfection and safe storage can effectively isolate people from water borne infections, independent of external factors – e.g. contamination of water sources by animals and humans, or failure to add chlorine to an established water system. Safe water storage through special vessels that inhibit hand contact with the water, prevent secondary contamination of the drinking water.

In conclusion, current strategies for providing people with access to water are promising, but may not be suitable for areas of low population density with little perspective for economic growth (e.g. rural areas). The number of people without access to improved water sources is high, but the population drinking contaminated water is estimated to be higher. It may further prove challenging to guarantee the quality of drinking water in these populations. Methods that allow the disinfection of the water at the place where it is consumed – point-of-use methods –, may provide a low-cost, promising, easy and flexible solution for increasing drinking water quality and reducing water-borne diarrhoeal diseases in much of the population in need.

1.5. Home-based water purification methods

Most studies do not differentiate sufficiently between impacts due to water quality and those related to the supply of sufficient water alone. Nonetheless, the attainment of high water quality is crucial for the health of consumers and the only way of preventing the transmission of water-borne diseases or epidemics, such as cholera.

The health impact of home-based water disinfection methods on local consumers may be considerably higher than that due to improved water quality from centralised treatment facilities, as such methods often include changes in hygiene behaviour as an integral part of their application. Pruess *et al.* estimated that the diarrhoeal disease burden could be reduced by half due to the introduction of home-based methods that guarantee the safe storage and quality of water (Pruess *et al.*, 2003).

Table 1.2 illustrates some of the recent investigations on the health impact of different methods for the disinfection of drinking water at the place where it is consumed, i.e. at point-of-use. The exact attributable fractions of improved water quality, safe storage and hygiene behavioural change to the measured diarrhoea risk reduction are difficult to assess, and remain controversial. However, single studies on point-of-use water treatment methods support the further research and promotion of these systems.

Gundry *et al.* recently reviewed some 28 studies on health outcomes, related to household water quality in developing countries (Gundry *et al.*, 2004). He found no direct and general association between 'improved drinking water quality at point-of-use' and diarrhoea, although all *single* studies showed a significant preventive effect.

On the other hand, water quality at point-of-use was significantly associated with cholera in the population, and point-of-use interventions successfully prevented cholera in general. The mismatch between the water quality indicator (thermo-tolerant coliform bacteria) and the diarrhoeal pathogens may conceal the true preventive effect of point-of-use interventions. Furthermore, a significant proportion of the measured preventive effect of home-based water purification systems may be attributable to hygiene education, which often accompanies the introduction of point-of-use methodologies. The results of this article were criticised due to its limited literature search (Clasen and Cairncross, 2004). More exact figures can be expected from a comprehensive Cochrane review of "interventions to improve water quality for preventing infectious diarrhoea", that is expected to be published by the end of the year 2004 (Clasen *et al.*, 2004b).

Recently, technologies and methodologies for the purification of household drinking water at point-of-use have been reviewed by the World Health Organisation (WHO), with the objective of identifying the most promising methods (Sobsey, 2002). Criteria for the selection of the most promising methods included: (a) high effectiveness in improving and maintaining microbial water quality; (b) significantly reduce water-borne infectious disease; (c) simple and accessible to the target population; (d) cost-effective for the beneficiary and provider; (e) socio-culturally acceptable, sustainable and have potential for larger scale promotion.

Table 1.2: Health impact of point-of-use water disinfection methods.

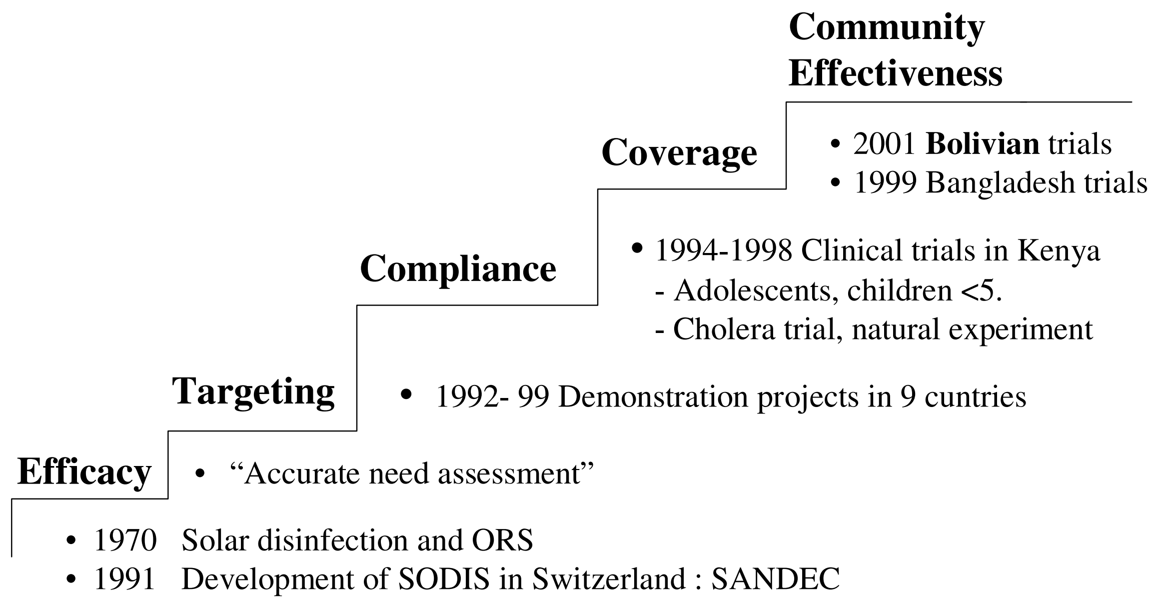
Study	*Intervention*	*Control-intervention*	*Study group, Place*	*Time follow up*	*Measured reduction in diarrhoea*
Clasen et al. *(Clasen et al., 2004a)*	Ceramic filters	None	Households, Bolivia	6 mths	64% (prevalence)
			Children<5y, Bolivia	6 mths	72% (prevalence)
Quick et al. *(Quick et al., 1999)*	Sodium hypochloride* + vessel	None	Household, Bolivia	5 mths	44% (incidence)
			Infants, Bolivia	5 mths	52% (incidence)
			Children 5 – 14y, Bolivia	5 mths	59% (incidence)
Reller et al. *(Reller et al., 2003)*	Flocculent-Disinfectant**	None	Households w\infants, Guatemala	1 year	24% (incidence)
	Flocculent-Disinfectant** + vessel	None		1 year	29% (incidence)
	Bleach	None		1 year	25% (incidence)
	Bleach + vessel	None		1 year	12% (incidence)
Roberts et al. *(Roberts et al., 2001)*	Improved vessel	None	Malawi Children <5y, refugee camp	4 mths	31.1% (incidence)***
Conroy et al. *(Conroy et al., 1996)*	Solar Disinfection (Heating)	Safe storage, no disinfection	Massai Children 5 – 15y, Kenya	12 wks	9% (incidence)
					24% (incidence) (severe episodes)
Conroy et al. *(Conroy et al., 1999)*	Solar Disinfection (Heating)	Safe storage, no disinfection	Massai Children <6y, Kenya	1 year	16% (prevalence)

***Legend**: * Same as bleach. ** Manufactured powder induces flocculation and leaves chlorine residuals in the water. *** Association significant at p=0.06. 'Vessel': Improved vessel inhibiting contact with hands.*

A summary of the technologies investigated is given in Appendix 2. Based on the above criteria, the WHO earmarked solar water disinfection (UV and heat) and chlorination, including safe storage, as the most promising and effective household water treatment and storage systems to protect people from drinking contaminated water and diarrhoeal diseases (Sobsey, 2002).

The solar water disinfection is especially appealing because it uses sunlight (UV-light and temperature) to disinfect water in freely available PET bottles. To date, efficacy of the method has been well documented (see below). However, high efficacy (i.e. the result of an intervention under ideal conditions) does not necessarily imply high effectiveness (actual result observed in "real life" situations).

In the case of solar water disinfection, high effectiveness is attained, when the highest success rate for each of the following factors is achieved: efficacy, accurate community need assessment, compliance and coverage (Tanner *et al.*, 1993).



From: Mäusezahl, D (Mäusezahl et al., 2003); adapted from Tanner, M (Tanner et al., 1993)

This research concentrated on (a) the promotion, compliance and methodological aspects of the home-based solar water disinfection method (SODIS); (b) estimated the effectiveness of the home-based methodology on diarrhoea frequency in rural children under the age of five years. The results intended to support policy decisions for further and wider dissemination of the methodology.

1.6. Solar Water Disinfection (SODIS) – moving towards effectiveness

Solar water disinfection (SODIS) represents one of the most promising home-based water disinfection methods, due to its easy application, low cost and reliance on abundant and natural energy.

In summary, water-filled, transparent or lightly tinted blue PET bottles are exposed to full sunlight for at least 6 hours. The synergistic effect of UV-A and temperature eliminates 99.9% (3-log-reduction) of the viral and bacterial contamination in the water.

The SODIS method is in a transition phase from efficacy to effectiveness. Under laboratory conditions, research was conducted on the efficacy of reducing the quantity of different microorganisms and pathogens in water, and the limiting factors of the methodology were identified. Field experiments were carried out to assess the applicability of the SODIS process under controlled conditions. A five-step user guide was developed, but the application of the method in the field was and is often adapted to specific local conditions. A limited series of studies on the method's impact on health were carried out under controlled conditions. Solid evidence on acceptance, compliance and coverage is scarce, although many pilot studies and programmes have been conducted on a world-wide basis. In the following, we consolidated a more detailed review of published literature that identifies the missing evidence that directed the current research.

1.6.1. Water disinfection efficacy

Already in 1877, the fundamental principles of the solar water disinfection methodology have been discovered (Downes and Blunt, 1877). Downs and Blunt conducted a series of simple experiments on growing media in test tubes and concluded that: (i) light can prevent the growth and development of bacteria and fungus; (ii) the preservative effect [of the sun on the exposed media] is highest in full light, but is also active under diffuse daylight; (iii) the effect is mainly […] associated with the chemically active rays of the spectrum; (iv) the germs present in such media may be wholly destroyed […] by the unaided action of sunlight.

Further experiments already pointed towards the need of oxygen in the disinfection process of previously vacuumed test tubes. Oxygen was later identified as a crucial component of the solar disinfection process. UV-A radiation generates oxygen radicals that are essential for the inactivation of microorganisms (Reed, 1997, Reed *et al.*, 2000). To achieve an equilibrium between oxygen levels in air and water, potential users are recommended to shake bottles before sun exposure (Kehoe *et al.*, 2001).

More than a 100 years after Downs' and Blunt's experiments, Acra *et al.* from the American University of Beirut placed the cornerstone for the further development of solar irradiation of water and oral rehydration solutions in 1980 (Acra *et al.*, 1980, Acra *et al.*, 1984a, Acra *et al.*, 1984b). He detected that coliform and other enteric bacteria counts (*Salmonella typhi*, *-enteritis*, *-paratyphi B* as well as *E.coli*) declined exponentially through the exposure of transparent, water-filled containers to sunlight for at least 70 minutes (Acra *et al.*, 1984a). This motivated several research groups to investigate the efficacy of the process on additional pathogenic organisms. The reduction and inactivation of *Vibrio cholerae* (McKenzie *et al.*, 1992, Solarte *et al.*, 1997) and *Shigella dysenteriae* (Kehoe *et al.*, 2004) in water exposed to sunlight was confirmed. *Salmonella typhimurium* was shown to no longer be infectious after 8 hours of sun exposure (Smith *et al.*, 2000). The ability of solar disinfection to inactivate viruses was also published (Wegelin *et al.*, 1994). In 1994, Wegelin *et al.* proved the synergistic effect of UV radiation and temperature and placed a further milestone in the development of the technology (Wegelin *et al.*, 1994). Recent field experiments in Bolivia found an inactivation rate for *Giardia lamblia* and *Cryptosporidium parvum* ranging from 34% to 68%, depending mainly on the climatic region – efficacy was highest at high altitudes. These experiments confirmed previous laboratory simulations in the conclusion that *Cryptosporidium parvum* was more resistant to sunlight than *Giardia lamblia,* and may not be easily destroyed by the SODIS process (Almanza, 2003, Oates *et al.*, 2003, Zerbini, 2000). Current field research is examining the effect of sunlight on *Entamoeba histolytica* cysts in different regions of Bolivia.

1.6.2. Limiting factors of solar water disinfection

A variety of factors that potentially influence the process of solar disinfection and aspects that could limit its use in the field were already identified in 1980 in Beirut (Acra *et al.*, 1984a): the intensity of sunlight (and local weather conditions); inherent properties of the microorganisms and the media they are in; characteristics of the container; the clarity of the water intended for disinfection and the limited volume that can be disinfected; additional work and time spent by local (target) people for water disinfection.

A turbidity threshold of <30NTU was defined where the disinfection of water could still be feasible during 6 hours of full sunlight exposure. The same group further discovered that 25% of UV-A was lost per 10 cm of penetration depth, concluding that containers for SODIS application should not exceed this measure of depth (Wegelin *et al.*, 1994). Later research provided more detailed insight into the technological process, and confirmed earlier findings on the SODIS method (McGuigan *et al.*, 1998).

The use of reflective surfaces produced more efficient inactivation, but transmittance of PET bottles was reduced after four months of continuous sun-exposure (Kehoe *et al.*, 2001). Prolonged exposure of PET bottles to the sun also required a chemical risk assessment. Recent research could not find health threatening levels of plasticizers or other critical organic components in the water after more than 90 days of constant sun exposure; all detected concentrations were under the recommended threshold for water quality (Kohler and Wolfenberger, 2003, Wegelin *et al.*, 2001).

The laboratory and field investigations described above led to various promotion material and a theoretical “field-applicable” 5-step operating instructions for the SODIS method (Meierhofer and Wegelin, 2002) including: [1] wash the bottle and cap well, [2] fill the bottle ¾ full, [3] shake the bottle for 20 seconds, [4] fully fill and close the bottle, [5] expose the bottle for at least 6 hours to full sunlight or 2 days under cloudy conditions.

SODIS Leaflet; from www.sodis.ch

1.6.3. Applicability and health impact of solar water disinfection

First field experiments in Africa yielded inconclusive results on the water disinfection by sunlight, and the authors concluded from their experience that the limited water volume and the large numbers of plastic containers needed for a family, made the method impractical for home disinfection (De Lorenzi *et al.*, 1989). The limitation of drinking water volume directed further research into generating a first model of a “continuous flow system” for the dechlorination and disinfection of water through sunlight (Acra *et al.*, 1984a). Other systems were later developed, but never tested on a larger scale (Sommer *et al.*, 1997).

By the end of the 80's a debate had started, concerning the applicability of the SODIS method in emergency situations, its usefulness and reliability (Miller, 1988, Acra *et al.*, 1989, Morley, 1988).

Solar water disinfection could not be proclaimed easily for emergency situations, as the reduction of water contamination through sunlight exposure seemed to vary according to local conditions, such as altitude and intensity of ultraviolet light (McKenzie *et al.*, 1992). On the other hand, optimistic results from laboratory experiments and field-tests in Columbia, Costa Rica, Jordan and Thailand were reported (Wegelin *et al.*, 1994).

After providing further evidence of the efficacy of the process "under the weak Irish sun" (Joyce *et al.*, 1992), Joyce *et al.* performed first experiments in Kenya under sub-optimal conditions (1996). Here, findings indicated that sunlight exposure of turbid water (~200NTU) can effectively reduce indicator bacteria, if the water temperature rises above 55°C (Joyce *et al.*, 1996). This study directed further research on the health impact of 'solar heating' of drinking water among Massai people.

The first health impact study reported that children aged 5 – 15 years, living in intervention households, suffered 9% less diarrhoea, and 24% less severe diarrhoea, than children of the same age in the control group (Conroy *et al.*, 1996). A one-year follow-up of the same cohorts indicated that the risk of diarrhoea was reduced by 16% in children under the age of six years living in intervention households compared to children of the same age, living in control households (Conroy *et al.*, 1999). Two years later, the same researchers were able to conduct a natural experiment during a cholera outbreak in the same population, and found a significant cholera preventive effect of 'solar heating' in children under the age of six years that belonged to the originally introduced families, compared to children of the control families in the study area (Conroy *et al.*, 2001).

The review of the literature shows that extensive research from independent groups demonstrates the high efficacy of the SODIS process to inactivate partly or entirely, different indicator – and pathogenic –organisms under different conditions. The formulated guidelines for the application of the SODIS method were bound to vary somewhat by area of implementation due to the identified limitations.

Regional investigations usually take place for adapting the operating instructions to local settings before the implementation of an approach for the prevention of diarrhoeal diseases can begin. Little, but encouraging evidence exist of significant health gain from introducing the SODIS method into a community or household.

However, high effectiveness at population level will depend on the accuracy of targeting the population most in need of the SODIS method, and on their acceptance and constant application.

1.6.4. Targeting communities in need of solar water disinfection

Need assessment serves to direct interventions towards places where the intervention has the highest potential impact. Areas where people drink microbiologically contaminated water seem to represent the target regions for the SODIS method. A computer simulation for estimating the applicability of the SODIS in any area of the world – based on solar intensities from satellite data – indicated that although useful for broad estimates, they do not replace the efficacy experiments (water quality) on the ground, to adapt the method to local conditions (Oates *et al.*, 2003).

Prioritising interventions cannot be based on normative needs alone, but must include perceived needs, if the intervention is to be successful (Tanner *et al.*, 1993). Current dissemination programmes usually apply certain criteria for the selection of NGO-proposals, to implement the SODIS method in a particular setting. Normative factors still predominate the selection process. During a pilot phase, social aspects are assessed, and any occurring issues tend to be related to a lack of education and to the difficulty of changing behaviour in the target population. The early inclusion of the local population in every stages during need assessment and designing an intervention has been recommended (Seeley *et al.*, 1995). In the SODIS promotion programmes, promising attempts have been made to include such principles into the selection process of accurate implementation sites, but the bottom line is, the implementers, not the population, usually decide on the “accurate” area and approaches for the intervention.

Specific criteria for the selection of potential communities were identified, including normative and locally perceived needs, during a field study on the acceptability, adoption and impact of the SODIS method in Bangladesh (see Chapter 6) (Hobbins *et al.*, 2000b):

- Environmental conditions are favourable for the application of SODIS
- Communities have the resources for the application of SODIS (e.g. contaminated water of low turbidity, places where no shading occurs, possibilities for bottle-provision)
- Social and cultural setting allow for the implementation and adoption of the SODIS method (e.g. the household head agrees on the topic and the new method)
- Family members perceive their drinking water sources as “dirty” or “unsafe”
- People feel the need, and request assistance for solutions concerning their polluted drinking water
- Local organisation or institution is capable to introduce, support, supervise and monitor closely the adoption and use of the SODIS method

We applied the above criteria during our study in Bolivia, to identify communities which were best suited for the planned intervention programme (see Chapter 3) (Hobbins *et al.*, 2002, Truninger, 2001).

Participatory approaches can accurately estimate the need for the method in a community. If need assessment is performed without the inclusion of the perceived needs in the population, poor compliance rates will reflect that communities followed other priorities.

1.6.5. Coverage of and compliance to solar water disinfection

The solar water disinfection method is being disseminated through pilot projects and long-term programmes in various countries in Latin America, Africa, Asia and South East Asia. Nevertheless, global coverage of the method is low – comparing provided “service” with potential need –. For example, in Latin America and the Caribbean, about 60 Million people are estimated to lack access to improved water sources.

A multi-country programme in seven countries of Latin America was able to convince about 2‰ of this population to adopt the SODIS method, through a three-year promotion, expansion and networking effort. Promotion efforts have been slow, because the stakeholders did not believe in the method. Reports of NGOs involved in the dissemination of the SODIS method, find uptake rates in the population of between 30% and 80%. One recent review classifies acceptability as “high to moderate”, based on the proportion of 50% – 75% of the people that were willing to continue after a demonstration project (Sobsey, 2002). The cost of the solar disinfection method was estimated at 3 US$ per year and family of five, based on the willingness to pay of the target population.

Other point of use methods reported adoption rates of 33.5% for chemical treatment and 18.5% for clay pots, modified for safe water storage, following a well-prepared six months’ implementation period, through existing community organizations and encompassing a newly-developed social ‘marketing campaign’ (Makutsa *et al.*, 2001). During a cholera epidemic, demand and compliance for a point-of-use method rose remarkably. Nevertheless, an epidemic setting could lead to the (wrong) perception, that the method is only necessary at such times, making the sustainable application in the population a major issue (Dunston *et al.*, 2001).

The differences in adoption rates can largely be attributed to the specific area, the season of evaluation, the method of implementation and the indicators used during the evaluation (Grimm, 2003, Meierhofer *et al.*, 2003, Vargas, 2003). The SODIS Latin America Programme suggests that the implementing NGO must remain active in the area for at least two years, to ensure better adherence to the use of the method in the target population.

Determinants of use and rejection of the SODIS method will vary by country and culture. Convincing people of the efficacy of the SODIS method means also to overcome cultural barriers, which needs to be taken into consideration during the development of promotion strategies. The selected promotion strategies may need to be based on prior assessments of the cultural context, perceived needs, and how these relate to water management. For example, in a rural Bangladeshi setting, compliance was dependent on cultural factors: the use of plastic containers was new to the target population and sometimes even perceived as a mean to circumvent religiously banned alcohol consumption (Hobbins *et al.*, 2000a).

Many different implementation methods have been tried in different cultural settings, via non-governmental organizations and by governmental ministries, including the mobilization of communities and of children in schools, as well as via household visits and specific motivation techniques. However, a lack of standards on the indicators for evaluating the adoption and continuous use of the method at household level prevents a true estimation of regional and global compliance, coverage, and potential for health improvement. The success of intervention strategies is based on the compliance of the people involved.

The sustained application of the SODIS method after a two-year intervention break was reported in a Massai population during a cholera outbreak where 51% of the originally introduced families were estimated to continue applying the method.

This short review demonstrates that conclusive evidence for the effectiveness of the SODIS method is missing. While the efficacy of the method is well documented, methodologies for need assessment, as well as evidence of compliance and health impact in the target population, are weak. Yet, the coverage of the SODIS method is on the rise and the home-based water purification process is already being disseminated in several countries around the globe at considerable expense.

This background made urgent the present research: to estimate the health effectiveness of the SODIS method. This study represents the first effectiveness investigation on solar water disinfection in a rural Bolivian context. Taking advantage of the focal nature of the solar water disinfection method, our results should find application during the implementers' and researchers' planning-, intervention- and evaluation phase. On a wider scale, the position of such potentially successful point-of-use approaches in the current context of development targets shall be discussed.

1.7. Study background

1.7.1. Site selection

Institutional aspects

A national and Latin American SODIS dissemination programme was launched in the year 2000. Its objective was to make the SODIS method available to people without access to safe drinking water. The programme is coordinated by the Fundación SODIS that arranges workshops for interested organisations, and provides a limited amount of funds and promotion material, for the implementation of the SODIS method as part of an existing development project (e.g. in health, water and sanitation, education). Through this effort some 100, 000 people, supported by about 100 collaborators, now apply the methodology in seven Latin American countries (Bolivia, Peru, Ecuador, Honduras, Nicaragua, El Salvador, Guatemala; *www.fundacionsodis.org*). In addition, a long-term collaboration existed between the Fundación SODIS and the *Universidad Mayor de San Simon* in Cochabamba. As part of the University, the *Centro de Aguas y Saneamiento Ambiental* performed several local research projects to adapt the methodology to the differing conditions in Bolivia – from high altitudes to tropical climates (Almanza, 2003, CdA, 1997).

The presence of a national Bolivian SODIS promotion and diffusion programme with strong ties to international and local NGOs and to research institutions, as well as the preliminary field tests already accomplished in the region, provided an ideal institutional platform for the implementation of an epidemiological study.

National aspects

Bolivia is one of the poorest countries in Latin America where 38% of the population lack access to improved water sources and 37% do not have sanitary installations. Inequity in the access to basic services between urban and rural areas is considerable. Thirty-eight percent of the countries' households are situated in rural areas where 70% lack the access to improved water sources and 67% require basic sanitation services.

In urban areas 17% need access to improved water sources and 18% lack basic sanitation services (*www.ine.gov.bo*, Census 2001). The WHO classifies Bolivia as a region with high child and adult mortality; and in 2002, about one in fifteen children died during the first year of life (*www.paho.org*).

Regional aspects

Our research was conducted in communities situated in the province and district of Mizque (Latitude: 17° 55' 60S, Longitude: 65° 19' 0W), a subtropical Andean valley of the department of Cochabamba, at a distance of 150 km to the main city (Cochabamba) and an altitude of more than 2000 metres above sea level. About 71% of the households lack access to improved water sources, 77% have no electricity and 88% need basic sanitation facilities (*www.ine.gov.bo*, Census 2001). Further details on the study site are described in Chapter 3). According to the records of the national health ministry, about 347 per 1000 children under the age of five years suffer from diarrhoea in the Mizque province. Mortality among infants (<one year of age) was twice as high in the rural Mizque area as in urban Cochabamba, although it had decreased by about seven percent since 1992 (*www.sns.gov.bo/asis.htm*). During our pilot study in 2001, we found a point prevalence of 24.6% of the children under five years of age that suffered from diarrhoea at the time of the interview (Appendix 7). Our later measurements showed that the weekly incidence of diarrhoea in children under the age of five varied between 8% and 17% in study children under five years of age, living in 10 communities in the Mizque district in 2002 (Appendix 8). Risk factors for diarrhoea in the pilot-communities included the drinking water present in the fields and mothers not washing their hands with soap.

We concluded from these facts that an area, where indications for water borne diarrhoeal diseases were so marked, would be ideal for interventions that promoted the disinfection and safe storage of drinking water, as well as appropriate hygiene behaviour messages.

1.7.2. Study design

The randomised control trial is the most rigorous approach for testing hypothesis in epidemiology. A cluster-randomised control trial was designed to measure the health effectiveness of the SODIS method in children under the age of five years in rural Bolivia (Mäusezahl *et al.*, 2003). Nevertheless, three significant factors led to the decision to postpone the planned randomised control trial.

First, funds were not guaranteed after the completion of the pilot study, so that the starting time of a randomised control trial was uncertain. Secondly, pressure to produce rapid results on the health effectiveness of the SODIS method was high among implementers and policy makers. And thirdly, operational challenges impeded the random allocation of the intervention – a key feature for choosing this design. An alternative approach that could be carried out with restricted resources and seemed better suited to the actual setting, was therefore developed.

The nested case-control approach provided the basic framework for estimating the effectiveness of the SODIS method for reducing diarrhoea incidence in children under the age of five years. The validity of the case-control approach for health impact assessment has been discussed extensively, particularly as a tool for the rapid assessment of the health impact of interventions (Baltazar, 1991, Kirkwood *et al.*, 1997). The inherent rare disease assumption in the case-control approach is not necessary in the chosen design, as cases and controls are recruited simultaneously from the surveyed population. Kirkwood *et al.* presented a pragmatic approach, where the credibility of observational research can equal that of a randomised control trial: different design elements are selected carefully and combined in such way that the sum of the evidence provides a clear picture of the impact of the intervention (Kirkwood *et al.*, 1997). Following a similar approach, a series of methodological tools for the evaluation of the health impact of water and sanitation facilities in Zimbabwe were developed and applied, and the findings from qualitative research and observational studies were united to draw valid conclusions (Mäusezahl, 1996).

Comparable tools were applied to assess major risk factors from urban agriculture in China, estimating community effectiveness from appropriate and cost-effective measures against Hepatitis A (Mäusezahl *et al.*, 1996). Since then, case-control approaches in combination with other study designs (e.g. repeated cross sectional studies and qualitative assessments) to evaluate the health effect of an intervention were effectively applied in various settings. Some example included measuring the effectiveness of net interventions against malaria mortality in children (Schellenberg *et al.*, 2001), and the effect of hand washing on diarrhoea (Curtis and Cairncross, 2003). The latter more closely relates to the challenges of this approach to measure the effectiveness of a home-based water disinfection method, where outcome (diarrhoea) and exposure (drinking SODIS purified water) require careful assessment through valid indicators.

This research assesses the effectiveness of a home-based water purification method through a nested case-control design supported by analytic–, qualitative– and cross-sectional studies. The advantages of this design, when compared to the cluster-randomised control trial in this setting, included the short time for the impact assessment, the low costs, and the simpler and quicker implementation of the study. On the other hand, retrospective studies are vulnerable to bias and confounding for which essential preventive measures were performed, such as blinding of field staff, unannounced visits to households, the use of spot-observations and careful interview technique, and others that can be read throughout the following chapters.

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2. GOALS AND OBJECTIVES

2.1. Goal

To measure the effectiveness of home-based solar water disinfection on the health of rural Bolivian children under five years of age

2.2. Specific objectives

- To formulate specific criteria for community selection for the SODIS implementation while identifying the role of solar water disinfection as an arsenic mitigation option in Bangladesh
- Identify, compare and validate indicators for classifying a household that applies the solar water disinfection methodology, enabling the rapid, large scale assessment of the uptake of the method at community level
- To describe main determinants for the adoption and rejection of solar water disinfection to formulate future implementation strategies
- Evaluate and compare the impact of different newly developed implementation strategies for the promotion of solar water disinfection on the household's readiness to adopt the methodology
- To compare the water quality between treated and untreated drinking water samples in households participating in the health impact assessment and identify the most effective field practice for solar water disinfection in this population
- To estimate the diarrhoea incidence rate of a child under five years of age living in the communities by monitoring the occurrence of diarrhoea in study children at community level on a weekly basis
- To identify main diarrhoea causative agents, their prevalence and risk factors for re-infection, by examining multiple stool specimens of children under five years of age in rural Bolivia

CHAPTER 3

Implementation and promotion essentials for home-based water disinfection in rural Bolivia

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3.1. Abstract

Background: Solar water disinfection (SODIS) is a simple, cheap and efficient home-based methodology. It is often not clear from field reports, to what extend a chosen implementation approach affected behaviour change in the target population by disseminating knowledge and influencing attitude. In the framework of a study to measure the effectiveness of the SODIS method on the health of children under the age of five, we developed and evaluated new ideas for the promotion of the SODIS method. *Goal*: To estimate the individual and joint effect of the applied promotion strategies on the knowledge of, attitude towards, and practice of the SODIS method in the target population. *Method*: We applied three different SODIS promotion strategies: (i) community-based workshops, (ii) monthly household visits, (iii) district-wide school campaign, during a nine-month period in the year 2002, in 18 rural communities in the province of Mizque, Cochabamba, Bolivia. The impact of the different implementation strategies were calculated by comparing indicators for changes in the knowledge of, attitude towards and practice of the SODIS method between families that were differently exposed to the various individual interventions. *Results*: As a result of the implementation efforts, about one third of the target population adopted the SODIS method. Individual strategies affected the population differently. The population was more aware of the SODIS method and its underlying germ-disease concepts (school campaign, household visits) and adopted the SODIS method effectively (workshops, household visits). Communication networks inside the community were supported (household visits) and tangible benefits (e.g. transportable water) of the new method were being recognised in the households (school campaign). *Discussion:* The coordination of several promotion strategies at the same time will lead to higher impact of the entire programme. Individual campaigns should be selected and combined with care, such as interferences can be avoided (e.g. competition for bottles). The presented findings contribute to allocate restricted funds towards efficient programming and increases chances for the sustainability of an intervention.

3.2. Background and introduction

Careful monitoring and evaluation of the impact of development programmes on behavioural change, can provide insights for future implementers on the success of different strategies (Curtis *et al.*, 1997). Several manuals have been written describing methodologies for bottom-up programming in connection with hygiene promotion. Findings from formative research – a systematic approach, that links key questions to methods for determining programme design – concerning people's awareness and practice, were combined with expert knowledge, so that appropriate communication strategies could be developed for achieving effective and sustainable behavioural change (Unicef, 1999). The use of several communication strategies, that present key messages in different ways, were suggested in order to enhance learning (Mitchell *et al.*, 2001). Demonstrations, videos, and leaflets can be shown widely, but they provide only limited opportunity for targeting messages at specific groups or individuals. The importance of performing *targeted* interventions was shown in a study comparing three programmes that were carried out in different African countries and that promoted the application of a point-of-use water disinfection technology. The study pointed out that in addition to social marketing campaigns, motivational household visits or community mobilization would reach the economically disadvantaged communities and increase product adoption (Quick, 2003). Information of this kind is essential for allocating restricted funds to efficient programming and maximizing the chance of sustainable application of a new method or lasting behavioural change.

During the last 20 years, research on solar water disinfection (SODIS) has resulted in a simple, cheap and efficient point-of use methodology for the disinfection of household drinking water (Acra *et al.*, 1980, Acra *et al.*, 1984, McGuigan *et al.*, 1998, Reed *et al.*, 2000, Wegelin *et al.*, 1994). A five-step protocol for disinfecting water in the home has been developed (Figure 3.1/www.sodis.ch).

The acceptance of the SODIS method at population level in different countries has been reported as high (Wegelin and Sommer, 1998). Key experiences and lessons learnt from the implementation of SODIS-pilot projects in various countries have recently been summarised (Meierhofer and Wegelin, 2002, Wegelin and De Stoop, 1999):

Normative needs should present in the target area (e.g. bad drinking water quality); local information channels are supposed to be followed to make a first contact with the target population; the key community decision makers may be involved in the promotion process; the implementation approach should be sensitive to gender roles and adapted to the cultural and traditional background of the target population; participatory methods with practical demonstrations could form the basis for introducing the SODIS application, accompanied with hygiene messages (such as hand washing); frequent follow-up of the target families, and a prolonged presence of the implementing NGO is recommended, to ensure a better incorporation of the SODIS method.

Figure 3.1: Five-step protocol for handling the SODIS method

Legend: [1] Use clean and transparent PET bottles with clean tap (or clean bottle and tap well) [2] fill the bottle with clear water and close it well (you may also shake the bottle for 20 seconds before filling it completely) [3] expose the bottles to the sun early in the morning by putting them on the roof of your house [4] and at night, take the bottles down (or after at least 6 hours, however, if the day was clouded, leave the bottles exposed for one more day) [5] let water cool down and drink out of a clean glass or mug. Kindly made available by EAWAG.

A national and Latin American SODIS dissemination programme was launched in the year 2000, with the objective to bring the SODIS method to people in need of safe drinking water. As of today, about 100 collaborators stimulated about 100'000 people in seven Latin American countries, to apply the SODIS method (Bolivia, Peru, Ecuador, Honduras, Nicaragua, El Salvador, Guatemala).

The *Fundación SODIS* in Bolivia is the central office and arranges workshops for interested organisations. Following a review process, limited funding and promotion materials are provided for the implementation of SODIS, as part of an existing development project (*www.fundacionsodis.org*). Community mobilisation and presentations, individual household visits, fairs and school campaigns, radio advertisements and songs, were and are among the main promotion strategies in the area (Fundación SODIS, 2004, EAWAG/SANDEC, 2002).

Through such common implementation strategies, the uptake in the target population is mostly reported as being between 30% - 80% (Grimm, 2003, Meierhofer *et al.*, 2003, Sobsey, 2002, Vargas, 2003). The sustained application of the SODIS method was observed in a Massai population following a two-year intervention break during a cholera outbreak, with 51% of the originally-introduced families continuing to apply the method (Conroy *et al.*, 2001). A comparison of field reports is hampered by the different and often poorly described assessment approaches. There is a need for standardized and reproducible methods that allow input, process and outcome to be properly measured.

Within the framework of a study to measure the effectiveness of the SODIS method on the health in children under the age of five (Hobbins, 2003), we have developed and tested new ideas for the methods' promotion. This contributed new knowledge on specific changes induced in the target population through a variety of promotion approaches (regular household visits, community events, school campaign). We report on the first scientific validation of the actual success of different promotional approaches in a rural Bolivian setting.

3.3. Objective

Our goal was to estimate the individual and joint effect of the applied promotion strategies on the knowledge of, attitude towards and practice of the SODIS method in the target population.

3.4. Approach

We first investigated local communication channels, peoples' perception of health, illness and water, their priorities and felt needs, as well as the households' water management habits and related risk factors for child health. Based on the findings of this pilot study we carried out in 2001 and on the experience of our local collaborators (*Unicef-Bolivia, Fundación SODIS*), we developed three implementation strategies that fitted the given setting. Each approach was designed to promote the use of the solar water disinfection method (SODIS) in the study communities, without replacing already existing and equally valid water disinfection habits (e.g. boiling of water).

(i) We started the nine-months' SODIS intervention with monthly community-based participatory workshops in March, to introduce the importance of clean water for the prevention of diarrhoea in children and in this context, the SODIS method and its application. (ii) The additional monthly household visits (until December) and (iii) a school campaign (September – November) complemented the entire intervention during the year 2002. The partner NGO provided experienced field promoters for the SODIS implementation, guided by a project coordinator and an auxiliary nurse. Two surveys evaluated the households' knowledge, perception and use of the method at different times during the year 2002. We compared indicators – for the knowledge of, attitude towards, and practice of the SODIS method (e.g. awareness of the relation between water and health, perceived benefits, observed SODIS-purified water in the house) – between households in our target community that were exposed to one or more of the promotional activities. In addition, we evaluated the communication channels and the potential for sustained use of the SODIS method in the examined households.

3.5. Study site and setting

The study was conducted in Mizque, a subtropical Andean valley of the department of Cochabamba, at a four hours distance from the main city and at an altitude of around 2000 meters above sea level. About 36'200 people, mainly of Quechua ethnicity, lived in the Mizque area. The majority followed the Christian religion. Population density was approximately 13.3 people/km2. On average, 4.1 persons lived in a household, with 3.3 persons sleeping in the same room.

Thirty-nine percent of the population was analphabetic. Approximately 70% of the 6 – 19 year olds had visited school, on average for three years.

Seventy-one percent of the households in the area had no access to piped water, 77% had no electricity and 88% lacked sanitation services (Instituto National de Estadístíca, 2002). The warm climate with a pronounced dry season (April–November) and a moderate rainy season provided ideal conditions for the application of solar water disinfection.

We selected our study communities according to specific criteria, including operational feasibility, normative and felt needs and demand in the community. A list of 161 potential study communities in the area was reduced to eighteen, Quechua speaking communities that took part in the intervention (Appendix 4). The sizes of the communities varied between 30 and 120 households. Agriculture was the main source of income. The farmers were centrally organized in a farmers' union, whose centre was in the village of Mizque. The community leader (dirigente) took care of water and agriculture concerns in the communities together with an elected group of representative community people, and decided on community development activities in general.

In 13 of the 18 participating communities, people completely lacked access to improved water systems. Irrigation channels, small springs and ponds served as water sources. All of them were highly contaminated with faecal matter and became turbid after intensive rainfalls. Five communities had water systems installed, to which only few inhabitants had access. These water systems provided untreated water from the heavily contaminated river *Rio Mizque*. On average, water was collected four times per day, mainly in buckets (74.5%) and small canisters (17%). More than 60% of all households were storing drinking water for more than 24 hours. Over 70% of the study population drank boiled water in the morning (e.g. tea, boiled local beverage), and about 10% of the families drank boiled water during the entire day. Outside their homes, most people were used to drinking untreated water. Secondary contamination at household level was common in this area, as indicated by the higher water contamination of household drinking water samples than that of community water sources (Hobbins *et al.*, 2002, Truninger, 2001).

Apart from respiratory tract infections, diarrhoeal diseases were among the main causes of child morbidity and mortality in Mizque (Servicio Nacional de Salud and Ministerio de Salud y Previsión Social, 2003). During a pilot study, we demonstrated that water was one of the main transmission pathways for acute diarrhoea in children in this area (Hobbins *et al.*, 2002). To design the approach for introducing the SODIS method, it was important to identify local beliefs for the causes of diseases and especially gastrointestinal illnesses as well as modes of prevention (Kaltenthaler and Drasar, 1996, Pitts *et al.*, 1996, Weiss, 1988). We found one general term and 10 specific vernacular terms that classified gastrointestinal illnesses according to the colour, odour and frequency of the stool.

Each term associated a cause with physical changes (e.g. falling on one's hindside, growth of teeth), age (e.g. beginning to crawl), climate (e.g. cold hindside, internal or external heat) or sensory and spiritual aspects (e.g. odours of cadaver).

Except for cholera and the general term “K’echalera”, standing for “liquid bowel movements”, none of the terms were related to hygiene, to water, or reflected the western understanding of germs causing illnesses (see Appendix 9). These health concepts led mothers of sick children to distrust the approaches of the local hospital and prefer to seek help from traditional healers.

3.6. Methods

All implementation strategies that were applied targeted the same study households at different times and with different intensities. Each presented the key messages for the adoption of the SODIS process in different ways and through various channels. An evaluation at the end of the intervention determined the extent to which each family was exposed to any of the implementation strategies. This enabled us to calculate at what level (e.g. with respect to knowledge, attitude, use) each strategy had its highest impact in the population.

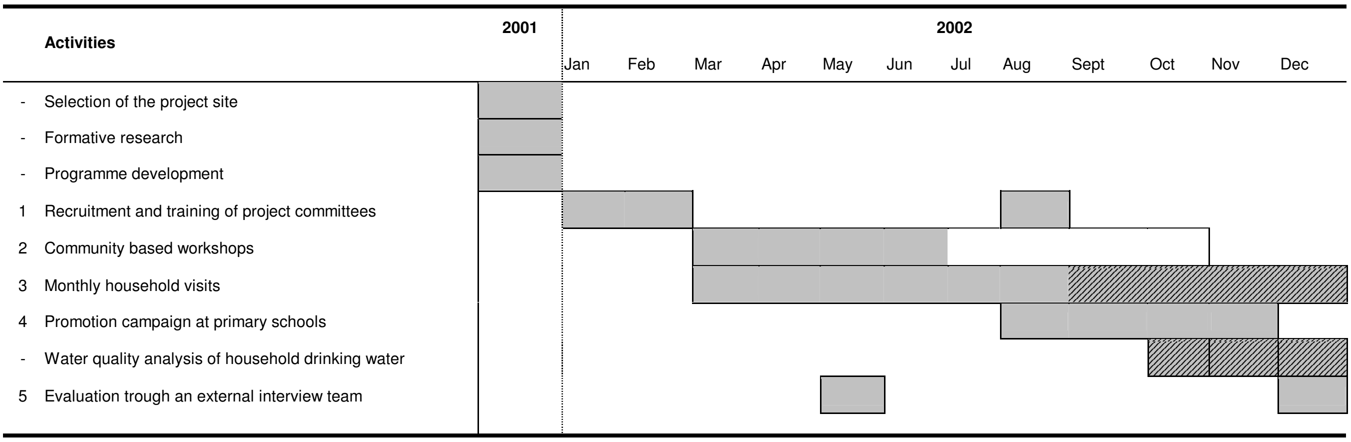
The entire study was approved by a WHO review board. We followed an established information channel that was mandatory for the programmes' acceptance in the area, since the population often deeply distrusted foreigners: first, we received written permission from the local government that enabled us to work in the area; second, we obtained informed consent from the local farmers' union; and third, we presented the project at the regular fortnightly community reunions. The population decided on the participation of their community by majority vote and a written consent form was completed with the community leader.

3.6.1. Community project committee

According to the standard procedure of the collaborating NGO in this area, a six-member project committee was organised in each community at the time of project approval. The committee included a president, one treasurer and four promoters.

Its main task was to become a peer user group, setting an example for hygienic behaviour and SODIS application. Further tasks included the support of all project activities within its community, the facilitation of the communication between the community and the project staff.

Figure 3.2: Framework for the implementation and evaluation of the SODIS method



All communities included; Only communities included in the health evaluation; Repeated workshops on request of the communities

The members of the committee were trained during two special workshops: an introductory course in March, and a refresher course in August 2002. Training topics included raising awareness of microbiological water contamination, disease transmission through drinking water, and the consequences of acute and chronic gastrointestinal illness (e.g. diarrhoea) in children. Diarrhoea prevention strategies – with special emphasis on the SODIS method – were discussed. The topics and practical instruction through planned community-based workshops (see below) were also introduced, so that committee members could actively take part in the promotional event. The demonstration of microbiological water contamination and its visualisation was the main topic during the refresher course in August. This helped to persuade people of the ability of the sun to kill pathogens, as we previously recognised that community people doubted the efficacy of the methods.

In total, 37 of 115 members selected by the community were women. The interest in the training-workshops was high and all communities were represented. Eighty members participated in the first and 83 members joined the second training-workshop. Participants were successfully convinced of the efficacy of the SODIS method in eliminating thermo-tolerant coliforms in community water samples through on-site demonstrations. Presenting protozoa and helminths with a light-microscope further educated participants on the existence of usually "invisible" pathogens. Project committee members explained the application of the SODIS method in their community assemblies, accompanied field-workers during household visits, and supported the distribution of bottles and information within the community. The members further supported the communication between project staff and community members to a considerable extent – e.g. for the organisation and promotion of events, or the reporting of recent difficulties in the community regarding the introduction of the SODIS method.

3.6.2. Community-based participatory workshops

We organised community-based participatory workshops to reach the highest number of people at the beginning of our intervention (March 2002). The purpose of the workshops was to show how water can put children at risk of diarrhoea, by explaining underlying germ-disease concepts, and to introduce the SODIS method to the participants, as a preventive measure. We demonstrated the application of SODIS and hygienic handling of associated materials during the course of four workshops per community. The specific topics of the workshops included: (i) the prevention of drinking water related diseases by using the SODIS method; (ii) the use of SODIS purified water for the preparation of local beverages; (iii) hygienic handling of the bottles for SODIS use.

The second topic addressed a possible tangible benefit of the method, namely avoiding the local habit of boiling the water before preparing local beverages with the same result. The third topic involved two themes: the production of brushes and soap for the cleaning of the bottles. The implementers' main tasks comprised (i) the dissemination of key messages and (ii) motivating and supporting participating families during the event.

We targeted the entire community, including both genders. Following the community leader's advice, the workshops took place during the two-weekly community meetings. However, we realised that predominantly men visited these meetings. We sought to improve the proportion of mothers attending, through coordinating the planned workshops with the local health districts' plan for community activities, such as vaccination campaigns and medical attention.

We followed a standard structure for each workshop: at the outset, a focus group discussion was conducted around the topic of the day, e.g. knowledge exchange on different recipes for the preparation of local beverages.

Then, a short teaching section would begin to disseminate the key messages to the participants, e.g. "you can prepare the same local beverages with SODIS purified water, instead of boiling and using precious wood". Information from the earlier group discussion was incorporated into the teaching section, e.g. types of local beverages.

The theory was then put into practice during a practical and participatory session, e.g. fruits (provided by the project) were prepared for mixing with SODIS-purified water that was brought in by the participants on the same day. Since participants expected taking these self-made products home, they also benefited materially from each workshop.

Of a planned number of 89 workshops, we were able to realize 80 in the 18 communities. The promotion and coordination of the workshops usually took place through channels such as the community leaders (80%), fortnightly community meetings (67%), project committee members (90%), local health district (51%), household visits (75%), and local schools (26%). Workshops usually took place during the community meetings (83%) or at a school and lasted a median of three hours. More than 80% of the workshops were carried out following the planned structure: discussion, theory and practice. As a rule, the majority of the time available was invested in the practical part, since participants enjoyed this the most.

Thirty-three workshops (41%) were organised jointly with other local activities, such as vaccination campaigns and medical attention (of the local health district) and a national NGO that promoted the use of the free national health insurance. The mean number of participants was 56 person/workshop (35% men; 29% women, 36% children). The participation rate dropped from about 80% to 50% after the first two workshops.

3.6.3. Individual household visits

From the first workshop onwards, three field promoters visited each household of the community on a monthly basis, to encourage people to adopt the SODIS methodology and to reach families that could not participate in the workshops. Each of the field promoters worked in a defined sector comprising three to six communities. To ensure that the quality of disseminated intervention messages was the same, sectors were exchanged once among field promoters, during the intervention year. Individual household visits were performed in all 18 communities during the first half of the year, and continued in 10 communities until the end of the project.

This provided us with the possibility of comparing 10 communities enjoying regular household attention, with the eight communities that received reduced intervention input. The approach used for household visits was based on the routine NGO methodology, involving a pre-coded form for assessing exposures in the population. Because participants perceived this method as a "control", we introduced a new approach that only involved an oral information exchange by way of more natural conversation.

The field promoters were trained to listen to the difficulties households expressed in connection with the SODIS application and to support them in incorporating SODIS use into the daily routine of the family. For example, promoters would help families to find optimal places for the exposure and storage of bottles and demonstrate best handling techniques.

Implementing field promoters were skilled in advising the families on technical aspects of the method – e.g. bottle quality, time of exposure, place of exposure, cleaning bottles etc. However, we noticed insufficient social skills and education to overcome the different subtle difficulties within individual households concerning the incorporation of the SODIS method into their day-to-day life. The regular household visits were perceived as 'good', as it reminded the participants to apply the technology. The visits further provided the study with valuable qualitative information, regarding the endorsement, refusal and SODIS-handling difficulties that had occurred in the household.

3.6.4. Promotion campaign at primary schools

To further promote the introduction of the SODIS method at community level, our implementation team organised a three-months' school campaign, starting in September 2002, together with the regional ministry of education and an international NGO, Project Concern International (PCI). Further objectives of the campaign included increasing the general acceptance of the SODIS method, by raising awareness in the entire area.

A preliminary workshop introduced the SODIS method to 122 teachers in 11 school centres of the district. The teachers promoted the SODIS method to approximately 2500 children in the surroundings of Mizque, by incorporating the topic into their curriculum. The school campaign covered the entire study area. Individual schools were supported with US$ 10 for the introduction and promotion of SODIS in their classes and surrounding communities.

Representatives of the involved institutions carried out qualitative evaluations of the SODIS promotion in every school centre. Subsequently, the school classes were invited to present their promotion tools (e.g. theatres, songs, drawings) at a public educational fair in the Mizque village, and the three best presentations received prizes.

Six hundred school children were invited to present their products at the large educational fair, which attracted roughly 1500 visitors from the area. The classes showed how the SODIS method was locally applied and the additional tools and infrastructures they had developed – e.g. stands for the exposure and storage of bottles, funnels for easier filling of bottles, and bottle carriers made of wool, cotton or plastic. The approaches developed for the SODIS-promotion were also presented by the pupils and included: making use of wall paintings in the main village; school children performing in puppet theatres; sketches, songs and poems; or entire schools organising public fairs in their community. All activities clearly demonstrated the relation between pathogens, water and gastrointestinal diseases. The SODIS-purified water was recommended to avoid such health conditions. Teachers reported no negative opinions or experiences with the method or with the taste of SODIS-purified water, during the retrospective end-evaluation of the school campaign (95 mail interviews, representing a 77% response rate).

3.6.5. Impact assessment of implementation strategies

We performed two cross sectional studies in May and December using semi-structured interviews, to estimate the impact of the intervention on the participants (see also Chapter 4). We selected households with children under the age of five from the list of participants, using a random number table. Field promoters from the surroundings of the Mizque district were appointed and specially trained in interview techniques to conduct the surveys. The questionnaire included spot observations and pre-coded queries, indicating the current status of knowledge, needs and practices of the mothers with regard to the SODIS method. The perception of the mother towards the intervention was assessed by open questions.

To reduce interviewer and respondent bias, we took special care that the implementation team and other project staff neither influenced the interviewers nor the communities. Only key personnel knew the schedule of the evaluation.

Further qualitative data were collected from the daily field reports of the monthly household visits. A semi-quantitative evaluation of the school campaign, through mail questionnaires directed towards the participating teachers, took place in November and was also taken into account in the analysis. Qualitative information and our personal experience helped to interpret the quantitative findings.

3.6.6. Indicators for impact assessment and interpretations

An intervention with the SODIS method will induce changes in the target population at different levels (e.g. knowledge and practice) and generate personal attitudes towards the new method.

Table 3.1 describes the selected indicators, to obtain quantitative results concerning changes that occurred in our study population, in their knowledge and practice of, and their attitude towards the SODIS method (see also Chapter 4). Here, one relies on answers of the respondent and on the technique of the interviewer.

We assumed that possible information bias would be distributed evenly among all interviews. Since the application of the SODIS method was generally perceived as simple, but varied between households, we did not assess the exact steps to prove “knowledge”. We were more interested to determine the awareness of the method in the population, and their specific knowledge of the relationship between germs and diseases, as a basis for understanding the messages and the method. For the assessment of the attitude of the respondents towards SODIS, we relied on responses on the willingness to pay (representing value), momentary use of the method (willingness to apply), and survival of bottles over time (care and value), as well as the number of bottles in the household (application and motivation to collect bottles).

Table 3.1: Indicators to evaluate use and acceptance of solar water disinfection

Variable/ Question	*Frequency (N) %*	*Interpretation*	*Category*
“Have you heard of ‘SODIS’?” (or describe the method in short)	(223) 87%	Awareness of the method – Assesses how well the message of a new method spread among the population	Knowledge, Awareness
“Why do you think your drinking water is bad?” (after respondent reports drinking bad water)	(200) 54%	Mentioning of “pathogens” in the water indicates awareness	Knowledge, Awareness
	(200) 22%	Mentioning of “bad for health” indicates awareness	Knowledge, Awareness
“Do you know other people of the community using SODIS?”	(207) 69%	Twofold: More aware of the presence of the technology, and indicates a less isolated living style (“*Networking*”)	Knowledge, Awareness
“Would you pay for bottles to apply SODIS?”	(106) 56%	Willingness to pay, reflects a good attitude and added value towards the SODIS method	Attitude
“Do you use SODIS at the moment?”	(224) 49%	A negative answer indicates a momentary non-compliance	Attitude
“How long can a bottle be used for SODIS in your household?” (month)	*(89) 1.9 {2.0}*	Indicates the lifespan of bottles at point-of-use and the perceived value of the method in the family	Attitude/Practice
“How many bottles do you own at the moment?” (per household member)	*(107) 1.2 {0.9}*	Indicates the possibility to frequently apply & drink SODIS; motivation to organise or collect bottles	Attitude/Practice
“Could I have some water please?”	(224) 24%	The observation of SODIS purified water indicates true application	Practice
Repeated observed SODIS purified water in the household (times/3visits)	*(137) 0.3 {0.3}*	Indicates regular application and potential for sustainability due to better incorporation	Practice
“Why do you apply SODIS”	(144) 26%	Perceived benefits, other than disseminated messages indicate personal experience with the method	Benefit/Attitude

In order to estimate the impact of the individual implementation approaches, we grouped our study population according to table 3.2. Our approach was designed to reach as many people as possible during the nine-months' intervention.

All families belonging to a group, therefore, represented household members that have essentially – but not exclusively – been exposed to one implementation strategy.

3.6.7. Data analysis

The specific impact on the study population of each separate implementation approach is defined by: the measured difference (in impact) between families exposed and not exposed to a particular promotion strategy. The overall impact of an implementation approach is defined by the sum of the measured differences (in impact) in the proportion of families with respect to each strategy.

All quantitative data were double-entered by two data entry clerks, using the software package EpiInfo 6.2 (CDC, 1998) and any inconsistencies were corrected with reference to the original form. The Stata 8.1 software was used for all quantitative data analysis comparing proportions (Stat Cooperation, 2002). The impact of project committee members was evaluated by qualitative analysis only.

Table 3.2: Classification of households by received implementation

Impact of	*Impact group*	*Comparison group*
Workshops	Reported participation by May 02	Reported absence by May 02
School campaign	Families having children in schools	Families not having children in schools
Household visits	Families of communities with 1-year follow-up	Families living in communities with reduced visits

In order to determine which implementation approach had the highest impact on a particular factor, we calculated for each indicator the difference in the proportions between groups and the probability for this to occur by chance ($\chi 2$-test). To compare the implementation methods with each other, we rated the differences in proportions according to the following scheme: 2=significant positive impact; 1=positive impact>5%; 0=impact <5% or >–5%; –1=negative impact<–5%; –2=significant negative impact. The sum of scores for each approach indicated which of them had the largest overall impact. The sum of scores for each indicator, revealed the factor on which the entire intervention had the largest impact.

Stratification of the population by exposure to implementation approaches would have compared families that were exclusively exposed to none, one, two or three promotion campaigns. However, stratification resulted in small sample sizes in most strata that made comparison inconclusive. We could, however, compare households exposed to all intervention methods with families from the eight communities that were not visited regularly in the second half of the year. Therefore the effect of prolonged household visits on the different selected indicators could be calculated.

3.7. Results

We first present how the study population adopted the new method by the end of the year. We then show the quantitative effect of the entire intervention in our study families, via the defined indicators. Subsequently, the quantitative impact of each individual strategy is described, with special emphasis on the effect of prolonged household visits in communities.

3.7.1. Adoption of home-based solar water disinfection

By December 2002, 109 of 224 (48.7%) families reported applying the method and 53 (23.6%) were able to provide SODIS-purified water at the time of an unannounced visit. Families reported usually drinking SODIS water on 5.4 days per week (sd=2.1). Families with observed SODIS-purified water at home drank SODIS water more often than families where raw or boiled water was observed (on average: 6.3days vs. 4.6 days per week, $p<0.001$). These families also owned significantly more bottles per family member (average: 1.5 bottles vs. 1 bottle per household member, $p<0.01$). The number of owned bottles correlated significantly with the frequency of drinking SODIS water at home ($r=0.29$, $p<0.01$). Fifty-nine percent of the families received bottles from the project promoters, whereas 36% of the families reported obtaining bottles from local shops or from friends. Mothers reported that everybody of the family drinks SODIS water but mainly women (50%) and children (35%) are responsible for the application and management of solar water disinfection at home.

3.7.2. Impact of the entire intervention

Table 3.3 shows how the entire SODIS intervention affected the knowledge, attitude and practice of participating families. The nine-months' intervention increased the awareness of the study population of the existence of the SODIS method and their knowledge of disease-causing agents. The promotion introduced the use of the SODIS method, which also benefited families in other ways (e.g. easier transport of water, large storage volume). The proportion of the target population willing to pay for bottles decreased once the intervention was over. The proportion of families willing to pay was equal across the promotion strategies. Nevertheless, families that agreed to pay for bottles, would spend on average four times more for used bottles than the project agreed to pay for in the next larger city (0.13US$/bottle vs. 0.03US$/bottle).

Table 3.3: Individual and total impact of the SODIS implementation approaches in rural Bolivia

Factors related to SODIS	*Community Workshops*					*School campaign*					*Household visits*					*Sum of Scores*
	Not target		Target pop			Not target		Target pop			Not target		Target pop			
	N	%	N	%	Score	N	%	N	%	Score	N	%	N	%	Score	
Heard of SODIS	25	88	120	90	[0]	56	82	162	89	[1]	65	80	130	95	[2]	**[3]**
Other people using	25	64	108	74	[1]	54	70	153	69	[0]	60	67	122	75	[2]	**[3]**
Pathogens in water	23	48	110	57	[1]	48	42	152	58	[2]	58	50	120	60	[2]	**[5]**
Water bad for health	23	9	110	26	[2]	48	31	152	19	[-1]	58	26	120	19	[-1]	**[0]**
Willingness to pay	9	78	63	48	[-2]	25	68	81	52	[-1]	24	58	76	54	[0]	**[-3]**
Reported use	25	36	120	53	[1]	56	46	168	49	[0]	65	39	131	60	[2]	**[3]**
N° of bottles in house	9	*1.1 {0.6}*	64	*1.2 {0.9}*	[1]	25	*1.6 {1.2}*	82	*1.1 {0.8}*	[-2]	25	*0.9 {0.8}*	76	*1.4 {0.9}*	[2]	**[1]**
Observed SODIS-water	25	12	120	28	[2]	56	23	168	24	[0]	65	19	131	31	[1]	**[3]**
Tangible benefits	12	25	87	29	[0]	33	9	111	31	[2]	20	20	122	27	[1]	**[3]**
Sum of scores					**[6]**					**[-1]**					**[10]**	**[15]**

Legend: *Numbers in italic describe the mean of continuous variables. {} encloses the standard deviation of the mean. Bold figures indicate a significant difference in proportion between groups ($p<0.05$). Rating: 2=significant positive impact; 1=positive impact; 0=impact ±5%; -1=negative impact; -2=significant negative impact. For a detailed description of the indicators, see table 3.1; Bolivia, 2002.*

3.7.3. Impact of individual implementation strategies

Each implementation strategy affected the population in different ways, both positively and negatively. This underlines the importance of applying different promotion strategies and evaluating their individual effect.

3.7.3.1. Community-based workshops

By the end of May 2002, 194 of 245 families (79.2%) in 18 communities reported that at least one member of the family had participated in the workshops. Participation in workshops had an encouraging effect on the adoption of the SODIS method in the household. Families that were present at workshops were more likely to have SODIS-purified water ready in their household at the time of the evaluation in December 2002 than families not participating in workshops (OR=2.9, 95%CI: 0.8 – 16.0). Participation in workshops seemed to raise awareness of the relation between water and diarrhoea (OR=3.8, 95%CI:0.8 – 35.0).
Nevertheless, participation in workshops reduced the willingness to pay for bottles when compared with families that did not participate in any community event.

3.7.3.2. School campaign

The school campaign in Mizque and surroundings had a considerable impact on the population's awareness of the new methodology. Families with children in school differed from other families by mentioning more often that the water was contaminated with "pathogens" (OR=1.9, 95%CI: 1.0 – 3.9). On the other hand, the same families seemed less likely to mention the relation between diarrhoea and water (OR=0.5, 95%CI: 0.2 – 1.2). Families with children in schools mentioned benefits from the use of SODIS other than those propagated during the campaign significantly more often than families without children in schools (OR=4.4, 95%CI: 1.2 – 24.0). The school campaign did not seem to influence the uptake of the new methodology. On the other hand, more than 72% of the teachers reported that children would carry SODIS water from school to home (31.2%) or from home to school (41.6%) during the retrospective mail questionnaire survey. The latter implied that the SODIS process was actually applied at household level.

As school children took bottles to their classes, families with school children had on average fewer bottles per household member in the home than other families ($\chi2=4.02$, $p<0.05$).

3.7.3.3. Monthly household visits

Prolonged household visits increased awareness of the existence of the SODIS method in the respective communities (OR=5.2, 95%CI: 1.7 – 17.3). More families also reported applying the new methodology, when living in communities that were visited for the entire intervention period, compared with families only visited until mid-term (OR=2.4, 95%CI: 1.2 – 4.5). The same families also owned significantly more bottles per household member ($\chi2=8.9$, $p<0.01$) and were almost twice as likely to have SODIS-purified water ready at the time of the visit in December than families of the other eight communities (OR=1.9, 95%CI: 0.9 – 4.4).

3.7.4. Impact of continuous personal encouragement

In summary, the community-based workshops and the regular household visits had the largest total impact on the study population, as emerges from the scores for each implementation strategy.

We were able to specify more accurately the added impact of prolonged household visits on the entire intervention, by comparing families exposed to all implementation strategies with families that were not exposed to extended monthly household visits. The additional household visits contributed significantly to awareness-building of the new technology in the communities (chi2=7.33, p=0.007). It further led the exposed families to own significantly more bottles (chi2=5.5, p=0.019). And, additional household visits supported the communication channels between families of the same community (chi2=4.6, p=0.032).

3.8. Discussion

Our implementation approach differed from other SODIS implementation programmes in several respects: the use of multiple communication channels; additional formative research, that enabled us to adapt the intervention and its messages to local beliefs and habits; a framework that limited the possibilities for designing, developing and applying an ideal intervention for the given target population.

Through a nine-months' intervention promoting the application of the SODIS method via three different promotion strategies, we successfully stimulated about one third of the target population to adopt the SODIS method, without replacing the existing habit of boiling water in the morning. We found that several factors in the target population changed as a result of the entire intervention: awareness of the existence of the SODIS method and its underlying germ-disease concept increased; adoption of the SODIS method was effectively encouraged; communication channels inside the community were supported; tangible benefits of the new method were recognised in the households. We can confirm, that the coordination of several promotion strategies at the same time will lead to a higher total impact of the entire programme (Mitchell *et al.*, 2001).

But our analysis also showed, that the individual campaigns should be selected with care, so that interferences are avoided (e.g. competition for bottles). External constraints limited the extent of our analysis, on which these results are based.

We reached the majority of the target population through at least one promotional channel. This also influenced the possibilities for the classification of families in the analysis. We were able to classify the families by their principal exposure, but could not compare groups that had only been exposed to a single implementation strategy. Comparisons therefore reflect factors most dominantly impacted by the individual approaches.

We selected specific and responsive indicators, representing the degree of knowledge and application of the SODIS method in our population. Other indicators helped to determine attitudes towards the new method.

The indicators were based on interviews and observations that were pre-tested and validated in a different setting, and later adapted to the present area ((Hobbins *et al.*, 2000)/Chapter 6). We made all possible attempts to minimise information bias.

We applied extensive formative research on the basis of focus group discussions and participatory methods, to prepare our implementation strategy for SODIS. However, the actual setting and the available time limited the potential use of these results for the selection of appropriate communities (Curtis *et al.*, 1997). The framework was set by the health effectiveness survey (Hobbins, 2003). This influenced the community selection process (see Appendix 4), as communities without water systems were favoured in order to raise the probability of measuring a significant health effect. The target population had no other options to choose from than the SODIS method; however, an *expressed demand* for the intervention during community consent was a decisive criterion for community selection. Later, in-depth surveys and qualitative data revealed that expectations among community people were not met by the SODIS method.

Our indicators could not confirm the sustainable application of the SODIS method in our target population. Sustained changes in hygiene behaviour result from giving high priorities to hygiene and education (Cairncross and Shordt, 2004), which requires time, communication skills and community involvement over long periods. Essentially, the external constraints defined our community selection strategy, the total time for the intervention and the communication skills of our implementing promoters, all of which limited the sustainable use of the SODIS method.

A majority of the families reacted positively to the method, describing the method as ‘easy’ and the taste of the water as ‘good’. But the expectation and goal of the local population was to receive piped water directly into their own yard. Although water systems often fail to bring purified water to the household, the implementation of the SODIS method faced significant drawbacks because of this existing mindset. Thus, people complained about additional and excess workloads and time involved from applying SODIS due to comparison with the desired “option” (Indergand *et al.*, 2004). The expectation for a water system was also raised by the presence of a known organisation that had previously conducted infrastructure projects in the region.

Consequently, our implementation team needed at least to support the communities in their desire.

While the promotion messages remained the same, it is likely that at least a portion of the target population understood the SODIS method as an intermediate and temporary relief, of comparatively low value. The low perceived value is further demonstrated by the decrease in the willingness to pay for bottles after the end of the implementation campaign, and the low lifetime of a bottle in a family.

During our intervention, the school campaign interfered with the community-based promotion activities and as a result bottles became scarce in the area. The school campaign collected over 3000 bottles through school children; however, the campaign also competed with the regular household visits, where promoters distributed bottles at the children’s homes. Networks between local and city schools were also employed for the transport of used PET bottles to the rural schools and communities.

In future intervention planning, the combination of community-based promotion and school campaigns should make use of the effective bottle-collection skills of school children, and of the possibilities for networking between schools, in order to provide schools and communities with the necessary hardware for the application of the SODIS method. The support of local retailers may also provide an entry point, but a social marketing campaign would be essential for creating demand in the population.

The value of the method is not only defined by its hardware. Our findings indicate that the population only started to recognise the benefits of applying the method by the end of the intervention. After extensive training in new implementation and monitoring techniques, we realised that the social skills of the field promoters were limited. This hindered the effective incorporation of the SODIS method into the households’ daily life. Other studies have reported similar problems (Thevos *et al.*, 2000). This underlines the difficulty of selecting adequate promoters for the interaction with community people, an essential ingredient for success. The restricted social skills of the promoters also limited the adaptation of promotion messages and their realisation at household level.

The key message used in the promotion of the SODIS method is its beneficial effect on the health of its users. A recent study on the promotion of a home-based water disinfection method showed impressive adoption rates, but this was due only to the established strong belief in the target population, that diarrhoea can be avoided by boiling water (Quick *et al.*, 2002).

Our setting was more challenging, as our investigation on the diarrhoea terminology demonstrated. People did not perceive water as a threat to health, and the promoted health benefits were therefore often not directly realised by the target population. Furthermore, our analysis of the determinants for adoption showed that the unaware and socio-economically lower class of the target population did not adopt the method (see Chapter 4). The development of key messages that target benefits in the population that can be felt and perceived, is essential for the rapid adoption of a method or a behaviour (Quick *et al.*, 2002). For example, since most malaria endemic areas have a perceived mosquito nuisance problem, treated nets have proved very popular and high coverage rates are usually achieved quite rapidly (Zimicki, 1996).

We found that the school campaign was especially strong in finding and promoting tangible benefits of the method, in contrast to community workshops or monthly household visits. These included the increased storage volume and the possibility of transporting drinking water to the fields or schools; two additional important features of the technology, that differentiate it from other home-based water disinfection methods, such as boiling or chlorination. More emphasis on these and other tangible factors during the promotion of the SODIS method may result in higher adoption rates than the promotion of health benefits and ‘safe water’ alone.

Formative research is helpful in recognising such additional benefits (Curtis *et al.*, 1997) and social marketing strategies, as well as the establishment of small local market economies, may further increase the appreciation of the method and lead to a sustainable uptake. Recent studies showed that the adoption of a home-based water disinfection method is considerably increased by household visits and community mobilisation activities, in comparison with social marketing alone (Quick, 2003, Thevos *et al.*, 2000). Community and household-based interventions further guarantee that the programme reaches the large majority of families.

The on-site situation at the outset will determine the various strategies and messages necessary to induce changes in the hygiene behaviour of populations (Cairncross and Shordt, 2004).

The development of dissemination strategies and the formulation of motivational messages directed towards *tangible* benefits (e.g. SODIS as a water-handling system) is a crucial requirement. Creating a general awareness of the underlying health concepts of the method in the target population is essential for its sustainable use.

However, this will require extended time and resources, and the use of various communication channels, including broad-scale social marketing campaigns and mass media, community and household-based interventions and the involvement of schools. Future research may look into the cost effectiveness of such a large undertaking. The present findings contribute to the situation, where restricted funds must be allocated to ensure efficient programming and the best chance of sustainability after a successful intervention.

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CHAPTER 4

Classification of families with individual user profiles of solar water disinfection

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4.1. Abstract

Background: The inaccurate classification of populations according to measured hygiene behaviour leads to flawed results, from which inappropriate conclusions are drawn that may even lead to a misguided allocation of funds. It is important to ensure that future studies on the health effect of the solar water disinfection method (SODIS) do not suffer from the flaws induced by the wrong estimation of compliance. *Goal:* To determined to what degree and under what circumstances, families adopted the newly introduced SODIS method in the framework of health effectiveness study in rural Bolivia, and describe main indicators for adoption of the method and their assessment. *Method*: We identified three indicators for estimating the proportion of families applying the SODIS method: reported use, reported frequency of drinking SODIS-purified water in the week preceding the interview, and the presence of SODIS-purified water at the time of the visit. The indicators allow gauging over reporting of use in the target population, and can be used for the rapid assessment of the adoption of the SODIS method during a one-time final assessment. *Results:* A combination of the selected indicators and subsequent classification of the families achieved a fair agreement (43%) to our reference (the repeated observation of the presence of SODIS-purified water at the time of the visit by staff unrelated to the programme). Determining the intensity of applying the SODIS method in each family permitted us to identify the key determinants for the adoption or rejection of the new technology (e.g. awareness of water as potential danger for health). *Discussion:* Special promotion strategies and messages must be developed to convince the undecided or insufficiently educated population to adopt the method. The future application of the valid indicators and their assessment under different conditions and settings will demonstrate their validity for wider application.

4.2. Background and introduction

The inaccurate classification of populations according to measured hygiene behaviour leads to flawed results, from which inappropriate conclusions are drawn that may even lead to a misguided allocation of funds. Classification of populations according to their exposure is dependent upon two factors: meaningful indicators and ways to assess them. A good indicator will measure what is of interest (validity), be sensitive to changes (responsiveness) and correctly identify the exposed/unexposed groups (sensitivity/specificity). However, a good indicator remains worthless if the assessment method does not measure it accurately. Curtis *et al.* demonstrated that agreement between interviews and structured observations on hygiene behaviour in Burkina Faso was poor (Curtis *et al.*, 1993). Repeated observations were found to be the most useful method for assessing the real exposure condition of a family, even though agreement among repeated structured observations is strongly dependent on behavioural variations (Cousens *et al.*, 1996, Curtis *et al.*, 1993). Despite these findings, a recent review on hand-washing reported that only two of the 17 studies reviewed, evaluated the exposure by observations, whereas the remainder classified exposure groups by relying on a one-time report at the end of the investigation (Curtis and Cairncross, 2003). Its authors urged that rigorous intervention trials be conducted and simple indicators developed, to identify hand-washing compliance.

Compliance is one of the major four factors influencing the overall effectiveness of an intervention (Tanner *et al.*, 1993). To ensure that future studies on the health effect of the solar water disinfection method (SODIS) do not suffer from the same flaws as the reviewed trials on hand-washing, standards for the application of specific indicators and their assessment methods must be developed early on. During one of the first surveys for measuring the health effectiveness of the SODIS method among rural Bolivian children under five years of age (see also Chapter 7), we defined specific indicators and approaches for estimating the exposure of our target population to this method.

Solar Water Disinfection (SODIS) is a simple and cheap point-of-use methodology, which requires exposing water-filled transparent PET bottles to full sunlight for at least 6 hours, for effective disinfection from bacteria and viruses (Sommer *et al.*, 1997, Wegelin *et al.*, 1994, Wegelin and Sommer, 1998). The SODIS method is being disseminated world-wide, and projects report high uptake rates in target populations (Sobsey, 2002, Wegelin, 1998).

The comparison of the effectiveness of projects concerned with implementing and evaluating the uptake rates of the SODIS method, is often challenged on the basis of the different methodological approaches and indicators used. Some projects rely only on the reports of their promoters, who assessed adoption mainly based upon their experience. Other indicators – such as observing the presence of sun-exposed PET bottles – have also been used as evidence of its application in the project area and even for calculating directly the rate of adoption. The validity of evaluations is usually not verified and interpretations of the indicators used, are often not precise. For example, an 80% reported SODIS use in a population is interpreted as: 80% of the families drink SODIS water on a daily basis (Vargas, 2003). All presently used indicators assess the proportion of families in a population that adopted, applied and/or drank SODIS purified water. However, the interpretation of these indicators and their mode of assessment need further investigation.

Within the framework of a health effectiveness study, we tested common indicators as to their validity, reproducibility as well as their sensitivity and specificity, for finding families that apply the SODIS method. To help identify important factors for the assessment of the indicators, we studied the extent to which reports of different staff, visiting the same study families at a similar time, agreed.

Our research suggests a way for rapidly estimating the proportion of families that apply the SODIS methodology. It is based on a one-time assessment in a population that combines interviews and spot observations, with the use of three easily measurable indicators.

4.3. Objective

Our goal was to determine to what degree and under what circumstances, families adopted the newly introduced SODIS method. In this context, we sought to identify, compare and validate classification indicators and to develop a rapid assessment tool for estimating the uptake of this method at community level

4.4. Approach

Over a period of nine months (March – December 2002), the SODIS methodology was implemented in collaboration with an international NGO in 10 communities of the Mizque district, Department of Cochabamba, Bolivia. A detailed description of the implementation methodologies is given elsewhere (Chapter 3 /(Indergand *et al.*, 2004)).
We evaluated the adoption of the SODIS method in our study population through the use of common indicators and assessment methods. Figure 4.1 outlines our approach, from the dataset to the classification of the population. We estimated the proportion of families applying the SODIS method by exploring different viewpoints (triangulation): spot observations, directly reported use, and reported frequency of drinking SODIS purified water in the family. Our reference value was the repeated spot observation of SODIS-purified water in the household. Sensitivity, specificity, positive and negative predictive values were calculated for each indicator, to describe its accuracy and characteristics. Through applying the identified indicators, we could estimate the amount of reporting bias by comparing the number of *expected* families with SODIS purified water with the number of *observed* families with SODIS purified water.

Four evaluations took place in the target communities at different points in time and through different field staff. This enabled us to test agreement between datasets and to identify possible reasons for concurrency or discrepancy.

In the light of our findings, we suggest a simple and rapid technique for estimating the SODIS adoption rate from a single, final evaluation of a promotion programme. A classification scheme of the target families, according to their intensity of use, is presented. The resulting proportions were compared with the reference value.

Determining factors for the adoption or rejection of the SODIS method were investigated, to demonstrate the underlying potential of an accurate classification of families for directing future adaptations in the programmes' promotion strategy.

4.5. Methods

We conducted the present research within the framework of a comprehensive evaluation of the health effectiveness of the SODIS method in rural Bolivian children under five years of age (Chapter 7/(Hobbins, 2003)).

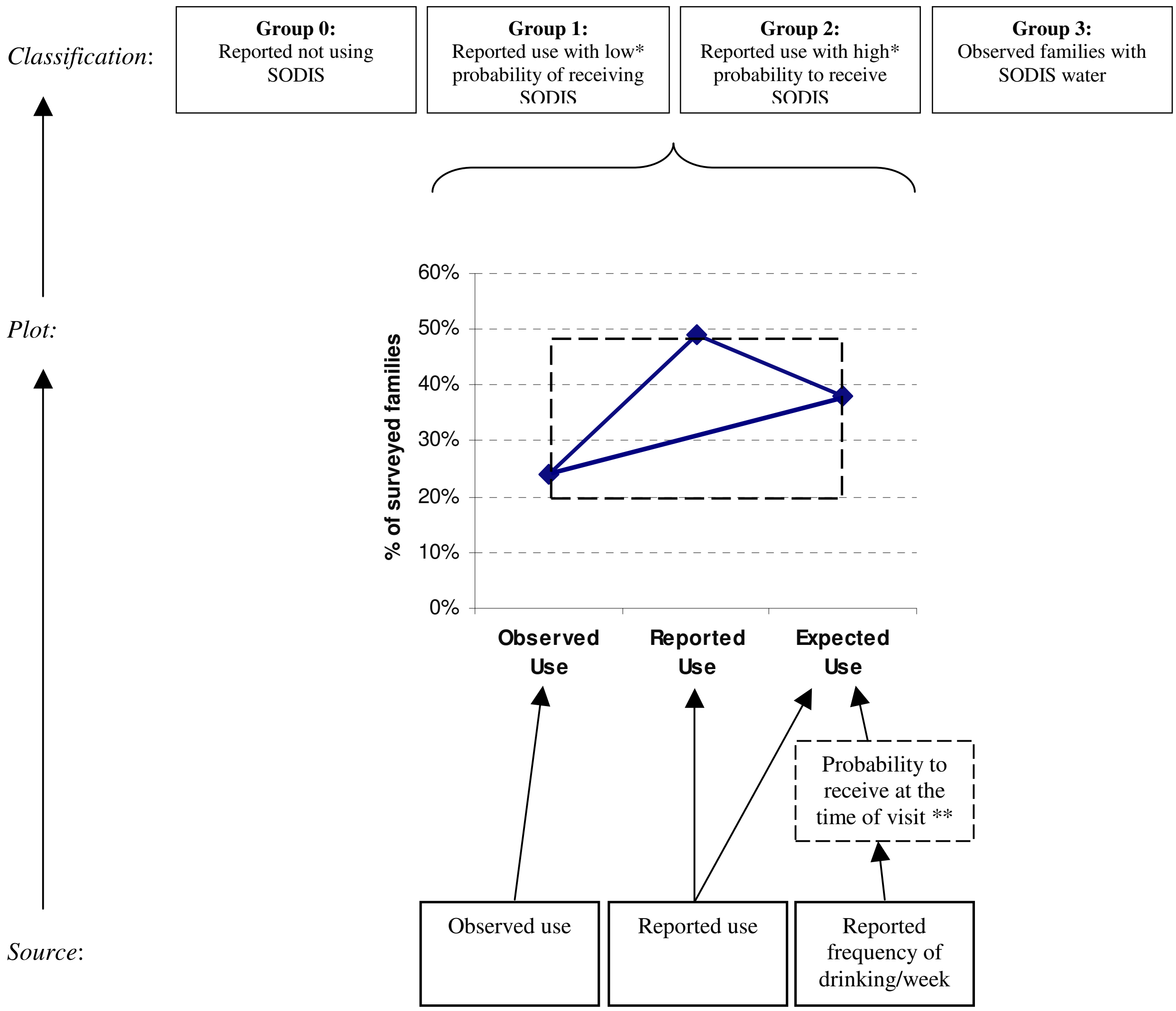
Our study population consisted of all families with children under the age of five, living in ten communities of the Mizque province of Cochabamba, Bolivia. All villages were introduced to the SODIS method during a nine-month implementation campaign, using new promotion strategies such as community participatory workshops, a school campaign and repeated household visits (see Chapter 3/(Indergand *et al.*, 2004)). The adoption of the new method within the target population was evaluated at different points in time and through different field staff.

As our reference value, we used our best estimate of the proportion of families applying the SODIS method at different intensities: namely, the observed presence of SODIS-purified water at three unannounced visits by independent field staff, in the period from October till December 2002. By 'independent', we mean that the study population did not associate the visiting staff (based at the University of Cochabamba) with the promotion of the SODIS method. Field personnel visited 135 randomly selected households and asked an adult household member – preferentially the mother of the child(ren) under five years – for any water-based beverage (e.g. treated or untreated water, coffee, tea etc.), that would be served to the child when thirsty. SODIS water (sun exposed or stored) was recorded whenever it was present in the household (see also Chapter 5).

4.5.1. Indicators for the use of SODIS

Table 4.1 lists common and new indicators for identifying families that adopt and use the SODIS method, as well as drinking the purified water. Each indicator's characteristics are described, based on our experience of its validity, responsiveness and specificity. Its interpretation and potential application for a cross sectional assessment is given.

Figure 4.1: Scheme to classify intervention families according to three indicators for SODIS use



Legend: *The three principal indicators are recorded at the "source" and then "plotted" into a graph, which shows the area where the real proportion of families using the method can be expected. The rectangle represents the area that is enclosed by the reference values (lowest %: Families observed ≥ 2/3 visits; highest %: Families observed 1/3 visits). Group 0-3 represents a suggested classification scheme by intensity of use. *High / low probability = above/below average probability of observed families to have SODIS purified water in the house at time of the visit. ** is calculated by: (1/mean frequency of use per week)x(proportion of reported use). Data are retrieved from the SODIS evaluation in December 2002 (end-evaluation), assessed by project - external staff (Sample: 222 households).*

Our analysis focussed on the most direct indicators, describing the SODIS-drinking behaviour of the household: reported SODIS use, reported frequency of drinking SODIS during the last seven days, and the observation of SODIS purified water at the time of visit.

To identify the level of over- and under-reporting within the dataset, we compared the number of families *observed* with SODIS-purified water in the house, with the number of families that we would *expect* to have SODIS-purified water present at the time of visit, according to their reports.

The expected number of families was calculated by multiplying the total number of families reporting the use of the SODIS method, with the mean proportion of days the families reported drinking SODIS purified water (=probability of obtaining SODIS-purified water in the house at the time of a single visit). If the observed and expected numbers of families are approximately equal, the data are consistent. On the other hand, if significant differences can be detected between the expected and observed number of families, other interpretations could be considered.

4.5.2. Methods for assessing indicators of use

Four evaluations took place to estimate the uptake of the SODIS method in the study population. The differences between the conducted evaluations were the field staff, the time of evaluation, and/or the applied assessment methods. Field promoters involved in the implementation of the SODIS method applied a short and structured questionnaire (without observations). Especially hired and trained interviewers conducted in-depth semi-structured interviews with the family members, involving spot observations.

During the months of June to August, and in the month of December 2002, three promoters involved in the implementation of the SODIS method evaluated the success of their intervention with short, simple and adapted data-collection instruments. They visited as many families as possible in each of the ten study communities.

The structured data-collection instruments included the assessment of the daily drinking behaviour of the family, the frequency of boiling water and of drinking SODIS purified water, and the presence of boiled or SODIS purified water in the house at the time of visit. The perception of the respondent about the SODIS method was assessed, as well as the reasons for not applying it.

The evaluation performed by the promoters in December 2002 was excluded from further analysis, as it turned out to be inconsistent with any other dataset presented here. Its attributes will be discussed in the context of the selection of appropriate evaluation staff and of reporting bias.

To carry out in-depth semi-structured interviews for the assessment of the uptake of the SODIS method in our study population, we trained seven women interviewers in May, and a further ten women interviewers in December. The interviewers were recruited from outside the permanent project field crew. In addition to spot observations, they used a questionnaire that included the same indicators as in the evaluation tool used by the promoters, but additionally prompted the respondent to answer more detailed questions concerning her/his knowledge, perception and practice of the SODIS methodology. The interviewer (visitor) would ask for a glass of water during the interview and would record its source (e.g. SODIS-, boiled-, raw water). If in doubt, the interviewer would ask the mother if and how the water had been disinfected. This method differs from the direct control of the presence of SODIS-purified water in the household, but approximates closely the approach used by the independent field personnel during their repeated visits (reference value).

4.5.3. Data analysis

Evaluation data were double-entered in EpiInfo 6.2 (CDC, 1998) by different data entry clerks and inconsistencies were corrected with reference to the original form. STATA 8.1 was used for data analysis (Stat Cooperation, 2002). The sensitivity, specificity and positive/negative predictive value of the selected indicators was calculated, using the standard STATA command *diagtest*, and compared with our reference value (defined as families that had SODIS-purified water in the house at least once during three visits).

To account for the differences in the number of visits for each family, we multiplied the number of affirmative observations with the ratio between the absolved number of visits and the total possible number of visits (3 visits). The degree of agreement between the results of different evaluations was assessed using the unweighted kappa (κ) statistics. This takes into account the number of observations expected to be in accord, if agreement is random. The κ-value was interpreted considering standard guidelines (Altman, 1991): $\kappa<0.21$ = poor agreement; $0.20<\kappa<0.41$ = fair-; $0.40<\kappa<0.61$ = moderate-, $0.60<\kappa<0.81$ = good and $0.80<\kappa\leq1.00$ = very good agreement.

Associations between indicators within and across datasets were explored, using Kappa Statistics with the standard STATA command *kap* or we applied $\chi2$ – calculations using the commands *tabulate* and *chi2*. For the identification of major determinants of uptake or rejection of the SODIS method in our study population, logistic regression analysis with automated step-wise elimination (forward and backward) was carried out using the standard STATA commands *sw* and *logit*.

4.6. Results

As shown in figure 4.1, the selected indicators define a sector, in which the real proportion of families applying the SODIS method is likely to lie (triangulation), and which fits into the area enclosed by the reference values (minimum/maximum). The three indicators show the proportions to be between 24% and 48%. Our reference dataset revealed that seven percent of the repeatedly observed families had SODIS-purified water ready during all three visits, 13% provided it twice, and 28% supplied the visitor once. Repeated observation of the presence of SODIS-purified water in the house was a powerful indicator for changes in the application of the method (responsiveness).

4.6.1. Description of common indicators of use

Table 4.1 shows that all commonly-used indicators have a poor to fair agreement with our reference value, and the highest κ-value is achieved by the reported frequency of drinking SODIS-purified water during the last week (agreement: 72.3%, $\kappa=0.4$). The same indicator predicted that 85.7% of the positive reports concerned families truly applying the SODIS method – positive predictive value (=yield) of 85.7%.

Table 4.1: Indicators for the adoption of the SODIS method

Indicator for SODIS uptake	*Characteristics of the indicator*	*Prevalence*[##]	*Indicator performance % (95%CI)**	*Possible Interpretation & use (at the time of assessment)*
Reported use	Based on the perception and report of respondent, prone to over-estimate use in the community	N= 223 48.9% (42.2 – 55.6)	*Sensitivity*: 73.3 (63 – 83) *Specificity*: 57.1 (46 – 68) *PPV:* 68.8 (59 – 79) *NPV:* 62.5 (52 – 73) *Agreement*: 42.3%, κ=0.11	Over-estimates the proportion of adoption but selects families that do not
Reported drinking frequency (X days in last 7 days**	Based on the perception and report of respondent. Reflects intensity of drinking in the family	N=107 5.4 (2.2)	*Sensitivity*: 72.7 (60 – 85) *Specificity*: 71.4 (59 – 84) *PPV:* 85.7 (76 – 96) *NPV:* 52.6 (38 – 67) *Agreement*: 72.3%, κ=0.40	Informs about the probability to receive SODIS water in the house; Misses families applying the method
Observed presence in the household	Validity depends on independent team and unannounced visits, user habits (e.g. only applying in the field)	N=221 24% (18.6 – 30.3)	*Sensitivity:* 42.2 (31 – 53) *Specificity:* 82.4 (74 – 91) *PPV:* 76.0 (67 – 85) *NPV:* 51.9 (41 – 63) *Agreement*: 59.5%, κ=0.23	Will mostly find families regularly and often applying SODIS; Misses families applying the method less intensely
Repeated observations of the presence in the household	Validity depends on independent team and unannounced visits. Indicates changes in behaviour. consumes time and resources.	N=135 ≥Once: 48.2% (39.5 – 56.9)	*Reference value*	Will mostly find regular users, and additional families missed during first observation;
N° of bottles currently owned by household**	Only for secondary analysis, for consistency checks and descriptive analysis	N=107 7.4 (4.8)	*Sensitivity*: 57.6 (43 – 71) *Specificity*: 78.6 (67 – 90) *PPV:* 86.4 (77 – 96) *NPV:* 44.0 (30 – 58) *Agreement*: 63.8%, κ=0.29	Reflects the household's possibility to frequently apply and drink SODIS; Misses families applying the method
Observed exposed bottles	Does not inform on drinking habits; Highly dependent on infrastructure and user habits; vulnerable to "pleasing the interviewer"	N=106 43.4% (46.6 – 66.1)	*Sensitivity*: 35.6 (25 – 46) *Specificity*: 88.2 (81 – 95) *PPV:* 80.0 (71 – 89) *NPV:* 50.9 (40 – 62) *Agreement*: 58.2%, κ=0.21	Informs about the present use of SODIS in the household, but can easily be biased; Misses families applying the method
Reports to <u>use</u> SODIS on *X* days in last 7 days	Explains proportion of observations; Possibility to check consistency with observed exposed bottles;	N=105 4.9 (2.4)	*Sensitivity*: 60.6 (47 – 75) *Specificity*: 50.0 (36 – 64) *PPV:* 74.1 (62 – 87) *NPV:* 35.0 (21 – 49) *Agreement*: 57.5%, κ=0.09	Probability to see bottles exposed. Can over estimate intensity of use. Misses families applying the method
Combination of reported use, observed water and frequency of drinking ***	Under-reporting of families applying (or that applied) the method possible; flexible indicator due to possibilities of classification	N=221 33.5% (27.4 – 40.2)	*Sensitivity*: 62.2 (52 – 73) *Specificity*: 82.4 (74 – 91) *PPV:* 82.4 (74 – 91) *NPV:* 62.2 (52 – 73) *Agreement*: 70.9%, κ=0.43	Approximation of repeated observations; possibility to classify families in more than 2 categories (according to their intensity of use)

Legend: **Reference value is the proportion of families observed at least 1/3 visits with SODIS purified water in the house. CI: confidence interval. PPV: positive predictive value (probability that family applies method when identified + by indicator). NPV: negative predictive value (probability that family does not apply method when identified – by indicator). **two categories were created with the mean as a threshold. *** categories: i) not observed, frequency of drinking <average, reported and not reported use. ii) observed and not observed, frequency of drinking >average, reported use. [##]proportion and their calculated 95% CI, means with standard deviation in brackets. Data from the SODIS evaluation in December 2002 (end-evaluation), assessed by project-external staff*

The probability of finding a family, using the SODIS method by direct questioning, was 75% (sensitivity). However, more than 40% of the families reported to use the method but did not seem to apply it (false positives), as indicated by the low specificity (57.1%). On the other hand, the probability of identifying a family that did not adopt the method was 82.4% when SODIS-purified water was not observed in the home; but the number of false negatives – families not observed with SODIS-purified water, but applying the method – was high, as implied by the low sensitivity (42.2%).

The two indicators with opposite characteristics – reported and observed use – in combination with a probability measure (frequency of drinking SODIS water during the last week) delivered a flexible and conservative estimate of the true situation through a one-time assessment at the end of the study. The 'combined indicator' showed a 71% agreement with the reference value, with a Kappa value of 0.43.

4.6.2. Evaluation of assessment approaches

There was "poor" to "fair" agreement on the observation of SODIS purified water in the household between datasets; the two evaluations performed in May and December by the external team showed the highest degree of agreement (73.4%, κ=0.32), despite the time-span between the two activities.

In general, the fair agreement between datasets indicated that families applied the SODIS method irregularly over time. This finding was confirmed by the only significant agreement between our reference value and the December evaluation by the external team (59.5%, κ=0.24) both conducted towards the end of the project (October till December vs. December 2002).

The poor agreement between the two evaluations carried out in May and June 2002 by different field staff (68.0%, κ=0.14) suggests reporting and/or interviewer bias.

4.6.3. Validation of indicators

Through the use of the above three indicators, we can calculate the extent to which bias was introduced into the dataset.

The expected number of families with SODIS-purified water at home during the December evaluation was significantly higher than the actually observed number of families (38.1% vs. 24%; $\chi2=10.2$, p=0.001) (Figure 4.1).

In such cases, we suggested grouping the study population into more than two categories, in accordance with the values of the assessed three indicators (Table 4.1).

By adopting such classification schemes, we found that 62% of families, that reported rarely applying the SODIS method, could never be observed with SODIS-purified water at repeated visits. On the other hand 100% of families, classified as frequent users, would be able to provide SODIS-purified water during repeated visits (Table 4.2).

Table 4.2: Accuracy of cross sectional estimates of SODIS user rates

Cross sectional assessment	Number of positive observations/3 visits				
	Never	once	twice	Three	Total
Not applying	20	10	2	0	32
Rarely applying	8	2	3	0	13
Often applying	0	5	4	0	9
Regularly applying	6	10	4	5	25
Total	34	27	13	5	79

***Legend**: Cross sectional assessment, combined indicator: Not applying (the SODIS method): reported non-use; Rarely applying: reported use + reported drinking frequency/week < average + no observed SODIS water; Often applying: reported use + high drinking frequency/week ≥average + observed SODIS water at the time of visit. Linear regression analysis resulted in a correlation coefficient=0.64 (0.35 – 0.93), p<0.0001.*

4.6.4. Description of intervention families

Once the correct assessment and classification of the families has been achieved – by repeated observations or cross-sectional study – the determinants of adoption and rejection among the population under study can be identified.

Where field personnel was able to observe SODIS-purified water at the home of the study families once during the three visits, mothers were older (OR=1.1, 1.0 – 1.2) and were more likely to report “dirt” as a cause of a child’s illness, than families where SODIS-purified water was never observed; children were also more likely to go to the kindergarten (OR=9.3, 1.5 – 59).

Families, where SODIS-purified water was observed twice or more during three unannounced visits, were more likely to live in a community with public latrines (OR=4.3, 1.2 – 15), than families where SODIS-purified water was never observed (during the three visits).

Faeces were not likely to be seen in the surroundings of their house (OR=0.17, 0.03 – 0.97), and families were more likely to report that their water contains “bugs” or pathogens (OR=3.1, 1.1 – 8.9). Young children of these families were more likely to be stunted than children of families where SODIS was never observed.

On the other hand, families that never had SODIS-purified water in their house during the three consecutive visits, were likely to drink untreated water (OR=2.4, 1.1 – 5.3), and keep drinking water uncovered (OR=3.0, 1.6 – 6.8), when compared with families able at least once to provide SODIS-purified water. Families that did not adopt the new technology were more likely to live under crowded conditions (OR=5.7, 1.6 – 20.3), than families adopting the method. The mother of the child tended to be younger (OR=0.9, 0.9 – 1.0) and children were unlikely to visit the kindergarten (OR=0.4, 0.2 – 0.8).

4.7. Discussion

We successfully identified and described three indicators for estimating the proportion of families applying the SODIS method and were able to develop a rapid assessment tool for determining uptake at community level. However, our analysis showed that some gaps exist, which future studies should seek to fill.

The identified indicators for estimating the proportion of families applying the SODIS method were: reported use, reported frequency of drinking SODIS-purified water in the week preceding the interview, and the presence of SODIS-purified water at the time of the visit. The interpretation of these three indicators during a cross-sectional evaluation permitted us to identify respondent bias and to classify the families according to the reported intensity of use and the observed application of the SODIS method. This classification closely mirrored the real application of the SODIS method in the study families.

The importance of correctly observing and interpreting these indicators, through using especially-recruited staff, was underlined by the poor agreement between evaluations carried out by the implementing staff and the external evaluation conducted simultaneously. Determining the intensity of applying the SODIS method in each family permitted us to identify the key determinants for the adoption or rejection of the new technology.

Our project targeted (i) vulnerable families, seeking methods to improve their living conditions, and (ii) households with a higher hygiene awareness, that already lived under improved conditions. The mother of a family adopting the use of the SODIS method in this setting was on average older, more experienced, and had some basic knowledge of the association between hygiene behaviour and the prevention of disease (biomedical concepts). Mothers of vulnerable families may recognise the need for the improvement of their surroundings and accordingly seek efficient support. Such families were also more likely to have stunted children, which might make the safe upbringing of their child a priority.

Families with established hygiene practices, a familiarity with biomedical concepts, and which lived under generally cleaner conditions (cleaner surroundings; public latrines) were likelier to apply the method more regularly. In contrast, our programme did not reach families that were likely to be less educated and less experienced in raising children. Here, the presence of SODIS purified water was unlikely to be observed and hygiene messages were either not known or too difficult to implement.

These findings suggest that although a method is generally well accepted, difficulties at household level prevent the application of SODIS as a matter of daily practice. Further research into these areas is strongly recommended. Amongst other approaches, special promotion strategies and implementation techniques may have to be developed, to convince the undecided or insufficiently educated population to take up the method (see Chapter 3).

Our results are based on the assumption that our reference dataset best describes the SODIS application in a family. The fact that these observations were unannounced and performed by independent staff strongly supports this assumption, since interviewer or respondent bias is reduced considerably.

The moderate agreement between the cross-sectional evaluation – combining the three main indicators – and repeated observations, may be due to the changes that occurred over time in the way SODIS was applied in the study population. Only a minority of the study population was found to apply the SODIS method regularly since the beginning of the implementation. While the majority of the study population tried the SODIS method, it may have remained undecided until, or even rejected the method by the end of the intervention campaign.

The irregular application of the method may also explain the observed low negative predictive value, which prevents an unambiguous classification of people to a non-user category. Thus, the combination of indicators produces a more conservative estimate, and the true percentage of families that have at least tried the method at some point in time can be assumed to be higher. The addition of an indicator, such as "have you ever applied the SODIS method?" could identify the proportion of the population that rejected the method from the start, and therefore reduce the current uncertainty.

In addition to meaningful indicators, well-trained, unbiased field staff is essential for correctly determining the true exposure of the study population (to SODIS). Field staffs that are unrelated to the promotion of the SODIS method will receive more accurate answers, due to the reduction of respondent bias (Hawthorn-effect). Furthermore, such staff will neither be personally involved nor feel pressure from their organisations to report a high uptake rate or/and to demonstrate their high competence as promoters. Preparatory activities in the communities by the inhabitants or promoters (e.g. preparing SODIS water one day before the evaluation) can be prevented through keeping exact evaluation schedules disclosed only to key personnel. Insufficient attention to all of these factors flawed the evaluation that was performed by the implementing staff in December 2002. In this dataset, the proportion of families where SODIS-purified water was observed added to up to 70%.

Repeated observations of a target population may reflect the exposure of the families best. The number of times SODIS purified water was observed indicates the intensity of application and drinking. This classification accounts for the observed variation in the SODIS application between families and remains flexible for interpretation. It might especially be useful for health evaluations that compare the health status of individuals over time.

Where an end-evaluation of a programme is planned, a cross-sectional survey applying the indicators identified in this research will permit a valid classification, without taking into account the variation in SODIS application over a prolonged time period.

When the expected and observed proportion of families using the SODIS method is similar, the reporting bias is low; and both percentages would estimate the number of families applying the new method at the present point in time (Figure 4.1). When the two proportions differ, a further classification of families is necessary and this may be carried out according to the scheme in Figure 4.1. People reporting a frequent use of the method are likely to be observed with SODIS-purified water at a later visit, whereas families reporting a rare application of the SODIS method are more likely to never be observed with SODIS-purified water at home. The repetition of such cross-sectional studies will result in a similar – if not better – outcome than repeated observations alone.

Meaningful indicators of hygiene behaviour change and their approaches for their accurate assessment must precede investigations on health impacts of the studied behaviour. A resulting rapid assessment tool can benefit both implementation personnel and researchers, and may prevent flawed exposure classifications (Curtis and Cairncross, 2003) through ensuring better quality results.

In summary, the ability to make a simple and rapid assessment of the number of families adopting the SODIS methodology after a programme intervention may be useful for future programmes and scientific studies. The assessment of three main indicators by staff unrelated to the programme – and at an unannounced visit – permits a rapid classification of the target families into four specific groups, for which interpretation stays flexible. Future application of this approach under different conditions and settings will demonstrate its validity for wider application.

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CHAPTER 5

Solar water disinfection improves drinking water quality under everyday rural conditions at the homes of Bolivian families

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Working Paper

5.1. Background and introduction

More than one ninth of the worlds' population has no access to water, and even more people drink microbiologically contaminated water and are therefore at an increased risk of water borne infectious diseases (Murray and Lopez, 1997, WHO, 2002). Gastrointestinal diseases are one of the most prevalent causes of morbidity and mortality in children living in developing countries (Kosek *et al.*, 2003). Solar water disinfection (SODIS) has been earmarked by the World Health Organisation (WHO) as one of the most promising point-of-use methodologies for the provision of clean water, next to boiling and chlorination (Sobsey, 2002). In light of the challenges to reach the seventh millennium development goal – to halve the population without access to safe water and sanitation – cost-effective, simple home-based water disinfection methods have been considered to secure water quality where needed (Mintz *et al.*, 2001).

The efficacy of solar water disinfection to reduce pathogens in the water, was tested extensively under controlled laboratory and field conditions (Acra *et al.*, 1980, Reed, 1997, Reed *et al.*, 2000, Wegelin *et al.*, 1994, Wegelin and Sommer, 1998). As a result, a five-step protocol to disinfect water in the home has been developed for rapid and simple application in developing countries: After cleaning the transparent PET bottles and taps, bottles are filled with ¾ of water. Shaking the bottle oxygenates the water, and the bottle is completely filled, and exposed to the sun for at least 6 hours, best between 9am and 3pm, or two days when the sky is covered (see Chapter 1 & 3/(Meierhofer and Wegelin, 2002). After the purification procedure, the water is cooled in the shade and ready for drinking.

The synergistic effect of UV-A and high temperature leads to a three-log reduction of the thermo-tolerant coliforms (as indicator bacteria for faecal contamination) leading to the conclusion that 99.9% of the bacterial load in the water is inactivated by sun exposure (Wegelin *et al.*, 1994). Weather conditions must be favourable, the transparent plastic container should not exceed ten centimetres depth and water must be of low turbidity (<30 NTU) for the method to function properly. User guidelines can vary according to local conditions, as the process strongly depends on UV-A, temperature and turbidity.

For example, field experiments in Kenya demonstrated that the disinfection process functioned successfully under sub-optimal conditions – the water had turbidity levels of more than 200 NTU. As the temperatures of the water attained 55°C during sun-exposure, solar heating was a feasible disinfection method in the area (Joyce *et al.*, 1996).

Before each implementation campaign, it is therefore necessary to test the method in each setting, such as adaptations to the guidelines can be formulated. Field experiments are mostly performed under controlled conditions but the quality of the purified water that people drink on a regular basis during or after a promotion activity has not been published yet.

In the framework of a health impact study to measure the health effectiveness of applying the SODIS method in rural Bolivian children under five years of age (Chapter 7/ (Hobbins, 2003)), we collected and analysed drinking water samples from study participants, to estimate the efficacy of the introduced method under natural conditions. The study framework was composed of collaborations between the Latin American SODIS programme, an international non-governmental organisation for the implementation of the SODIS method in the study area, and the reference laboratory for water quality at a University in Cochabamba. The latter performed the water quality surveys. The partners already conducted controlled field tests before the study started, and concluded that the method was applicable in Bolivia, following the common protocol (CdA, 1997).

5.2. Objective

To measure the efficacy of the newly introduced solar water disinfection method in disinfecting water samples under natural, uncontrolled field conditions. In this context we also sought to compare the drinking water quality between participants that applied the method differently, and to deduce the most effective application scheme for this area.

5.3. Approach

Household and community water samples from ten study communities were collected and analysed on a monthly basis by a local team from a reference laboratory for water quality in Cochabamba, Bolivia, during three month (October – December 2002). The team measured the water temperature, pH and turbidity for each received or collected water sample on the spot, and later determined the number of thermo-tolerant coliforms – as indicator for faecal pollution – in the water sample in the field laboratory. We compared the water quality between treated drinking water samples (boiled or SODIS-purified) and raw drinking water samples at household level. To examine the degree of secondary contamination, the water quality of community water sources was compared to raw drinking water at household level. In case SODIS purified water was present in the household, technical factors such as the exposure time and the presence of a reflective surface were investigated. The quality of SODIS purified water was stratified by technical factors and weather conditions to investigate what application method worked best under the present field conditions.

5.4. Methods

The three water-sampling activities took place in ten communities situated in the district of Mizque, Bolivia. The framework of this survey was an evaluation of the effectiveness of the SODIS method on the health of rural children in the same communities and 205 participating households (Chapter 7).

Four field staff from a reference laboratory at a University in Cochabamba, collected drinking water samples from 130 randomly selected study households at unannounced monthly visits. The staff also collected water samples from previously identified major water sources in each community.

Drinking water samples included any water-based beverage that the mother would give to her child to drink at the time of the visit, in case the child was thirsty (this included raw water, SODIS purified water, tea, coffee, boiled flavoured water).

As the visit was unannounced and the staffs were unknown to the population, the offered beverage represented a true sample of what the household or child drank at the time of collection. Water sampling followed a standard protocol of the reference laboratory.

The samples were collected in previously autoclaved 300 ml sealed plastic bottles and rapid opening, filling and re-sealing of the bottle at time of sampling reduced the risk of contamination. Labelling of the household or source on the bottle guaranteed the identification of the sample. During the visits, specific observations were recorded regarding weather conditions, the storage container, the storage place, if the drinking water was covered and if utensils were used to serve water from the container.

Water temperature, pH and turbidity were measured at the household. Field staff further examined and evaluated the sample on a macroscopic scale recording the water samples' appearance, smell or colour. In less than 12 hours, samples were analysed in a field laboratory for the presence of thermo-tolerant coliforms (fcu) per 100ml water – as indicator for faecal contamination, expressed as number of colonies per unit volume – using the 'Oxfam DelAgua Field Test Kit' (*www.robenscentres.com/delagua*). For validation purposes, each collected sample was analysed two times, at different dilutions.

The field staff informed the participants personally about their drinking water quality and community leaders received all analysis results on the water quality of the examined water sources in their community.

We monitored the weather conditions on a daily basis at our central office (sunny, partly cloudy, cloudy and rain). These data were later merged with that of the water sampling to calculate the performance of the SODIS method in reducing water contamination at different weather conditions.

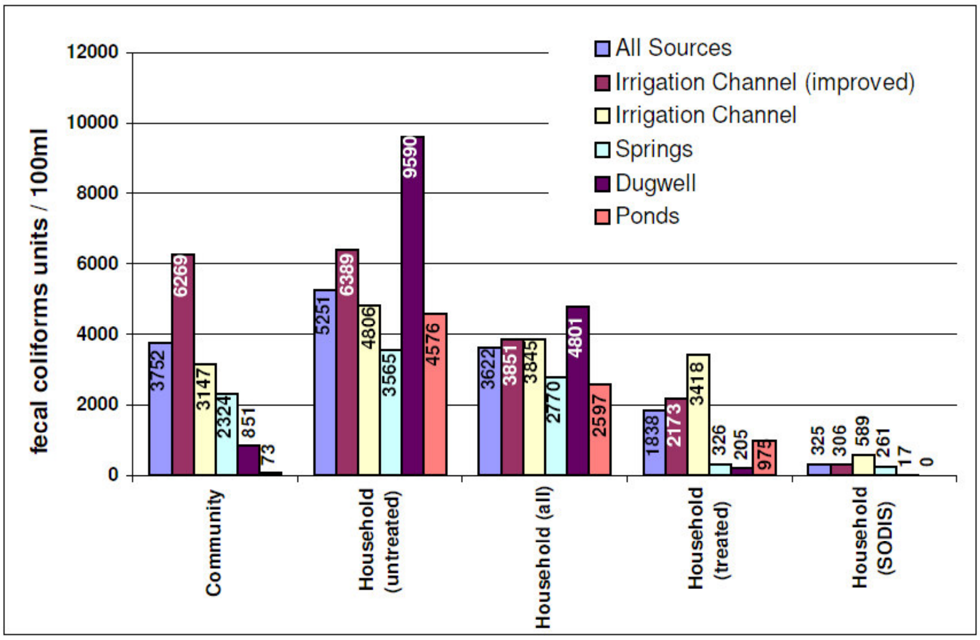
Results were entered in an excel spreadsheet, and checked twice for inconsistencies. Stata 8.2 was used for the analysis of the data (Stat Cooperation, 2002). Mean numbers of thermo tolerant coliforms were compared between water sample types, such as treated with untreated drinking water and untreated drinking water with community water source. We used the non-parametric *Kruskal Wallis* test to analyse whether the detected difference in the mean water contamination was due to chance.

We estimated the efficacy of the solar water disinfection method by calculating the ratio between the difference in the mean number of colonies and the mean contamination of the raw drinking water or, the difference in the mean number of colonies and the mean contamination at source.

5.5. Results

During the three consecutive monthly surveys, the field staff collected drinking water samples from 135 households. We included 140 from 145 community water samples and 342 from 371 household water samples in the analysis. Findings of water quality were excluded because results were inconclusive. From a 135 households, 9, 32 and 94 families were visited once, twice and three times respectively.

Figure 5.1: Mean faecal coliform load in water samples by origin and applied treatment



Legend: Numbers in the graph represent mean contamination of samples with thermo-tolerant coliforms (=faecal coliforms) as indicators for faecal pollution. Household treated samples are either boiled or purified through SODIS. Bolivia, 2002

Study families mainly offered drinking water from improved (lined) and natural irrigation channels (72.4%), springs (12.7%) and dugwells or ponds (6% and 4.9% respectively).

The average water contamination with thermo-tolerant coliforms ranged from around 850 fcu/100ml in dugwells to 2300 fcu/100ml in springs and 3000 – 6300 fcu/100ml or more in natural or improved irrigation channels (Figure 5.1).

On average, a 60% higher contamination with thermo-tolerant coliforms was detected in untreated drinking water samples than water collected at the source.

Tables 5.1: Proportional differences between thermo-tolerant coliform counts of differently treated drinking water samples

	SODIS vs. Raw	*Boiled vs. Raw*	*SODIS vs. Community*	*Boiled vs. Community*	*Raw vs. Community*
All	-93.6%	-64.4%	-89.5%	-42.0%	+62.8%
Number of samples	(78 vs. 210)	(42 vs. 210)	(78 vs. 132)	(42 vs. 132)	(210 vs. 132)
95%CI of above Value	(-96.3%) – (-91.9%)	(-118.4%) – (-30.4%)	(-92.2%) – (-88.3%)	(130.6%) – (-95.4%)	(108.4%) – (43.1%)

Legend: 95%CI: 95% Confidence Interval calculated of value under "All"; SODIS: SODIS purified water (<30NTU, >5 hours exposed); Raw: Untreated household drinking water; Community: water sample from community water source

Observed water management habits in this population endorsed the measured secondary water contamination. Previously water-washed plastic buckets or canisters were often used for water collection, stored outside and left uncovered. Water was taken out of the bucket using plastic glasses or coconut shells ("Tutuma"). Water from canisters was poured out into a glass or smaller container for later consumption.

Then again, the water management of the families changed through the adoption of the SODIS method. Almost all covered water containers observed were SODIS bottles (98%). Furthermore, SODIS was mostly drunk directly from the bottle, following the implementation messages.

Field staff received and collected SODIS purified drinking water – or water that was in the process of purification – in 24% of the samples, and 15% of the collected water samples were boiled. Purified SODIS water showed mean contamination levels between 17 (dugwells) and 589 fcu/100ml (natural irrigation channels). Families applying the SODIS method drank water with 93% less contamination than families not using any water treatment method (Table 5.1).

Table 5.2: The effect of sun-exposure time, reflective support and weather conditions on water quality

Exposure time & support	*All weather conditions*				*Sunny*				*Partly cloudy*				*Cloudy*			
	N	*Med*	*Mean*	*sd*	*N*	*Med*	*Mean*	*sd*	*N*	*Med*	*Mean*	*sd*	*N*	*Med*	*Mean*	*sd*
6 hours – $1^1/_2$ day																
On reflecting sheet	(17)	8	276*	615	(8)	14.5	318	785	(6)	134	359*	540	(3)	0	0	0
No reflecting sheet	(21)	38	574	1050	(8)	30.3	195	319	(11)	35	840	1370	(2)	630	630	806
2 days & more																
On reflecting sheet	(10)	0	1.4*	3.2	(2)	1.5	1.5	2.1	(6)	0	1.7*	4.1	(2)	0.5	0.5	0.7
No reflecting sheet	(18)	0.25	301	996	(4)	0.5	248	495	(8)	1	541	1472	(6)	0	16	36

*Legend: Numbers represent water quality (cfu/100ml). N: Number of samples (in brackets). sd= standard deviation of the mean. Med=Median. *Significant difference (p<0.05) between marked values in a column. Water samples exposed for a prolonged period of time on a reflective sheet were collected at irrigation channels (9 samples) and from a spring (1 sample). Mizque, Bolivia 2002.*

The water quality of SODIS purified water depended upon the procedures followed by the households to disinfect their drinking water (Table 5.2). The median number of thermo tolerant coliforms was low when water was exposed for two or more days. The comparison of the mean number of thermo-tolerant coliforms indicates that a reflective sheet may be helpful during sub-optimal conditions, such as partly clouded sky.

5.6. Discussion

The objective of this research was to measure the efficacy of the newly introduced SODIS method in disinfecting drinking water under natural, uncontrolled field conditions in a rural area of Bolivia. We further looked at the differences in the methods' efficacy in response to the mode of application and weather conditions, and were able to see trends that could influence the methods' future application guidelines.

Solar water disinfection was well placed in an area where community water sources were highly contaminated and untreated water showed high risk of secondary contamination. The adoption of the method inherently led people to safer water handling.

Purifying the raw water through simple exposure to sunlight reduced household drinking water by more than 90%, when compared to untreated household water. Best efficacy was reached when the water was exposed for at least two consecutive days (near to 100% reduction).

Our findings suggest, that sub-optimal conditions may require additional artefacts to guarantee the disinfection process, such as a reflective sheet as structural supports to hold bottles in place. These are promising results for the development of field applicable guidelines. The measured field efficacy of solar water disinfection is lower than the values from laboratory and controlled field studies (Encinas, 2003, Wegelin *et al.*, 1994). SODIS purified water also showed average contamination levels of 240fcu/100ml, which needs further consideration.

The analysis of water samples was a routine practice of the staff and previous controlled field experiments applied the same methodology (CdA, 1997, Encinas, 2003). The indicator for faecal contamination used in this study – thermo-tolerant coliforms – has been accepted as a surrogate for *E.coli* (World Health Organisation, 2004). We cannot exclude that reports from the household, about the number of hours water was exposed to the sun, were unbiased. Yet, we stratified the reported exposure time by 1 or 2 days sun exposure, and therefore overcame possible imprecise reports. The observed variation between efficacies in this study may be due to inaccurate application, varying local climatic conditions, and other unknown factors. Some of the measurements represented extreme values, as is represented in the differences between the mean and median in our analysis, but the difference in water contamination between exposure times are marked in both values. Sample size was small for the stratification by three factors: exposure, support and climate. The number of samples was strongly dependent on the adoption of the SODIS method, but a larger sample size would not have been a feasible option in the current framework for operational reasons and lack of resources.

Nevertheless, our findings suggest that exposing water-filled bottles for at least two consecutive days could almost produce drinking water quality with the recommended zero detection level of indicator bacteria (World Health Organisation, 1985). Under the local conditions, the use of a reflective support may further guarantee the high water quality during sub-optimal conditions.

Rigorous water quality guidelines may not be appropriate to all developing countries, as the maintenance of water provider services may not ensure the actual profit of drinking ‘zero *E.coli*’ (World Health Organisation, 2004).

This is mainly dependent on the local hygiene conditions and the risk of water contamination, and especially the risk of cholera outbreaks. In the case of a home-based water disinfection method, "maintenance" is entirely in the hands of the household, and best water quality should therefore be guaranteed by the user instructions.

It is well-known, however, that faecal indicator bacteria *alone* may not be a reliable guide to microbial water safety (World Health Organisation, 2004). Some pathogens, including viruses and protozoal cysts and oocysts have shown to be more difficult to eliminate from the water through sun exposure (Almanza, 2003, Zerbini, 2000). User instructions for the SODIS method should therefore also foresee enough exposure time to eliminate the most resistant pathogens.

Future studies need to further examine the differences in water quality between controlled field experiments and uncontrolled field conditions and the determinants leading to such variation. We suggest revising the general protocol for the application of the SODIS method to ensure best possible drinking water quality under sub-optimal conditions.

Apart from guaranteeing high drinking water quality and being less dependent on the weather condition, prolonged sun exposure of the water may also simplify the implementation and increase acceptance among the target population. Some participating families adopted the SODIS method according to their daily chores and water situation. For example, in one community, families received water from the irrigation channel – used for drinking and irrigation – only once every nine days. Under such conditions, using plastic bottles in the process of disinfection represented additional volume for drinking water storage. Bottles were kept on the roof for a prolonged time (two days or more) and consumed when needed. In contrast to reports from other countries (Hobbins *et al.*, 2000), the growth of algae due to prolonged exposition was only exceptionally observed in this setting. A two- to three day rhythm for the application of the SODIS method may further suit households better, as the workload may be perceived as less (Acra *et al.*, 1984).

More general guidelines that can assure acceptable water quality under uncontrolled conditions, may also reduce the costs of extensive testing of the method in each setting, and therefore further adapt the method for future large-scale promotion campaigns.

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CHAPTER 6

Solar water disinfection protects a rural population in Bangladesh from water related diarrhoeal diseases after abandoning arsenic contaminated drinking water sources

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6.1. Abstract

Background: The framework of a large international programme for local water and sanitation planning and the mitigation of the arsenic crisis in Bangladesh gave rise to test the solar water disinfection method (SODIS) for securing clean water where people needed to choose between arsenic- or microbiological contaminated drinking water. In short, the SODIS method includes the exposition of water-filled PET bottles to sunlight for at least 6 hours. *Goal:* To measure the health impact of the SODIS methodology through a controlled trial and evaluate the role and acceptance of the SODIS methodology as a local short-term arsenic mitigation option. *Method:* The SODIS method was introduced to ten families in each of the 16 pilot villages, and ten randomly selected families per village served as control. Fortnightly diarrhoea monitoring for eight month, and exposure assessment interviews were performed. We determined major risk factors of diarrhoea by comparing the observed with the expected number of diarrhoea episodes in the household in relation to the once assessed exposure factors. The acceptance of the SODIS method was evaluated through focus group discussions and semi-structured interviews. Water quality testing and climatic monitoring checked the efficacy and applicability of the SODIS method in the current setting. *Results:* Distance to water source (RR=2.4, 1.3 – 2.6) and awareness of the arsenic crisis (RR=0.42, 0.2 – 0.9) were the two major factors increasing or preventing the risk of diarrhoea respectively in the study population. The felt need in the population and the alternative water source (e.g. pond were always rejected) determined compliance to the SODIS method. The efficacy of reducing indicator bacteria from the water through sunlight under field conditions was high. As was expected, the health status did not alter in the 150 intervention families (with about 20% uptake rate) that partly changed the water source from pathogen free ground water (but arsenic contaminated) to microbiologically contaminated sources (but purified with SODIS water) (RR=1.0, 0.8 – 1.4). *Discussion & Interpretation:* The SODIS method provides a part-time arsenic mitigation option in Bangladesh. The method can be highly efficacious in preventing diarrhoea episodes in the population switching from “clean” to microbiologically contaminated drinking water. The high efficacy of the method confirmed this finding. Interventions based on the felt need in the population will result in best uptake rates. Other aspects for implementing the SODIS method in this setting are discussed.

6.2. Background and introduction

About 95% of the population of Bangladesh is supplied by groundwater from five million wells. Over thirty million people are constantly exposed to high levels of arsenic in drinking water (>50µg/l). Half of the population of Bangladesh is estimated to ingest arsenic contaminated groundwater and is therefore at risk of suffering from arsenic poisoning (Alam *et al.*, 2002, Mudur, 2000, Smith *et al.*, 2000). Many household-based simple arsenic mitigation technologies have been tested with varying degrees of success (Anstiss *et al.*, 2001, Caldwell *et al.*, 2003, Hoque *et al.*, 2004, Hug *et al.*, 2001, Jakariya *et al.*, 2003, Lee *et al.*, 2003, Meng *et al.*, 2001, Ramaswami *et al.*, 2001, Zaw and Emett, 2002). Well-switching has recently been reported to be one of the most feasible and successful methods (van Geen *et al.*, 2002, van Geen *et al.*, 2003). The risk of microbiological water contamination may rise in many of these proposed methods due to more intense water handling and the use of multiple water containers (Sutherland *et al.*, 2002). In desperate situations, where arsenic-free ground water is not available as an alternative water source, households may need to switch to surface water, which – while arsenic free – is often highly faecal contaminated, making it unsafe for consumption without prior treatment.

Solar water disinfection (SODIS) may represent the most rational solution to the above problem as it can be performed almost free of costs and is easy to learn. Water-filled PET bottles are exposed to sunlight for at least six hours. The synergistic effect of UV-A and high temperature leads to a three-log reduction of the thermo tolerant coliforms (as indicator bacteria for faecal contamination) (McGuigan *et al.*, 1998, McGuigan *et al.*, 1999, Wegelin *et al.*, 1994, Wegelin and Sommer, 1998).

While the high efficacy of the methodology is widely accepted, solid evidence of health improvement by drinking SODIS-purified water is scarce. In a series of tightly controlled trials, Conroy *et al.* demonstrated that the adoption of solar water disinfection could reduce the incidence of diarrhoea in Massai children by 2.1 occurrences (Conroy *et al.*, 1996, Conroy *et al.*, 1999, Conroy *et al.*, 2001).

A local Swiss-funded project, involving three international and 15 local partner NGOs, performed different action research projects as part of local water and sanitation planning and the mitigation of the arsenic crisis in the 640 villages involved. In a pilot phase, 15 NGOs selected 15 villages to introduce the SODIS method as an arsenic mitigation option in ten households per village.

This setting provided an opportunity to conduct a study to measure the health impact of the SODIS methodology in the population studied. If the SODIS method were a successful arsenic mitigation option, we would expect diarrhoea frequency to remain the same between people applying the SODIS method and families continuing drinking microbiologically clean ground water. Waterborne diarrhoeal disease transmission could generally be assumed low due to the high coverage of ground water supply in the studied villages. In addition, we also report on factors that favour or limit the acceptance of the SODIS methodology under these special conditions.

6.3. Objectives

To measure the health impact of the SODIS methodology through a controlled trial and evaluate the role and acceptance of the SODIS methodology as a local short-term arsenic mitigation option

6.4. Approach

Fifteen partner NGOs introduced the SODIS method to ten families in each of the 16 pilot villages. Ten additional families per village were randomly selected and served as control. The difference in diarrhoea frequency between the intervention and control group was determined through the risk rate. From the fortnightly diarrhoea monitoring over a period of eight months, we described the ratio between observed and expected frequency of diarrhoea per household.

Exposure assessment interviews were conducted to assess the prevalence of exposure factors in the study population and their association to the occurrence of diarrhoea in the population.

A final Poisson model comparing the observed to the expected number of diarrhoea episodes described the major risk factors for diarrhoea in the study population.

To evaluate the role and acceptance of the SODIS method in this special setting we applied qualitative and quantitative methodologies. Focus group discussions with intervention and control families as well as unrelated families were performed. Interviews on the water and SODIS management, as well as socio-cultural and economic conditions were carried out.

We defined a family that adopted the new method by their ability to provide SODIS purified water at an unannounced visit. Comparison of potential factors influencing the adoption of the new method between families and villages revealed determinants of use of the SODIS technology under such conditions.

6.5. Population and setting

In a preliminary phase between January and July 1999, 15 local partner NGOs selected 16 from 640 rural villages (40 per NGO) as pilot villages for the implementation of the SODIS method in the area of Rasjhahi and the Chapai Nawabganj district in Bangladesh. On average, a village included 125 households with a mean of 5.7 inhabitants per household. The SODIS methodology was introduced in ten pilot families per village on a demand basis. Solar water disinfection was introduced through repeated motivational household visits. The NGOs provided PET-bottles that were previously painted in black on one side.

6.6. Methods

6.6.1. Health and risk assessment

Diarrhoea was defined as three loose stools within the last 24 hours or one loose stool containing blood (World Health Organisation, 1994).

During an eight months' period (August 1999 – May 2000), two project staff members carried out fortnightly visits to each of the previously selected 300 households (on average 20 households per village), determining the occurrence of diarrhoea in any member of the family during the past two weeks. Wherever possible, they interviewed the housekeeper (usually the mother).

We included previously assessed vernacular terminology to determine the frequency and consistency of stools, as well as the duration of illnesses. Sick persons were referred to the nearest health facility.

To identify the major factors contributing to the occurrence of diarrhoea in a household, five previously trained field staff carried out semi-structured interviews during a two-week period in May 2000. The interviews included topics such as health, hygiene, water management habits, and the knowledge of, attitude towards, and practice of the SODIS methodology.

6.6.2. Water analysis

To measure the efficacy of the SODIS method in reducing indicator bacteria for faecal contamination in water under field conditions, we analysed drinking water samples from households known to apply the SODIS method. One sample of purified SODIS water (stored and ready for drinking) and one sample of untreated water were collected. In addition to the samples from intervention households, stored drinking water and respective water samples from the source were collected from control households. We sampled three different ponds to test their grade of contamination.

To ensure a true sample of ground water, field staff pumped water through the tubewell to clear residual water in the tube. Dugwell water samples were collected with the bucket associated with the well or a bucket lent by a family. Both of these sampling methods approximate closely the water collection habits observed in the villages.

The samples were collected in sterile 250ml propylene bottles. All samples were analysed for the presence of thermo tolerant coliforms (indicators for faecal contamination) with the membrane filtration method (DelAgua field-test kit, OXFAM) in the local field laboratory. Highly turbid or suspected contaminated water samples, such as from ponds or dugwells, were diluted to 1:2 until 1:100. All results are reported as the number of faecal coliform counts in a 100ml water sample (fcu/100ml).

6.6.3. Assessment of climatic conditions

To estimate the applicability of the SODIS methodology during one year in this Bangladeshi setting, office staff recorded air and water temperature as well as weather conditions up to eight times a day, from April 1999 to April 2000 on the roof of the rural office building. Up to six water-filled PET bottles were supported with a tin shed and exposed on the flat office roof.

6.6.4. Data analysis

All data were double entered by two different data-entry clerks, using the Epi-Info software 6.2 (CDC, USA), and any errors were corrected with reference to the original form. Consistency checks were performed before starting the analysis with Stata 7.0 (Stata Cooperation, USA) and SAS 8.0 software (SAS Systems).

We measured the impact of the SODIS method on the occurrence of diarrhoea in the intervention group by using the repeated measurements as outcome. Our outcome is a risk rate (RR) describing the ratio between observed and expected mean numbers of diarrhoea episodes per household, for each relevant factor. The ‘observed’ mean number of diarrhoea episodes per household was equal to the average of the repeated 16 measurements, carried out over an eight months’ follow-up of each household. We estimated the ‘expected’ mean number of episodes per household by calculating the mean number of diarrhoea episodes observed per age group (0-4. 5-9, 10-14, 15-19, 20-39, >40), and subsequently averaged the values for each household according to its age composition and size.

We merged the data collected during the exposure assessment with the sum of the 'observed' and 'expected' number of reported diarrhoea occurrences per household and observation time. Two main assumptions were made: (a) possible reporting bias in the diarrhoea monitoring was distributed evenly among all participating households, and (b) the exposure factors remained stable over the follow-up period.

We analysed the association of each factor with the outcome. Variables with a strength of association of $p<0.2$ were taken under consideration for further processing in the multivariate model.

Backwards and forward step-wise elimination of previously identified variables resulted in the final model. Additional explanatory models were formulated to analyse the factors associated with the frequency of diarrhoea more closely.

To compare the mean contamination in purified water samples with that in raw water samples, the matched-*paired t-test* was used where data was normally distributed. It was assumed that the contamination of water samples collected at the village sources did not differ significantly between the day of collection and the day when the family filled the bottles. In the event that data were not normally distributed, the non-parametric *Kruskal Wallis-test* was used to calculate the probability that the detected difference in mean water contamination was due to chance.

For the identification of determining factors for adoption or rejection of the methodology, we compared households applying and households not applying the SODIS method in the intervention group. We classified families to one or the other group according to their ability to provide SODIS purified water at the unannounced visit of the interviewer.

The $\chi 2$-test was used to define the strength of association, and multivariate logistic regression identified the most dominant factors associated with the adoption of the new methodology.

6.7. Results

In total, 307 households representing 1513 persons were selected. One hundred and fifty households (727 persons) were introduced to the solar water disinfection method (SODIS), and 157 households with children under five years of age were randomly selected as controls (786 persons). One of the 16 villages did not participate in the trial, as no acceptable alternative water source was present for the inhabitants to apply the SODIS method.

Two hundred and sixty-four households were interviewed in the cross sectional survey. As indicated in Table 6.1, children under five years of age were more prevalent in the control households ($p<0.001$) and intervention households had spent on average more years in school (more than 10 years; $p<0.001$).

Both study groups showed a similar proportion of arsenic affected households, but the intervention group had better access to dugwell water ($p=0.016$).

Table 6.1: Comparison of SODIS intervention and Bangladeshi control families

	Intervention (N=137)		*Control (N=127)*	
	% or *mean*	CI or *sd*	% or *mean*	CI or *sd*
Demographic				
No. of Household members	*5.0*	*2.6*	*5.1*	*2.1*
Presence of children under 5y§	42.3%	34.0 – 51.1	68.5%	59.6 – 76.3
Mean age of person interviewed	*33.4*	*11.2*	*30.3*	*9.5*
Mean education§	*3.3*	*2.1*	*2.5*	*2.1*
Arsenic affected	15.3%	10 – 22.7	12.6%	7.6 – 19.9
Socio economic				
Monthly Income*	*2430*	*2708*	*2220*	*1131*
Water management				
Use tubewells	87.6%	80.6 – 92.4	89.0%	81.9 – 93.6
Use dugwells§	24.1%	17.4 – 32.3	12.6%	7.6 – 19.9
Use ponds	64.2%	55.5 – 72.1	59.1%	50.0 – 67.6

*Legend: *Income (1US$=60.0 Taka). CI = 95% Confidence interval of proportion. §significant with $p < 0.05$; Rasjhahi, Bangladesh, 2000.*

6.7.1. Health impact

During the cross sectional exposure assessment, 7 of 137 intervention households reported the occurrence of diarrhoea on the day of the interview, compared to 12 of 127 control households (OR=0.52, 95%CI: 0.17 – 1.48).

Table 6.2 illustrates the uni- and multivariate Poisson regression for the continuous outcome. In the uni-variate analysis, exposure factors related with hygiene behaviours, water management as well as demographic factors and exposure to the arsenic crisis were significantly associated with the outcome.

After step-wise elimination, two factors remained significantly associated with the frequency of diarrhoea in the study population. Families in need of storing their tubewell water for drinking purposes were at two times higher risk of suffering from diarrhoea than families having easier access to tubewell water (RR=2.1, 1.1 – 4.0). On the other hand, households that had tested their tubewell water for the presence of arsenic were significantly less likely to contract diarrhoea (RR=0.4, 0.2 – 0.9). Families that tested their tubewell for the level of arsenic contamination were likelier to personally know people suffering from arsenic poisoning (OR=4.4, 95%CI: 1.3 – 14.9). Field staff observed SODIS purified water more frequently in the homes of families that tested their tubewell for arsenic content (OR=1.4, 95%CI: 1.1 – 1.9).

6.7.2. Attitudes and use of the intervention

One year after the introduction of the SODIS methodology (May 2000) and constant follow-up by the local NGO, 19% of the introduced families were able to provide SODIS purified water at the time of an unannounced visit.

Table 6.2: Uni- and multivariate analysis of main factors associated with diarrhoea frequency in Bangladeshi homes

	N	*% Exposed or Mean (sd)*	*RR (95%CI)*	*RR, adjusted (95%CI)*	*p-value*
SODIS intervention	264	51.9	1.0 (0.8 – 1.4)	-	-
Demography					
Mean age of household (years)	263	*22.5 (sd=7.6)*	1.0 (1.0 – 1.1)	-	-
No. of household members[§]	264	*5.1(sd=2.4)*	0.9 (0.8 – 0.9)	-	-
Children under 5 years present	264	54.9	0.6 (0.4 – 0.8)	-	-
Mean education of household	264	*3.2 (sd=3.4)*	1.0 (1.0 – 1.1)	-	-
Sanitation & hygiene					
Animals observed in the compound	264	43.2	0.7 (0.5 – 0.9)	-	-
Latrine observed	264	68.9	1.4 (1.0 – 2.0)	-	-
All the kids in household use latrines	148	48.8	1.8 (1.2 – 2.8)	-	-
Child defecates in the compound	237	29.5	0.9 (0.6 – 1.2)	-	-
Water Management					
Dugwell use	264	18.6	0.4 (0.2 – 0.7)	-	-
Store tubewell water for drinking	198	22.2	1.6 (1.1 – 2.3)	2.4 (1.3 – 4.6)	0.007
Distance to tubewell	231	*47.0 (sd=115)*	1.0 (0.9 – 1.0)	-	-
Arsenic awareness					
Tested tubewell for arsenic content	201	43.3	0.6 (0.4 – 0.8)	0.42 (0.2 – 0.9)	0.017
Mean No of persons known As-affected	192	*0.2 (sd=0.38)*	1.3 (0.8 – 1.9)	-	-

Legend: RR: Rate ratio. sd: standard deviation. CI: confidence interval. As: Arsenic. Final regression model includes 61 observations and a LOG-likelihood = -66.9, p=0.003; Bangladesh, 2000.

Families that adopted SODIS had significantly more bottles at home ($p<0.05$), were 3 times more likely to know patients suffering from Arsenicosis (OR=3.0, 95%CI: 1.3 – 6.7) and may have spent more years in school ($p=0.06$). Furthermore, families continuously applying SODIS seemed to adopt other hygiene approaches more readily – such as washing the babies' bottoms after defecation ($p=0.07$) and keeping the surroundings clean ($p=0.06$).

6.7.3. Expressed needs of intervention families

Five villages had completely stopped applying solar water disinfection by May 2000. The main arguments for rejecting the newly introduced methodology were the lack of a culturally accepted alternative water source. Families refused to drink pond water, independently of its purification status (Table 6.3). Another reason for stopping the application of the SODIS method was the absence of felt need – e.g. where tubewells were clean and free of arsenic.

More specifically, the additional workload and socio-cultural factors directed households to drop the further application of the SODIS method – e.g. husband disliking "SODIS", or disliking that their wives are too busy with "SODIS".

Table 6.3: Reasons for rejecting the use of pond water for drinking purposes in Bangladesh

Use of pond water for solar disinfection is refused as it…	*Person reporting*
"…is dirty, with fertiliser…"	(Woman, ~30y, nAs),
"…has no good taste…"	(Woman, ~35y, nAs)
"…is not hygienic", "…is with faeces…"	(Woman, ~25y, As), (Woman, 26y, nAs)
"…is open, dirty, not good…"	(Woman, 21y, nAs)

Legend: nAs: entire village not affected by Arsenic poisoning. As: entire village affected by Arsenic poisoning. Focus group discussions, Rasjhahi, Bangladesh, November 1999.

6.7.4. Expressed difficulties

Table 6.4 lists the difficulties families reported with the bottles needed for the application of the new method. Two-thirds of the introduced families claimed to need more bottles. On average, people claimed to need 2.3 bottles per household member. Bottles needed to be exchanged every four to six months.

Table 6.4: Expressed difficulties with PET bottles and reasons for exchanging bottles

	Mentioned as problem	*Reason to exchange*
Cap loss	77.8% (45)	--
Smell	4.4% (45)	--
Colour loss	77.8% (45)	--
Deformation due to heat	20.0% (45)	52.4% (21)
Dirty	11.1% (45)	33.3% (21)
Cracking due to roof fall	8.9% (45)	23.8% (21)
Transparency loss	2.2% (45)	23.8% (21)
No problem	11.1% (45)	--

Legend: In brackets: Sample number. Semi structured interviews, Rasjhahi, Bangladesh, December 1999.

Over half of the reasons for exchanging bottles at the local NGO were deformation due to excessive heat. Deformation of plastic bottles often resulted in leaks or even cap-loss, relating to the most frequently mentioned difficulties. Rapid detachment of the black paint on one side of the bottles reduced its aesthetic appearance vis-à-vis families, relatives and neighbours.

6.7.5. Efficacy of the intervention

The efficacy of the SODIS methodology under household conditions is an essential component in the evaluation of its impact on health. Thirty-eight samples were collected in total. Twenty samples originated from intervention households, eighteen from control households. Three samples originated from ponds. Pond water was found to be the most polluted with an average of more than 500cfu/100ml, followed by dugwell water (>80cfu/100ml), and tubewell water (<20cfu/100ml).

The water quality of all collected untreated water samples did not differ significantly between intervention and control families. Purified drinking water from intervention households was less polluted than drinking water samples from control households ($p=0.07$). That was mainly due to the 100% reduction of faecal coliform contamination in dugwell water samples. Regardless of the water samples' origin, the SODIS method reduced contamination by on average 90% under field conditions in sentinel households.

6.7.6. Effect of climate variation on the intervention's applicability

The climatic dependence of the solar water disinfection method (SODIS) is important for planning complementary intervention to secure purified water during the entire year. In 84% of the measurements weather conditions were at least partly sunny. Water temperature within the plastic bottles reached 50°C or more in 11.4% of the measurements during all seasons, and in 29.3% of all measurement during the dry season.

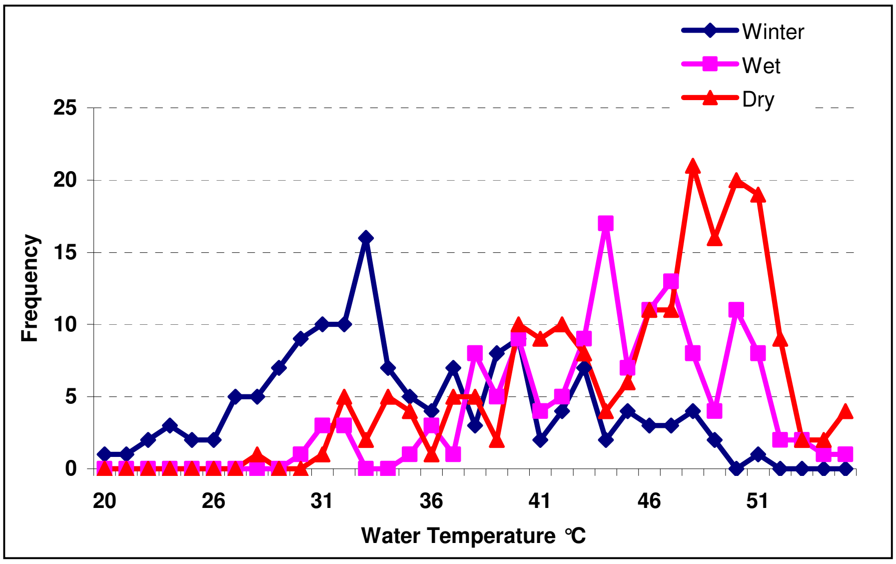
Table 6.5: Comparison of drinking water quality by treatment and source

	Raw water			Drinking water			
	Mean (N)	*sd*	*Min / Max*	*Mean (No)*	*sd*	*Min / Max*	*p-value*
Intervention Group							
All Sources	0.8 (10)	0.9	0 / 2.0	0.1 (10)	0.3	0 / 2.0	**0.04**
Tubewell w\ P							
Tubewell no P	0.3 (7)	0.5	0 / 1.0	0.1 (7)	0.3	0 / 0.8	0.42
Dugwell water	2.0 (3)	0.1	1.9 / 2.0	0 (3)	0		**0.04**
Control Group							
All Sources	0.3 (9)	0.5	0 / 1.5	0.8 (9)	1.2	0 / 3.5	0.79
Tubewell w\ P	0.1 (5)	0.2	0 / 0.5	0.5 (5)	0.8	0 / 1.9	0.75
Tubewell no P	0.6 (4)	0.7	0 / 1.5	1.2 (4)	1.6	0 / 3.5	0.66

Legend: All calculations in LOG-scale. Legend: Raw Water: Water collected at source. Drinking water in the control group: Water stored at home. Drinking water in the SODIS group: SODIS purified water. In brackets: Number of samples. sd: Standard Deviation. Min / Max: Minimum and Maximum value. p-value was calculated with the paired t-test. Tubewell w\P: Tubewell with concrete platform. Tubewell no P: Tubewell without concrete platform. Rasjhahi, Bangladesh. May 2000.

Figure 6.1 indicates that the optimal season for the application of the SODIS method is during dry season (February – May), where winter season seems least optimal (October – January). In rainy season, the water temperature rose to similar heights as during dry season, but more frequent clouded sky may impede the disinfection process for the lack of UV-A radiation.

Figure 6.1: Seasonal differences between water temperatures achieved during sun exposure



Legend: Only sunny days are taken into account. Time range of measurement: 14.00 – 16.00. Seasons: Winter: Oct – Jan; Wet: June – Sept; Dry: Feb – May. Rasjhahi, Bangladesh, Apr 1999 – Apr 2000.

6.8. Discussion

Our aim was to assess the health impact, field efficacy, acceptance and role of the solar water disinfection methodology (SODIS) as an arsenic mitigation option in a rural setting in Bangladesh. Our results show, that where the SODIS method was adopted, it may have preserved people from suffering additional diarrhoea episodes due to switching wells from arsenic contaminated tubewells to microbiologically contaminated dugwells. The high reduction of faecal contamination of dugwell water confirmed the usefulness and applicability of the SODIS method in this setting. For the evaluation of the exact health impact of the introduction of the SODIS method, our control household would have needed to drink from faecal contaminated water, which was not considered ethical.

Storage of tubewell water for drinking purposes was a dominant risk factor for diarrhoea and pointed towards a combined effect of secondary water contamination at household level and lower socio economic status. Our water analysis results indicate secondary contamination in drinking water from control households but not from intervention households. Due to the use of a closed system, the SODIS method proved effective in preventing secondary contamination in intervention households.

The role of the people's awareness of the arsenic problem on the prevention of diarrhoea is explained with induced behavioural changes due to water related epidemics. The rise in felt need for preventive action led people to adopt and apply the SODIS method regularly. However, this was only the case, when an acceptable water source for switching wells was present. As both, dugwells and the arsenic crisis, were not common in the pilot villages, the overall uptake rate of the SODIS method was low. Ponds were not perceived for drinking, and other tubewells were usually free of microbiological contamination.

The adoption of the method was further facilitated when families received more education and already followed certain hygiene behaviours. Awareness and acceptance of health concepts related to germs and diseases and according preventive measures may support the uptake of the method in any population considerably.

At time of the study, approximately 27.8% of the 640 villages had access to dugwell water and 42% of these had at least one tubewell with confirmed arsenic contamination (>50µg) in the entire programme area. About 11.6% of the programme area could have benefited from the SODIS method as a short-term complementary arsenic mitigation option.

However, our one-year climate and water temperature monitoring showed that next to the SODIS methodology, other complementary solutions would be needed, such as solar water disinfection in combination with rainwater collection systems, boiling or chlorination. Only one season favoured the use of the method. Despite more cloudy skies in rainy season, periodic floods during and after the wet season may hinder the application of the SODIS method considerably due to the turbidity of the water, loss of bottles, access to bottles and water to clean the bottles.

People living in an arsenic affected village that could switch to dugwell water were satisfied with the SODIS method. Future programmes must therefore carefully select villages according to the populations' felt and perceived need and village infrastructure.
The scarceness of plastic bottles and their few functions in the rural villages, as well as the quality and replacement of bottles that were painted black on one side, calls for actions and good preparation on the supply side.

The introduction and establishment of local markets for trading second-hand PET-bottles may solve many of the supply, quality and management difficulties. Hygiene behaviour messages could be included in the daily management and practice of the SODIS methodology; and the household management of the method could be adapted to the preferences of the local population. For example, the need to paint half of the PET bottle in black may need to be evaluated in each setting as accompanying operational constrains can be considerable. However, some families started to use black supports instead, which seemed more convenient and feasible under the present conditions.

Given our experience and reported results, we conclude that solar water disinfection could be introduced as a short time arsenic mitigation option in Bangladesh. The method showed to be efficacious in preventing diarrhoea in families forced to change to microbiologically contaminated water sources.

The availability of acceptable and faecal contaminated wells may be necessary for people to accept switching water sources. Awareness building of water related diseases – arsenic and microbiological contamination – may prove a necessary part of the introduction of the SODIS method as well as complementary methodologies to assure safe water at household level. Cost and benefit may vary considerably according to the specific setting; the presented criteria for the implementation of the SODIS method as an arsenic mitigation option may need to be assessed beforehand in the form of a comprehensive need assessment including normative and perceived needs.

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CHAPTER 7

Measuring the health impact of solar water disinfection in children under five years of age in rural Bolivia

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7.1. Abstract

Background: The WHO earmarked solar water disinfection of drinking water as one of the potential key low cost home-based interventions. Advocacy, international acceptance and political will to adopt the method on a large scale, have been hampered by a lack of solid evidence about its effect on the health of populations. *Goal:* To assess the health effectiveness of applying the solar water disinfection (SODIS) method in reducing diarrhoea frequency in rural Bolivian children under five years of age. *Method:* We conducted a nested case-control study within the framework of a district-based SODIS dissemination programme in a rural Bolivian setting. Cases were selected from the established weekly diarrhoea monitoring in the 205 study children living in ten study communities over a four-month period. Controls were concurrently selected at random from the entire healthy study population (ratio: 1:2). Exposure factors relevant to childhood diarrhoea were assessed during one-hour interviews. Step-wise elimination in the multivariate analysis resulted in a Poisson model explaining the occurrence of diarrhoea in our study children. *Results:* The adoption of the SODIS method was able to avert 59% to 75% of the diarrhoea episodes per child aged under five years depending on the households' frequency of applying solar water disinfection. Other exposure factors significantly associated with the diarrhoea incidence rates of study children were the age of the child (IRR=0.97, 0.95 – 0.98), number of animal species owned in a household (IRR=0.83, 0.75 – 0.93), and the study child contracting a new *Giardia lamblia* infection within two months after investigation (IRR=4.66, 2.68 – 8.11). *Discussion*: The introduction of SODIS can reduce childhood diarrhoea by 14.5% at child-population level given a population uptake rate of 20% of the SODIS method. We may have found a dose-response relationship between the preventive effect and frequency of consumption, supporting the current result. Estimates for the costs of SODIS and childhood diarrhoea are discussed. This study supports the further advocacy of solar water disinfection as an effective measure to improve health at population level.

7.2. Background and introduction

The World Health Organisation has earmarked solar purification of drinking water as one of the key low cost interventions besides hand washing with soap and water chlorination to assure drinking water of adequate quality at household level (World Health Organisation, 1997). Considerable evidence of its efficacy to reduce pathogens and indicator bacteria in water samples under laboratory- and field conditions have been reported, which justified the promotion of the solar water disinfection (SODIS) method in pilot-projects across seven countries (Brofferio, 2000, CdA, 1997, Hobbins *et al.*, 2000, Oates *et al.*, 2003, Robins, 2000, Sommer *et al.*, 1997, Walker *et al.*, 2004, Wegelin *et al.*, 1994, Wegelin, 1998, Wegelin and Sommer, 1998). Results from these small scale projects usually indicated good acceptance of the method in different cultural settings (Mintz *et al.*, 2001). Advocacy, international acceptance and political will to adopt the technology on a large scale, have been hampered by a lack of solid evidence that this home-based water treatment method improves health at population level. Three controlled field trials among a nomadic Massai population in Kenya resulted in promising findings. Solar heating – increased water temperature was the dominant disinfectant in this setting – was associated with a reduction of diarrhoea in children of 5 to 16 years of age (OR=0.66) (Conroy *et al.*, 1996). Sixteen percent of the reduction of diarrhoea in children aged under six years could be attributed to drinking SODIS purified water over a one year period (Conroy *et al.*, 1999). The ability of the SODIS method to prevent cholera in children during an outbreak in the same region and population was also demonstrated (Conroy *et al.*, 2001). However, a recent review of the effect of household water quality on diarrhoea, failed to find an overall significant health gain from point-of-use water treatment technologies (Gundry *et al.*, 2004). More extensive reviews, that may provide more comprehensive estimates, are under way (Clasen *et al.*, 2004).

The health effectiveness of solar water disinfection for reducing drinking-water transmitted diseases needs to be described under daily life conditions to enable stakeholders to take appropriate decisions for its further promotion (Tanner *et al.*, 1993).
In our project, we assessed the effectiveness of applying the solar water disinfection on the reduction of diarrhoeal diseases in rural children under five years of age. In addition, we estimated the cost-effectiveness of the SODIS method at family level.

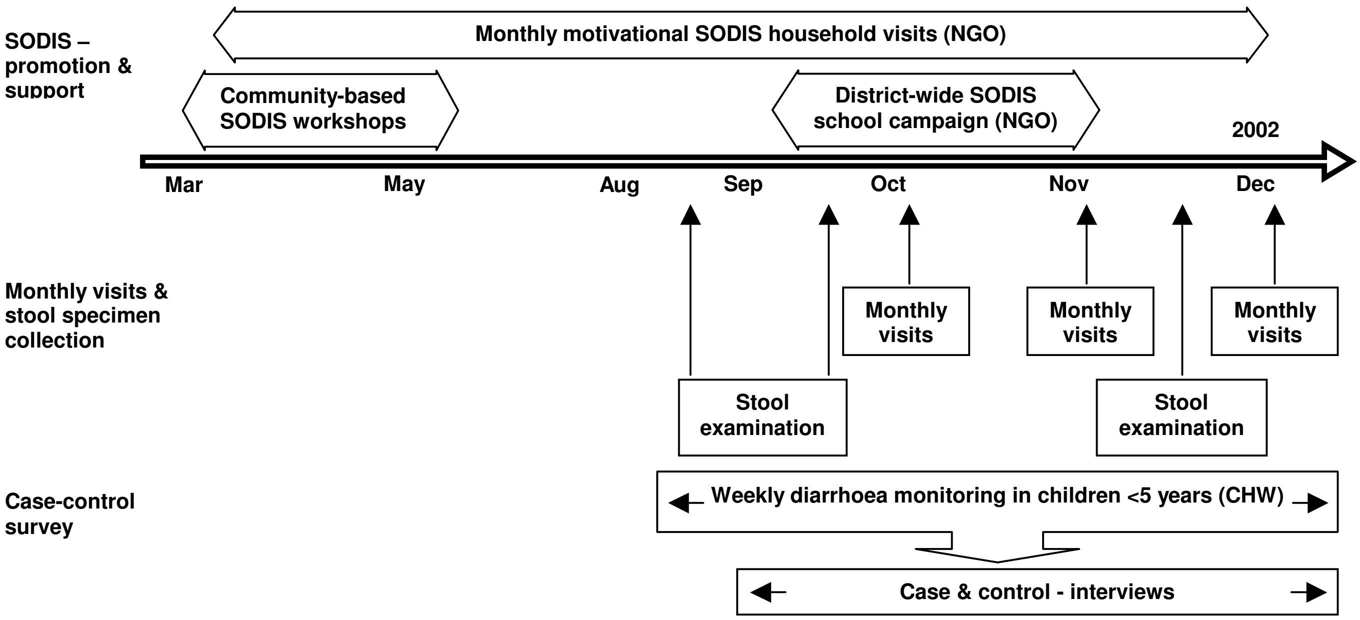
7.3. Objective

To assess the effectiveness of applying the SODIS method in reducing diarrhoea frequency in rural Bolivian children under five years of age at community level.

7.4. Approach

We conducted a time-matched nested case-control study within the framework of a district-based SODIS dissemination programme, executed by a locally active international non-governmental organisation (NGO) in the district of Mizque, department of Cochabamba, Bolivia (Figure 7.1).

Figure 7.1: Approach for measuring the impact of the SODIS intervention



Eighteen communities were involved in the dissemination programme. From these, we selected ten communities for health assessment, according to their motivation, accessibility, lack in water infrastructure and poor water quality. Our study population consisted of rural children aged under five years living permanently in the selected communities. All families with children under five years of age in the study area underwent a strict informed consent procedure, prior to involvement in the study. One child per family aged under five years was randomly selected as the study child.

Cases and controls (ratio: 1 to 2) were selected from the established weekly diarrhoea monitoring in the study communities over a four-month period. Exposure factors enhancing or reducing the risk of childhood diarrhoea were assessed during one-hour interviews with mothers of study children.

Factors associated with the diarrhoea episodes of the study children were identified, by comparing case- with control households. A Poisson model was constructed, with relevant exposure variables including the application of the SODIS method, which explained the occurrence of diarrhoea in our study children using our continuous outcome. Furthermore, the cost effectiveness of the SODIS methodology at household level was estimated based on reports from study households.

7.5. Methods

7.5.1. Informed consent procedure

The study was reviewed and accepted by a WHO review board. The project was presented locally and accepted by the municipality. After approval of the project by majority vote at individual community meetings, the written consent of each community leader was obtained. Prior to involvement, each family with children under five years of age, that could potentially participate, was informed in detail about the activities that would be carried out and their purpose. Doubts or uncertainties identified whilst probing the mothers' understanding were resolved. Verbal consent from one or more household members – usually the mother – concerning the children aged under five years of age classified the family as a participant. Additionally, consent of the mother or guardian was sought prior to each activity in the household.

Our field staff translated all data collection instruments into Quechua, the widely spoken local language. All translated documents and tools were back translated independently into Spanish to check the accuracy of the translation. Interactions with community people were also held in Quechua.

7.5.2. The intervention

We implemented the SODIS methodology using newly developed implementation techniques: e.g., monthly community-based participatory workshops; regular household visits; and a school campaign in all the involved communities. A detailed description of the implementation process, lessons learnt and its specific impact on the study population, are described elsewhere (Indergand *et al.*, 2004).

7.5.3. Diarrhoea surveillance system

A child suffering from diarrhoea was defined as having three loose ("liquid" or "semi-liquid") stools, or one loose stool containing blood within the last 24 hours.A diarrhoeal episode was defined as a new episode, when at least three days had elapsed between it and the previous one. (World Health Organisation, 1994).

As a basis for estimating the incidence of diarrhoea in our study children, and for the concurrent selection of the case- and control children, we established a community-based weekly health monitoring system in the ten study communities. Eleven community health workers (CHW) were thoroughly trained in interview techniques and the identification of moderate to severe dehydration symptoms in children. A CHW asked for the occurrence of seven previously identified vernacular terms, describing repetitive and unusual liquid bowel movements in the child. Additionally, three symptoms were assessed and included in the questionnaire: stomach-ache, fever and vomiting. From any reported symptom, start, duration and symptom-free periods between episodes were recorded on a weekly morbidity calendar. If a child suffered from any gastrointestinal illness, more detailed information about consistency, frequency and the occurrence of blood in the stool was recorded for later classification of the diarrhoea episode.

The CHWs taught mothers how to prepare home-made rehydration salts, by supplying sugar, salt and lemon, following standard recipes (de Zoysa *et al.*, 1984a, de Zoysa *et al.*, 1984b). Field personnel further provided linseeds to the households for the relief of fever in the child (locally known remedy), which reflected our acceptance of local health concepts in the household and community. Supplies were distributed equally to all families, independent of the health report by the mother.

Equal distribution avoided the introduction of reporting bias, as households usually lacked sugar.

7.5.4. Case and control selection and risk exposure interviews

On six days per week, each CHW delivered data on the passed and current health status of the child to the central office in Mizque, where it was discussed jointly and validity checks were performed. Cases were selected immediately from the revised information.

A case was defined as a study child that had suffered from a new episode of diarrhoea within the past six days or on the day of the visit. In order to achieve a case-to-control ratio of 1:2, four controls per case were concurrently and randomly selected from the child population that had been diarrhoea-free during the last two weeks. A child was not eligible for control selection, if it had taken antibiotics or medications, or if data on diarrhoea symptoms covering the last 14 days were missing.

Mothers or – in their absence – caregivers of selected case- and control children were interviewed for one hour within two days of selection by seven woman interviewers. Table 7.1 illustrates the different topics included in the questionnaire to assess exposure risk factors of the selected child. A household was dropped from selection, if no interview or appointment had been made after two visits to the household.

7.5.5. Blinding of field staff

Interviewers were not told about the morbidity status of the selected child and CHWs were not informed regarding the selection of a study child for interviewing. To clarify differing reports between CHWs and interviewers regarding the health status of the child, the CHW and the interviewer re-visited the household jointly to ascertain any potential misclassification of disease status. In case uncertainties remained, the information collected by the interviewer on the child's well being was assumed valid.

Table 7.1: Main exposure factors for childhood diarrhoea

Category	*Description*
Demography	No. of household members, no. of rooms, occupation, gender, age, anthropometric data of study children education of all household members (years in school)
Socio-economic	Roof and house construction Ownership of land, radio, TV, bicycle Number of animal species owned
Mother's health perception	Perceived causes of diarrhoea Severity of illness
Environmental hygiene, hygiene behaviour	Understands concept of dehydration Observed faeces surrounding the household, presence of flies Reported cleaning habits of house and yard Hand washing behaviour, bathing of child Child eats with hands / mother feeds child with hands Place of defecation
Water management, drinking behaviour	Water sources used (entire year), distance to water source Amount of water used; daily drinking water habits Responsibility among family members Perception of water quality and use of other disinfection methods
SODIS related factors	Heard of -, reported application of SODIS Frequency of SODIS use/drinking, opinion towards SODIS Bottle number, responsibilities among family members Reasons for not adopting (or stopped)

7.5.6. Classification of families adopting the intervention

Previous studies showed that the best indicator for assessing hygiene behaviour change and exposure are repeated observations (Curtis *et al.*, 1993, Strina *et al.*, 2003). To classify families by their application of the SODIS method we assessed the observed presence of SODIS-purified water during unannounced, repeated visits by independent staff. With 'independent', we mean that the study population neither associated the promotion of the SODIS method nor the assessment of the child's health status with the visiting staff.

We classified the families according to their ability to provide SODIS-purified water during three monthly visits: never, once, or at least twice. We corrected the number of positive observations for differences between the number of accomplished and planned visits (maximum of three visits).

7.5.7. Stool specimen examinations

To investigate causative agents of childhood diarrhoea, we performed three stool analysis surveys, involving all children under five years of age living in the study communities. To evaluate the prevalence of protozoa and helminths in study children, fresh and fixed stool specimens underwent microscopic examination with Lugol's iodine stain in a field laboratory. Participants were personally informed concerning the outcome of the analysis, and pathogen-specific treatment – prescribed by the medical doctor of the project team – was available to each infected child free of cost at the local project office or through the local health district. Detail description of methodology and results can be read elsewhere (Chapter 8).

We were able to calculate the re-infection rate of children for different dominant protozoa during the same time as the case-control study, which we included in the final analysis when associated with the diarrhoea incidence in the child.

7.5.8. Data analysis

All data were double entered by two different data-entry clerks, using the Epi-Info software 6.2 (CDC, USA), and any errors were corrected with reference to the original form. Consistency checks were performed before starting the analysis with Stata 7.0/8.1 (Stata Cooperation, USA).

Our study was designed to detect an effect of the application of the SODIS method on childhood diarrhoea at a significance level of 95% and a power of 80%. Univariate analysis identified factors associated with the discrete outcome ($p \leq 0.1$) by applying cross tabulation and chi-square statistics. Identified variables were grouped according to Table 7.1, and checked for cross-associations within each group. Only independent and significant variables were included in the final Poisson-regression model.

Significant differences between statistical means were calculated with the t-test when data were normally distributed. Else, the non-parametric Kruskal-Wallis test was applied. We adjusted our continuous outcome for the differences in the time each study child was observed.

We multiplied the number of reported diarrhoea episodes with the ratio between the actual observed number of days and the total number of days a child could have been observed.

The offset variable was the natural logarithm of the total number of days a child was observed. The outcome of the Poisson model was an incidence risk ratio (IRR). To identify major explanatory factors for the occurrence of diarrhoea in our study children, we used automatic step-wise forward and backward elimination procedures, applying the standard Stata command *sw*, followed by the regression model command *poisson*. The significance level for inclusion or exclusion of factors during step-wise elimination procedure was set at $\alpha = 0.05$.

Attributable Fraction (AF) was calculated as (1-IRR) x 100, for preventive effects (IRR<1.0), and as (IRR-1/IRR) x 100, for effects representing a risk of diarrhoea in the child (IRR>1.0). Community effectiveness (population attributable fraction, PAF) was calculated as the product of the AF and the frequency of exposure in the entire study population (Hennekens and Buring, 1987, Kirkwood, 1988).

In order to estimate the number of diarrhoea episodes per study child and year, we extrapolated our data, following the monthly distribution of national diarrhoea surveillance data from the national health districts' website (Province of Mizque, years 1996 – 2001): www.sns.gov.bo.

7.5.9. Cost effectiveness estimate

The cost for a household to avert one episode of diarrhoea in a child by the application of SODIS ($C_{eff(sodis)}$) was estimated, using the formula $C_{eff(sodis)} = \{C_d\ (Ne_{(0)} - Ne_{(exp)}) - C_s\}$, where: ($Ne_{(0)} - Ne_{(exp)}$) is the number of diarrhoea episode averted by being exposed to the SODIS method ($Ne_{(0)}$ = Number of diarrhoea episodes in unexposed; $Ne_{(exp)}$ = Number of diarrhoea episodes in exposed). C_d is the cost of one episode of diarrhoea per child and C_s the cost of applying the SODIS method for one year in a family with children under five years of age. We based our estimation of the cost of one diarrhoea episode on the reported direct and indirect costs of a past diarrhoea episode of the study child: cost of treatment, amount of time lost and an estimate of the monetary value for lost time.

The cost of applying SODIS for one year in a family with children under five years of age included: the price of bottles available on the market, the mean number of bottles in the family, the reported time a bottle can be used for SODIS, and the average reported time needed to use SODIS per day. In order to determine the monetary value of the 'time spent for SODIS', we used the same estimate as for the monetary value of time lost due to one diarrhoea episode. We used the exchange rate of 1US$=7.2 Bolivianos.

7.6. Results

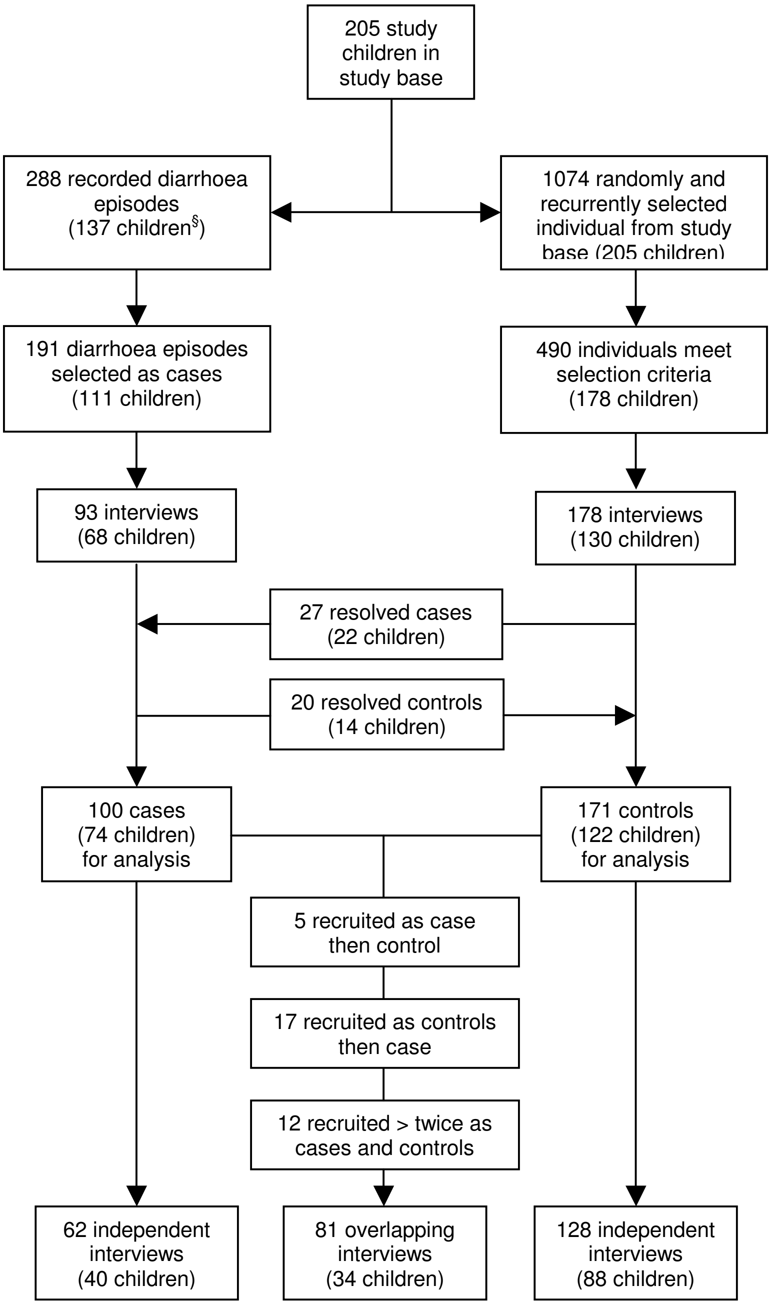
Two hundred and five study children under five years of age were observed during 19'083 child-days (mean: 94 days, sd=27.9) for later inclusion in the analysis. Loss of follow-up occurred among 5 of 206 families participating in the study. One family refused the visits of the CHW and four families moved during the observation period. The study children suffered from a total of 288 episodes of diarrhoea that lasted 1422 child-days (mean duration of one episode: 5.3 days, sd=3.6). The adjusted extrapolation of our data demonstrated that each study child suffered on average 6.2 diarrhoea episodes per year (sd=1.5). Seasonal variation in the monthly incidences of gastrointestinal illnesses in the region showed a peak around the month of March, and a minimum in August.

Exposure assessment interviews of 100 cases and 171 controls were available for analysis (Figure 7.2). Selected families (tot: 162) were usually interviewed less than two times (range 1-4 times). Thirty-four study children (81 Interviews) were concurrently recruited as case and control or vice versa. Except for the age of the study child and a socio-economic proxy measure, cases and controls did not vary significantly as regards demographic and descriptive factors (Table 7.2).

One hundred and thirty-five households were visited independently and without pre-announcement during three consecutive months to investigate the availability of SODIS-purified water in the household. Of these, 9, 32 and 94 households were visited once, twice and three times respectively.

Twenty-eight percent of the 135 households were able to provide SODIS purified water once, 13.3% provided it twice, and 6.7% three times, during the repeated visits. The proportion of households providing SODIS-purified water samples decreased continuously over the three visits (42.5%, 30.9%, 17.7%; $\chi 2$ for trends = 8.02, $p<0.005$).

Figure 7.2: Case/control study profile



Legend: §One randomly selected study child per family. Bolivia, 2002.

The more regularly a household applied the SODIS method, the lower the risk for the study child of suffering from diarrhoea (Table 7.3). The individual reduction in risk lay between 42% and 76% in households that were able to provide SODIS-purified water at least once during the three monthly visits (IRR=0.38, 0.24 – 0.58). The risk of diarrhoea incidence decreased slightly more for study children from households that provided SODIS-treated water at least twice than only once (IRR=0.25, 0.13 – 0.52).

At population level, the diarrhoea burden in our study population under five years old was reduced by 14.5% (9% - 17%), if we assume that 20% of the households chose to apply the methodology more frequently (Table 7.3).

Table 7.2: Descriptive data for cases and controls

Characteristics	*Cases (N=100)*	*Controls (N=171)*
Areas		
Near main village	48 (48%)	80 (48.8%)
Thako Thako	32 (32%)	61 (35.7%)
Tipa Tipa	20 (20%)	30 (17.5%)
Sex of child		
Boys	62 (62%)	95 (55.9%)
Girls	38 (38%)	75 (44.1%)
Age of child (months)		
0 – 24	68 (71.6%)	73 (43.6%)
≥ 25 (max.: 61)	28 (28.4%)	97 (56.4%)
Age of mother (years)		
<25	28 (28.8%)	36 (22.5%)
25 – 29	22 (22.7%)	35 (21.9%)
30 – 34	16 (16.5%)	33 (20.6%)
35 – 39	16 (16.5%)	25 (15.6%)
≥ 40	15 (15.4%)	31 (19.3%)
Education of mother (No. of years in school)		
No formal schooling	14 (14.9%)	26 (16.5%)
1 – 3	33 (35.1%)	63 (39.8%)
4 – 6	40 (42.6%)	62 (39.2%)
≥ 7	7 (7.5%)	7 (4.4%)
Occupation of mother		
House-work	14 (14.6%)	20 (12.6%)
Other work than house-work	82 (85.4%)	139 (87.4%)
Family size (No. of members)		
2 – 5	44 (44%)	74 (43.3%)
6 – 12	56 (55%)	97 (56.7%)
Number of animal species owned		
0 – 3	67 (71%)	91 (54%)
4 – 8	28 (29%)	79 (46%)

We included eleven variables in our Poisson model before step-wise regression, representing different topics associated with the diarrhoea in study children: SODIS application (SODIS, water); age of child (demography); sex of child (demography); number of owned animal species per household (socio economy); doing nothing in case of diarrhoea in the child (perception and care); perceiving heat as the cause of childhood diarrhoea episodes (awareness and perception); keeping the kitchen orderly (hygiene behaviour): child newly infected with *Giardia lamblia* (crowding, person-to-person infection); child usually bathes in the irrigation channel (hygiene behaviour); child defecates outside the household compound (hygiene behaviour). Hand washing was not significantly associated with the outcomes.

Table 7.3: Individual and community effectiveness of home-based solar water disinfection on diarrhoea incidence in Bolivian children

	N	*% Exposed or Mean (sd)*	*OR (95%CI)***	*IRR (95%CI)****	*p-value*	*AF (95%CI)*	*PAF (95%CI)*
Demography & Anthropometrics							
Age of child (in month)	271	*27.3 (sd=15.4)*	0.96 (0.9 – 1.0)	0.97 (0.9 – 1.0)	<0.001	3 (2 – 5)	3 (2 – 5)
No. of household members§	271	*6.0 (sd=2.1)*	0.96 (0.8 – 1.1)	-	-	-	-
Child is stunted§	191	18.9	1.98 (0.9 – 4.1)	-	-	-	-
Child is a boy§	271	57.9	1.3 (0.8 – 2.2)	-	-	-	-
Socio-economy							
Number of animal species owned	265	*3.2 (sd=1.7)*	0.82 (0.7 – 1.0)	0.83 (0.75 – 0.93)	0.001	17 (7 – 25)	17 (7 – 25)
Sanitation & Hygiene							
Child defecation outside the compound	269	31.6	0.54 (0.3 – 0.9)	-	-	-	-
Orderly kitchen observed	209	65.1	0.68 (0.4 – 1.2)	-	-	-	-
Child bathes in the irrigation channel	256	48.8	0.65 (0.4 – 1.1)	-	-	-	-
No. /day child washes his hands normally§	154	*3.3 (sd=1.1)*	0.79 (0.6 – 1.1)	-	-	-	-
Infection & Disease Perception							
Child contracted new *Giardia* infection#	113	30.1	1.6 (0.7 – 3.7)	4.66 (2.68 – 8.11)	<0.001	79 (63 – 88)	18 (14 – 20)
Belief in heat as cause of diarrhoea	269	52.8	4.1 (2.4 – 7.1)	-	-	-	-
No help-seeking for child's disease	270	24.4	1.6 (0.9 – 2.9)	-	-	-	-
SODIS							
SODIS present in the house once*	196	38.6	1.34 (0.7 – 2.7)	0.41 (0.26 – 0.64)	<0.001	59 (36 – 74)	22.8 (14 – 29)
SODIS present in the house at least twice*	196	19.3	0.77 (0.3 – 1.9)	0.25 (0.13 – 0.52)	<0.001	75 (48 – 87)	14.5 (9 – 17)

Legend: *§ Variables not included in the multivariate Poisson regression model. #new Giardia lamblia infection within two month. * compared to 'SODIS water never present in the house'; **OR: Odd's Ratio (discrete outcome);IRR: Incidence Rate Ratio (continuous outcome); 95%CI: 95% Confidence Interval; AF: Attributable Fraction (=(IRR-1)/IRR; or 1-IRR if IRR<1); PAF: Population Attributable Fraction (=AF*Exposure); sd: Standard Deviation; (No. of observations in final model: 57; LOG Likelihood = -97.5, p<0.001)*.

The forward and backward step-wise elimination of variables resulted in the same multivariate model, identifying three additional main exposure factors significantly associated with the continuous outcome: the age of the child (IRR=0.97, 0.95 – 0.98), the rising number of owned animal species in a household (IRR=0.83, 0.75 – 0.93), and the study child contracting a new *Giardia lamblia* infection within two months during the health assessment (IRR=4.66, 2.68 – 8.11).

One diarrhoea episode in a child under five years of age amounted to a mean cost of about 47 Bolivianos (≈6.6US$), where applying the SODIS method for one year would cost a household about 65 Bolivianos (≈9US$). The family reported to loose in average 22 Bolivianos (≈3.05US$) during the two days lost for the diarrhoea episode in the study child, and paid on average 25 Bolivianos (≈3.5US$) for the treatment.

For the application of SODIS, families reported to need on average 12 minutes per day, applying SODIS on average 4.9 days per week. They needed about 6.3 bottles per family that would need replacement 6.5 times a year (more than once in two month), at a cost of 0.2 Bolivianos per bottle (≈0.03US$).

7.7. Discussion

This is the first study that measured the health effectiveness of SODIS in children under five years of age under daily life conditions over a four month period. The application of the SODIS method was able to avert 62% of the diarrhoea episodes per child aged under five years in the current setting. Regular, day-to-day availability of SODIS purified water in the household will lead to highest health benefits (75% risk reduction).

The reported reduction in risk of diarrhoea by the application of the SODIS method translates into five-times lower community effectiveness, assuming that a conservative 20% of the population continuously applies the methodology. Even under such assumptions, the introduction of solar water disinfection into a similar community could reduce the diarrhoeal burden in the entire child-population by 14.5%, preventing on average about one episode per child and year in the entire community.

The increase in individual risk reduction with more regular application, as well as the higher community protective effect due to more families that less regularly applied the method (22.8%), support the large-scale and low-cost promotion of SODIS.

The measured diarrhoea-preventive effect of the SODIS method was adjusted for age and a proxy-measure of the socio-economic status of the family. The child reduces its risk of diarrhoea by 17% with each additional animal a family can afford to keep.

A child contracting a new infection by the parasite *Giardia lamblia* was at considerable risk of suffering from diarrhoea (AR=79%). One third of the children contracted a new *Giardia lamblia* infection within two month. Contracting a new infection was mainly associated with older age of the child and the mother believing in traditional, spiritual health concepts, the child visiting the kindergarten and education of household members.

Giardia lamblia was hyperendemic in this area and transmission happened rapidly and through many channels with similar intensity. We could therefore conclude that we have adjusted the effect of the intervention with all major transmission pathways for a child to contract diarrhoea. Taking into account the newly acquired *Giardia lamblia* infection of the child into the final model increased the protective attributable fraction of SODIS in the most regular families from a 35% to 75%, and in the less regular families from 2% (not significant) to the reported 59%. This may indicate that the hyperendemic presence of *Giardia lamblia* may underestimate the protective effect of a water intervention for the prevention of diarrhoea in young children. As contracting a new *Giardia lamblia* infection was not significantly associated with water related variables, we may assume that water transmission of this protozoa is not dominant in this setting.

Although the child acquired new infections by other intestinal parasites such as *Entamoeba hist/disp* (22.8%) and few new helminth infections (4%), they were not related to the child's incidence of diarrhoea and therefore not included in the model (Chapter 8).

The regular application of the SODIS method can directly benefit the household economy through improving the child's health, and therefore contribute to poverty alleviation. A rural family with one child under five years of age could augment their yearly budget (~230US$) by 2% (4.2 US$) or more, assuming optimal use of, and maximum preventive effect through the adoption of the method (averting >2 diarrhoea episodes per year and child). The reported costs of the SODIS method and an episode of diarrhoea may indicate the potential of such calculations, but misses more detailed estimates that may or may not be included in the figures reported by the mother – e.g. exact time and cost of transport to health facility, the saved energy in terms of wood that by not boiling the water, the time saved through larger storage volume and less water collection.

Such benefits and gains in terms of the improvement of the child's health, pass often unrecognised by the beneficiaries. People mainly claimed that the application of the SODIS method was time consuming. The cost of applying the SODIS method for an entire year was mainly dominated by the reported time spent for the method per day (51 hours/year). The recommended daily application of the method may not suit the household best and explain the frequently reported missing time for SODIS by the community people.

To promote strategies for a less frequent application but daily availability of SODIS purified water in the household may raise the acceptability and adoption of the method in the study population: e.g. exposing all bottles two times a week to the sun. This is a feasible method in the current setting, as algae growth was not observed in this region. Such practice of the method was also shown to be even more efficient in reducing faecal coliforms in drinking water (Chapter 5).

This study deals with the constraints of observational research, such as information bias, selection bias and residual confounding of the measured associations. Standardised indicators of the application of SODIS in a household are missing. We classified families into groups estimating their frequency of drinking SODIS purified water, as it fitted local household application methods best.

As the staff that performed these repeated observations was unrelated to the health assessment activities or the promotion of the SODIS method, we consider this dataset as the best representation of SODIS practice in our study communities. A detailed analysis of different indicators of the application of SODIS and their interpretation is written elsewhere (Chapter 4).

We measured our outcome assessments through well-trained CHW, who applied vernacular terminology to define a diarrhoea episode. We found a 96.6% agreement between the Quechua term "K'echalera", which was used, and the WHO definition of diarrhoea (κ=0.88; $p<0.001$).

We applied control measures to minimise reporting bias, such as the separation of interviewers for the health assessment and for the evaluation of the practice of solar water disinfection at household level. We blinded our staff about the health status of the selected children, as well as about the SODIS management in the specific family previous to reaching the household. Over-reporting of diarrhoea due to the essential distribution of ingredients for home-made rehydration solution by the CHW, cannot be excluded. As supplies were distributed on demand and mainly independent of the health status of the study child, we can assume equal distribution of such possible effect over the entire population involved.

We report about a higher individual risk reduction than previous findings under more controlled conditions and in a different area (Conroy *et al.*, 1996, Conroy *et al.*, 1999). In addition to passed studies on the health impact of solar water disinfection, we measure the synergistic effect of heat and UV-A – in contrast to heat only due to high water turbidity – and include a diarrhoea causing, hyper-endemic pathogen into the final model that may represent major transmission pathways in this setting. In a separate analysis, household drinking water samples purified with the SODIS method contained at least 90% less thermo-tolerant coliform bacteria than samples with raw household drinking water or water from community sources. This efficacy was measured in the same population during the health assessment, and details can be read elsewhere (Chapter 5).

The measured health effect of the SODIS intervention could be especially impressive if a large part of the population would adopt the technology. Our intense nine-month intervention was well received by the community people and demand for continuing activities was high. The monthly community based workshops and regular household visits were significantly associated with the observation of SODIS purified water at time of visits, where the school campaign had a considerable effect on awareness building in the region (Chapter 3, Indergand *et al.*, 2004).

The results of this study add to the evidence for advocating the inclusion of the SODIS method – as a low-cost household-based drinking water quality intervention as a part of large-scale intervention programmes, targeting the improvement of people’s health and well-being.

Our group is currently conducting a randomised control trial to measure the effectiveness of the solar water disinfection method on rural Bolivian children's health and its associated costs. The expected results will overcome the inherent shortfalls of this study and result in more comprehensive yearly estimates of the protective effect of SODIS on childhood diarrhoea in this setting (Mäusezahl *et al.*, 2003).

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CHAPTER 8

Risk factors for re-infection of rural Bolivian children by the protozoa *Giardia lamblia* and *Entamoeba hist/disp*

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Working Paper

8.1. Background and introduction

In developing countries, intestinal parasites remain highly prevalent, ranging to sometimes up to 100% of the person analysed, and multiple infections are common. With about 2.8 million infections of per year, *Giardia lamblia* is one of the most common intestinal protozoic parasite in the world. *Giardia lamblia* has been reported as hyper-endemic in developing countries, and has been associated with diarrhoea in children (Redlinger *et al.*, 2002). Rapid re-infection of children make anti-parasitic treatments questionable under such conditions (Gilman *et al.*, 1988, Ish-Horowicz *et al.*, 1989, Mason and Patterson, 1987).

Giardia lamblia, *Entamoeba histolytica* and *Cryptosporidium parvum* have been recognised to contribute to the diarrhoeal burden (Black, 1993). Parasitic infections can also seriously influence the nutritional condition of young children (Gupta & Urrutia 1982, (Farthing *et al.*, 1986), Gupta 1990), and may play a major role in immune-suppressed patients.

Infection rates were seen to vary considerably by area, climatic condition, socio-cultural contexts, occupation and behaviour of people studied as well as contacts to animals (Esteban *et al.*, 1998a, Esteban *et al.*, 1998b). Parasitic infections are therefore likely to contribute differently to the local burden of disease.

In Bolivia, only few early studies have shown that prevalence of infection in a rural or urban population can reach over 90%, where helminths (e.g. *Ascaris lumbricoides*) *Giardia lamblia* and *Entamoeba histolytica* were the most frequently observed (Cancrini, 1988).

Although it is generally accepted that intestinal pathogens are transmitted through the faecal-oral route, major pathogen specific transmission pathways are not often reported. Such data may contribute considerably to understanding the dynamics of pathogen transmission and can support the development of preventive strategies.

Within the framework of a study to measure the health effectiveness of the SODIS method in children under the age of five (Chapter 7 / Hobbins, 2003), we repeatedly collected and examined stool specimen from rural Bolivian children under five years of age. We report about the association between *Giardia lamblia, Entamoeba histolytica/dispar (hist/disp)* and the health of the study children, the major risk factors leading to re-infection of the children by the specific parasites and the role of malnutrition in this setting and population.

8.2. Objective

To assess major risk factors for *Giardia lamblia*, *Entamoeba hist/disp.* infection in rural Bolivian children under five years of age, and evaluate their association to childhood diarrhoea

8.3. Approach

Three consecutive cross-sectional stool surveys were carried out in all children under five years of age in ten rural communities of the province of Mizque, Bolivia, from August to December 2002 (Figure 8.1). The first survey identified the prevalence of protozoa and helminths in the study population. The second survey was conducted two weeks later to measure the efficacy of the distributed mass treatment. Two month later, the third survey measured the number of children that contracted a new infection during the given time. At the end of the study, we took height and weight of the study children to estimate nutrition indicators in this population. Risk factors for contracting a new infection in the passed two months were evaluated with univariate and multivariate analysis. The association to diarrhoea morbidity was analysed using the data from the diarrhoea morbidity monitoring that took place during the same time period as the stool surveys (Chapter 7).

8.4. Methods

8.4.1. Stool specimen collection

Mothers were taught to collect the stool sample in a new black plastic bag that was placed over a plastic basin provided by the project. Before distribution of the material, the name, the ID number of the child and the date of material delivery were written on coloured stickers. In case two or more children were present in the household, illiterate mothers could differentiate the delivered material for each of their children by the colour of the nametags.

Once the child produced the stool sample in the plastic bag, the mother closed it tightly and stored it in the shade or in the house. Each child had at most two days to provide a sample after the field staff delivered the material to the mother. During the stool collection surveys, seven field staff visited each household twice a day (morning and afternoon) to check for new stool specimens. When a sample was ready for collection, a form was filled with the name and ID of the child, and the date and time of collection. Stool specimens were transported using a cool box to protect it from heat and sun exposure. Stool specimens were analysed and fixed as soon as they arrived in the field laboratory, where time and date was completed on the given form.

8.4.2. Stool sample processing

One professional technician examined the fresh and fixed stool specimens by microscopic examination in a field laboratory to detect helminth eggs or larvae, and protozoa trophozoites or cysts using direct microscopy and Lugol's iodine stain. Stool specimens were fixed in 10% formalin and concentrated before microscopic examination following a standard protocol. Five percent of the stool samples were fixed in SAF (sodium acetate-acetic acid-formalin) for later quality control in a reference laboratory in Switzerland (Marti and Escher 1990).

8.4.3. Treatment procedure

The projects' medical doctor was responsible for prescribing all the treatments. Participants were personally informed about the outcome of the stool examination by the field staff, in written form. The first treatment was distributed to the households where infections were found in the child. The field staff assisted the mother with giving the first treatment dose to the child. Treatment was always available for free for each infected child at the local project office or at the regional hospital on demand basis.

Metronidazol in the form of sweetened syrup was handed out to treat children infected with facultative pathogenic infections (such as *Entamoeba hist/disp*, *Giardia lamblia* or *Blastocystis hominis*). Children infected with *Hymenolepis nana* received Niclosamida, and Albendazol was distributed for all other detected helminth infections. Dosage was calculated according to the included manufacturers guidelines.

8.4.4. Risk factor assessment

As a basis for estimating the incidence of diarrhoea in our study children we established a community-based weekly health monitoring system in the ten study communities. The set up has been described in detail in Chapter 7. Mothers were interviewed about factors possibly associated with infection such as crowding, hand washing behaviour of child and mother, general hygiene behaviour, perception of cleanliness and disease, help seeking behaviour, water management and quality.

8.4.5. Anthropometric measurement

In order to assess the association of nutritional and infection status and disease course, we obtained weight and height for each study children during the months of November and December 2002. Weight of the child was measured using a calibrated spring scale (scale: 0.1kg), and height was obtained using a tape measure (scale: 0.1cm).

Weight-for-height (malnourished), weight-for-age (underweight) and height-for-age (stunted) Z-scores were calculated using the ‘Nutrition Programme’ in EpiInfo 2002 software (CDC, 2002), which compared the study population with the WHO/NCHS standard population (1978). According to the WHO classification scheme, we defined children as stunted, underweight and malnourished if the Z-score of the respective indicator was two or more standard deviations below the mean.

8.4.6. Data analysis

All data were double entered in Epi 6.04 (CDC, 1998) and inconsistencies were corrected according to the original form. STATA software release 8.1 was used for the statistical analysis of the data (Stat Cooperation, 2002).

Our outcome measure was an Odd’s Ratio (OR) describing the risk of an exposed child to acquire a new infection in the two months previous to the last stool survey. To measure the degree of association during the uni-variate analysis with categorical variables we used the χ^2-test, and the non-parametric *Kruskal Wallis* test was applied for continuous variables.

Variables associated with the binary outcome were further examined for independence between each other, and included in the multivariate model if mostly independent. To identify major factors explaining the occurrence of a new infection in a study child, we used automatic step-wise forward and backward elimination procedures, applying the standard Stata command *sw*, followed by the logistic regression model command *logit*. The significance level for inclusion or exclusion of factors during step-wise elimination procedure was set at $\alpha = 5\%$.

8.4.7. Ethical considerations

Informed consent was obtained from the parents of the study children before enrolment. The study was part of a larger study to measure the health effectiveness of a water intervention in the same population, which proposal was approved by a WHO review board (Chapter 7).

8.5. Results

8.5.1. Prevalence of nutrition indicators in Bolivian children

We were able to obtain the weight and height (or length) of 214 children under five years of age, of which 38 (17.8%) were classified as stunted, 14 (6.5%) were underweight and 2 children (0.9%) were moderately to severely malnourished (Table 8.1).

The prevalence of severely stunted children was significantly higher in children that were two years or below (p=0.004). Significantly more girls were mildly stunted than boys when older than two years of age (p=0.017), where significantly more stunted boys were in a moderate to severe state (p=0.023). None of the children above two years of age were in a moderately to severe malnourished state, and seven children (7%) could be classified as mildly malnourished.

Table 8.1: Prevalence of indicators for malnutrition in Bolivian children

		Stunted			*Underweight*			*Malnourished*		
	N	*Mild (%)*	*Moderate (%)*	*Severe (%)*	*Mild (%)*	*Moderate (%)*	*Severe (%)*	*Mild (%)*	*Moderate (%)*	*Severe (%)*
<25 months										
Girls	55	18.2	3.6	12.7	16.4	1.8	5.5	7.3	0.0	1.8
Boys	60	13.3	10.0	16.7	16.7	3.3	5.0	8.3	1.7	0.0
>24 months										
Girls	47	38.3	2.1	4.3	19.2	4.3	0.0	6.4	0.0	0.0
Boys	53	17.0	17.0	5.7	17.0	3.8	1.9	7.6	0.0	0.0

Legend: Stunted: Loss of height for age. Underweight: Loss of weight for age. Malnourished: Loss of weight for height. Reference population NCHS/WHO 1978. Z-score = (observed value – median reference value) / standard deviation of reference population. Malnutrition classification (WHO): $-2 < Z \leq -1$ = mild, $-3 < Z \leq -2$=moderate, $-3 \leq Z$ = severe (1); All children under 5 years of age.

8.5.2. Quality of sample processing

Stool samples from 321 children (tot: 332) under the age of five years were collected and analysed in the field laboratory: 260 samples during the first survey, 219 and 216 during the second and third survey. Participation decreased throughout the three surveys (80%, 71.2%, 65.9%, $\chi 2$ for trends=12.3, p<0.001).

For estimating the quality of our field diagnosis, sensitivity, specificity and predictive values were calculated comparing the analysis of fresh specimen (direct microscopy) to findings from the examination of concentrated samples. Joint results from the field laboratory were then validated against the SAF fixation and subsequent analysis at the reference laboratory in Switzerland (Table 8.2).

Table 8.2: Diagnostic accuracy of various microscopic stool examinations in rural Bolivia

	Children infected with	*Sensitivity*	*Specificity*	*PV+*	*PV-*
D vs. C (456s, all surveys)	Any protozoa/helminth	81.3% (75.6 – 85.9)	81.9% (76.0 – 86.6)	82.7% (77.0 – 87.2)	80.4% (74.5 – 85.3)
	Giardia lamblia	84.3% (79.8 – 88.7)	91.7% (88.4 – 95.1)	84.3% (79.8 – 88.7)	91.7% (88.4 – 95.1)
	Entamoeba hist/disp	62.5% (53.2 – 71.0)	92.6% (89.1 – 95.0)	75.0% (65.2 – 82.9)	87.4% (83.3 – 90.5)
D&C vs. SAF (32s, QC)	Any protozoa/helminth	100% (69.9 – 100)	94.7% (71.9 – 99.7)	91.7% (59.8 – 99.6)	100% (78.1 – 100)
	Giardia lamblia	80.0% (29.9 – 98.9)	88.5% (68.7 – 97.0)	57.1% (20.2 – 88.2)	95.8% (76.9 – 99.8)
	Entamoeba hist/disp	66.7% (24.1 – 94.0)	84.0% (63.1 – 94.1)	50.0% (17.4 – 82.6)	91.3% (70.5 – 98.5)

Legend: Findings that were based on the detection of Trophozoites during direct microscopy were not included. PV+/-: Predictive Value positive/negative; in brackets (95% Confidence Interval); QC: Quality control from a Pilot survey, where the combination of direct microscopy and concentration lugol-stain were compared to the results of a Swiss laboratory (using SAF-method). D: Direct Microscopy; C: Concentration and lugol stain; SAF: sodium acetate-acetic acid-formalin. Underlined method represents the reference value. Patients: rural Bolivian children under 5 years of age, 2002.

The analysis of fresh stool specimen generally resulted in values above 80%, except for the identification of *Entamoeba hist/disp* that was only detected at a sensitivity of 62.5% when compared to the analysis of concentrated specimens. The same trend was seen when field results were compared to the findings in Switzerland. The positive predictive value for specific intestinal parasites such as *Giardia lamblia* and *Entamoeba hist/disp* were at 57.1% and 50.0% respectively.

8.5.3. Prevalence of intestinal parasites

The prevalence of infection in our study population was 61.9% during the first survey. Multiple infections were found in 35% of the children, reaching a maximum of 5 infections of different protozoa and helminth at the same time in one child. *Entamoeba hist/disp* was frequently found jointly with *Giardia lamblia* infection, and were both, the most frequent protozoa detected in the study children (31.9% and 39.6% respectively). Helminths were found in 9.6% of the samples only. About 72% of the helminth-positive samples contained *Hymenolepis nana*.

8.5.4. Treatment efficacy and rate of re-infection

The overall treatment efficacy one weeks after the completion of treatment was 90% for *Giardia lamblia*, 85.1% for *Entamoeba hist/disp* and 80% for helminth infections (Table 8.4). Treatment was well accepted, and reports from mothers were usually positive although side effects were reported in 52% of a representative sample of mothers. Stomach pain (14.5%), fever (9.6%), diarrhoea and diarrhoea with blood (11.3%) as well as the defecation of small worms were the most frequent descriptions of these side effects.

Two month later, almost 50% of the previously healthy children were re-infected with a protozoa or helminth. Most children contracted a *Giardia lamblia* infection (29%) during that time, where an infection through *Entamoeba hist/disp.* seemed to happen less rapidly (18%). New helminth infections were detected in 7.3% of the children.

Table 8.4: Treatment efficacy and probability of re-infection in rural Bolivia

	Survey 1	*Survey 2*		*Survey 3*	
	No. Infected	No. Infected (new infections)	% Treated*	No. Infected (new infections)	% New infections**
Total Infections (124 children)*	81	52 (15)	54.3%	73 (35)	48.6%
Total *Giardia lamblia* infections	50	17 (12)	90.0%	38 (31)	29.0%
Total *Entamoeba hist/disp*	47	19 (12)	85.1%	25 (19)	18.1%
Total Helminths	15	15 (12)	80.0%	18 (8)	7.3%

Legend: *Only children participating in each survey are taken into account. *Applied formulas: Number infected at survey 1 – (number infected at baseline-new infections) / number infected at screening ; *Formula: Number of new infections at follow up / (total number of participants – number of infected at baseline) ;Time between treatment and re-infection: 2 month;*

8.5.5. Symptomatic infections

Infected children usually did not suffer from more or less symptoms than other children on the day of stool collection (Table 8.5). However, contracting a new infection with *Giardia lamblia* was associated with a five-times higher risk of suffering from diarrhoea in the week preceding the exposure interview in children aged under three years (OR=5.2, 1.4 – 21.5). Reported blood in the stool during exposure interviews (18.8%) was not related to any new infection in the child.

Table 8.5: Prevalence of Protozoa infections during three surveys in symptomatic and asymptomatic children

	No. Health Reports	*% Infected (Health Re.)*	*% Symptomatic in infected*	*% Symptomatic in uninfected*	*p-value*
Survey 1 (260 samples)					
All	176	58.5	8.7	21.9	0.012
Giardia	176	36.4	12.5	15.2	ns
Entamoeba hist/disp	176	34.1	6.7	18.1	0.039
Helminths	176	9.1	6.3	15.0	ns
Survey 2 (219 samples)					
All	191	37.7	16.7	18.5	ns
Giardia	191	15.7	20.0	17.4	ns
Entamoeba hist/disp	191	12.0	21.7	17.3	ns
Helminths	191	9.4	5.6	19.1	ns
Survey 3 (216 samples)					
All	184	59.8	14.5	28.4	0.022
Giardia	184	34.2	15.9	22.3	ns
Entamoeba hist/disp	184	17.9	18.2	20.5	ns
Helminths	184	12.0	18.2	20.4	ns

8.5.6. Risk factors for infection

The fact that children were re-infected by *Giardia lamblia* or *Entamoeba hist/disp* with different probabilities suggests different transmission pathways for the two protozoa parasites.

Risk factors for infection with intestinal parasites. The age of the child, the ownership of pigs as well as visits to the kinder garden put the child at an increased risk of infection by any detected protozoa or helminth. On the other hand, breastfeeding and hygiene behaviours such as hand washing with soap prevented infections in the child.

In the multivariate model, the risk of contracting any new infection in the two months after the second survey increased with the age of the child (OR=1.1, 1.0 – 1.2), and the presence of pigs in the household (OR=8.8, 1.9 – 40). Study children from households possessing bikes were significantly less likely to contract a new infection during the same time (OR=0.2, 0.1 – 0.9).

Table 8.6: Uni- and multivariate analysis explaining new Protozoa infections in rural Bolivian children

	Exposure (N=67) No Infected (%)	*Crude Odd's Ratio*	*p-value*	*Adjusted Odd's Ratio[1]*	*p-value[1]*
Demography					
Age of child (in month)	*25 (sd=15.5)[2]*	1.1 (1.0 – 1.1)	<0.001	1.1 (1.0 – 1.1)	0.001
Age of mother	31.3 (sd=10.6)	0.9 (0.9 – 1.0)	0.170		
Number of household members	6.1 (sd=2.2)	1.1 (0.9 – 1.4)	0.336		
Child is stunted*	4 (15.4)	0.7 (0.2 – 2.8)	0.644		
Child is a boy	11 (29.0)	0.3 (0.1 – 0.9)	0.015	-	-
Child goes to kindergarten	13 (81.3)	10.1 (2.1 – 63)	<0.001	-	-
Socio-economy					
Possession of bike	12 (29.3)	0.4 (0.1 – 1.4)	0.097	0.2 (0.1 – 0.9)	0.031
Hygiene & Sanitation					
Pigs are present in the house	20 (54.1)	4.5 (1.3 – 16.9)	0.009	8.8 (1.9 – 40)	0.006
Hand washing with soap	20 (35.1)	0.2 (0.0 – 1.5)	0.061	-	-
Water					
Breastfeeding	2 (8.3)	0.2 (0.0 – 0.9)	0.017		

Legend: Multivariate model included all variables listed. Adjusted Odd's Ratio and corresponding p-value ([1]) represent value after step-wise elimination procedure (inclusion at p<5%). ([2]) continuous variables are described with mean and standard deviation (sd). No of samples: 59; All children under 5 years of age.

Risk factors for infection with Entamoeba hist/disp. In the uni-variate analysis, factors related to person-to-person transmission, to food transmission and to age and sex of the study child, as well as to the socio economic condition of the household, were significantly associated with contracting a new *Entamoeba hist/disp* infection.

Step-wise elimination of associated exposure variables described that girls were at significantly higher risk of contracting a new *Entamoeba hist/disp.* infection than boys. Children from households that owned pigs (OR=5.5, 1.3 – 24) and consumed their home-grown vegetables (OR=7.9, 2.0 – 32) were at considerable risk of contracting a new infection of *Entamoeba hist/disp*. On the other hand, children were at lower risk of infection when the mother reported to wash their clothes frequently (OR=0.6, 0.3 – 1.0).

Table 8.7: Uni and multivariate analysis explaining new infections with *Entamoeba hist/disp.* in rural Bolivian children

	Exposure (N=114) No infected (%)	*Crude Odd's Ratio*	*p-value*	*Adjusted Odd's Ratio[1]*	*p-value[1]*
Demography					
Age of child (in month)	*27.2 (sd=16.5)**	1.04 (1.0 – 1.1)	0.012	1.05 (1.0 – 1.1)	0.014
Number of household members	*6.4 (sd=2.1)*	1.1 (0.9 – 1.4)	0.223	-	-
Child is stunted (>12month)*	3 (16.7)	1.8 (0.2 – 10.3)	0.470		
More than 1 person sharing bed with child	14 (53.9)	1.4 (0.5 – 3.9)	0.414		
Child is a boy	8 (11.6)	0.2 (0.1 – 0.6)	<0.001	0.14 (0.0 – 0.5)	0.004
Child goes to kindergarten*	12 (46.2)	4.5 (1.5 – 13)	0.001	-	-
Socio-economy					
Possession of bike	13 (17.8)	0.45 (0.17 – 1.2)	0.076	-	-
Hygiene & Sanitation					
Pigs are present in the house	20 (30.8)	3.2 (1.1 – 10.5)	0.020	5.5 (1.3 - 24)	0.022
No. of times child's clothes are washed / week	*2.6 (sd=1.6)*	0.7 (0.4 – 1.0	0.031	0.6 (0.3 – 1.0)	0.039
Buying fruits at the market	4 (17.4)	0.4 (0.1 – 1.4)	0.138		
Home-grown vegetables are eaten	14 (32.6)	2.3 (0.9 – 6.3)	0.059	7.9 (2.0 - 32)	0.004
Child relieve himself outside the compound	20 (33.3)	3.9 (1.3 – 13)	0.006	-	-
Water					
Child is breastfed*	0 (0.0)	0 (0.0 – 0.75)	0.025		
Perceive water contains "bugs"	12 (48.0)	2.8 (1.0 – 7.7)	0.027		
Perceive water as cause of diarrhoea	6 (23.1)	0.8 (0.2 – 2.4)	0.670		

*Legend: Multivariate model included all variables listed. Adjusted Odd's Ratio and corresponding p-value ([1]) represent value after step-wise elimination procedure (inclusion p<5%)). ([2]) continuous variable described with mean and standard deviation (sd). *dropped in multivariate model due to estimability. (No. of Samples: 94); All children under 5 years of age.*

The ownership of pigs was also associated with living under more crowded conditions (OR=2.1, 1.2 – 3.9), and the respective children were often looked after by other persons than the mother (OR=5.0, 1.5 – 17.3).

Risk factors for new infection with Giardia lamblia. In contrast to *Entamoeba hist/disp*, less specific factors were significantly associated with the new infection through *Giardia lamblia*. Stunted children were at higher risk of infection, so were children coming from larger families and going to kinder garden. On the other hand, children were at lower risk of infection through *Giardia lamblia* when mothers were unsatisfied with their current drinking water.

Lacking awareness about germs and diseases of the mother resulted in higher risk of *Giardia lamblia* infection for the child (OR=8.2, 1.7 – 40), independent of the age of the child (OR=1.1, 1.0 – 1.1). This was the only significantly related factor to contracting a new infection of *Giardia lamblia* when other exposure factors were included in the multivariate model.

Table 8.8: Multivariate analysis to explain new infections with *Entamoeba hist/disp.* in children under five years of age in rural Bolivia

	Exposure (N=113) No. infected (%)	*Crude Odd's Ratio*	*p-value*	*Adjusted Odd's Ratio[1]*	*p-value[1]*
Demography & Anthropometric data					
Age of child (in month)	*27.3 (sd=15.4)*	1.04 (1.0 – 1.1)	0.005	1.05 (1.0 – 1.1)	0.010
No. of household members	*6.0 (sd=2.1)*	1.2 (1.0 – 1.5)	0.042	-	-
Child is stunted**	7 (43.8)	5.3 (1.1 – 26)	0.012	-	-
Child is a boy*	21 (61.8)	1.4 (0.6 – 3.8)	0.471	-	-
Child goes to kindergarten	16 (47.1)	3.8 (1.4 – 10.0)	0.002	-	-
Socio-economy					
Possession of bike	19 (57.6)	0.5 (0.2 – 1.2)	0.135	-	-
Sanitation & Illness Concept					
Child defecates outside the compound	13 (39.4)	2.5 (0.9 – 6.7)	0.039	-	-
Associates spiritual causes to diarrhoea episodes	8 (23.5)	3.7 (1.0 – 14.3)	0.040	8.2 (1.7 – 40)	0.009
Water					
Buying fruits at the main village	17 (50.0)	0.6 (0.3 – 1.4)	0.246	-	-
Breastfeeding	2 (6.7)	0.3 (0.1 – 1.5)	0.156	-	-
Mother is satisfied with own drinking water quality	19 (55.9)	0.4 (0.2 – 1.0)	0.033	-	-

*Legend: Multivariate model included all variables listed. Adjusted Odd's Ratio and corresponding p-value (1) represent value after step-wise elimination procedure (inclusion p<5%). (2) continuous variable described in mean and standard deviation (sd). *dropped in final model because of colinearity; **only for children under three years; all children had an OR=2.1, p=0.162. (No. of Samples: 86).*

8.6. Discussion

Our aim was to describe the prevalence of intestinal parasites in a rural Bolivian population of children under five years of age, and investigating most dominant pathways of transmission of the most prevalent parasites in this setting.

The prevalence of infections in our study children under the age of five was concerning, with over 60% of the children infected. *Giardia lamblia* and *Entamoeba hist/disp.* are the most prevalent facultative pathogenic protozoa in this child population.

The low prevalence of helminths in our study population can be explained by the regular free distribution of Mebendazol to children less than five years of age by the local health district in the surrounding communities. Risk factor analysis would therefore not have led to conclusive results.

Even more concerning are the rapid re-infection rates, where half of the previously healthy population was infected by an intestinal parasite within only two month. Again, *Giardia lamblia* was the protozoa, which most rapidly infected children in this age range – being caught by one third of the study population. Infection through *Entamoeba hist/disp.* happened more slowly, but still infected almost 20% of our previously healthy study children. The difference in re-infection rates suggested differences in the transmission pathways and attack rates between the two dominant protozoa.

The differences in the vulnerability between children play an important role in the health and infection status of children. Nutritional status as indicator for vulnerability of the child was defined using standard indicators for stunting, underweight and malnourishment. The prevalence of chronic malnutrition (stunting) in our study population showed lower values than the national WHO estimates for the year 2002 (17.8% vs. 23%) (*www.who.int*), and low prevalence of moderately to severe underweight and malnourished children were found.

Predominantly children below the age of 24 months were stunted. Differences in measuring techniques in infants and children may be one of the reasons for the higher prevalence in the lower age group.

Stunted children under the age of three years were at considerable risk of contracting a *Giardia lamblia* infection even though the general risk for *Giardia lamblia* infection rises with age. This finding may indicate the higher vulnerability of stunted children under three years towards infections. However, stunted status of the child was later not identified as a major risk factor for any infection in the multivariate analysis.

New *Giardia lamblia* infections were associated with a more frequent occurrence of diarrhoea episodes in the child, confirming previous findings. No other intestinal parasites were associated with the health of the child.

The mother's lack of incorporation of biomedical concepts was identified as main risk factor for a new *Giardia lamblia* infection. This unspecific risk factor may confirm that *Giardia lamblia* is hyper endemic, and as such, is transmitted through many pathways equally, making the identification of specific and dominant factors difficult. Missing biomedical concepts may be an indicator for low socio-economic status, crowding, education and lack of hygiene and safe water management.

Our data on the exposure of the child towards risk factors for infections further suggested that the child was constantly exposed to faecal matters: Forty-eight percent of the study children reportedly defecated inside the compound where over 70% of the mothers and adult family members used places outside the compound (not including latrines). Faeces were detected in the yard in 17% of the visits. Flies were observed in over 70% of the households and could represent important carriers and distributors of faecal matters and pathogens. Only 25% of the mothers report to cover the prepared food, and fewer households were observed to cover the stored drinking water (17%). Many mothers reported to wash the hands of the child before food intake (86%), but we suspect that hand washing was over-reported. Over 70% of the children were observed with dirty hands during the day, mainly soiled with earth (58%).

Food preparation and care-giving were the most dominant factors leading to infection with *Entamoeba hist/disp*. The finding that girls are likelier infected by *Entamoeba hist/disp* mainly points towards differences in the transmission pathways between boys and girls.

Gender inequity and differentiation in upbringing for infant girls or boys, as well as behavioural differences between sexes may result in a higher risk of infection for girls in the compound, and a higher risk of infection in boys outside the compound, e.g. kinder garden. Going to the kinder garden increased the risk of infection more than four times. This association was only maintained for boys visiting, compared to boys not going to the kinder garden, independently of the age of the child (OR=9.9, 1.5 – 68).

The risk of infection is higher in girls than in boys that did not visit the kinder garden (OR=12.5, 2.4 - >100). In kinder garden, boys were still less likely to contract an infection by *Entamoeba hist/disp* (OR=0.3), though this association was not significant (p=0.135). The associations were independent of the stunted status of the child.

The health risk from home-grown vegetables has been extensively studied in urban settings (Cissé *et al.*, 1999). The finding of an increased risk of *Entamoeba hist/disp* infection through home-grown vegetables may associate to soil fertilisation with untreated human and animal faeces. Explanatory models further indicated that the same families were more likely to use a latrine (OR=2.2, 1.0 – 5.0), and latrines were also more frequently observed in their compounds (OR=2.6, 1.0 – 6.9). This may either represent the source of fresh fertiliser or/and point towards higher socio economic status. A higher – but riskier – organisation level, where faeces are dropped at a fixed place and later used to fertilise their field, may fit the local context well.

For better understanding of the transmission of *Entamoeba hist/disp* in such settings, future studies should focus on the dynamics of disposal and spread of faeces, the qualities of food products bought at markets or at private homes, as well as observe the preparation of food under such conditions.

Large-scale interventions and educational programmes concentrating on the safe disposal of faeces may at least inhibit the uncontrolled spread of the parasite in the environment. Nevertheless, focussing an intervention on one or few transmission pathways is unlikely to result in a large preventive effect on intestinal parasites infections. Only comprehensive approaches, building lasting barriers to major transmission pathways, can reduce significantly the burden of intestinal parasites in these settings.

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DISCUSSION

The purpose of this research was to measure the health effectiveness of the solar water disinfection method (SODIS) under natural conditions, representing the day-to-day life of a Bolivian family, which permits extrapolation of the findings to population level. Our results indicate that a child under the age of five years of age will suffer up to four diarrhoea episodes less, if it often drinks water that has been purified through the SODIS method. We measured that at population level, the effectiveness of the method was between 14% to 23% diarrhoea risk reduction representing about one episode of diarrhoea prevented by the introduction of the SODIS method with an uptake rate of around 20%. An effectiveness of this magnitude could affect district or even national planning, given that solar disinfection is a simple and cheap method.

Following a critical review of the study design, we outline how these results contribute to a better definition of, and a possible future increase in, the effectiveness of the method. We especially discuss the lessons learnt from our implementation of the SODIS method, and discuss possibilities for improvement in coverage. We then attempt to position solar disinfection among other point-of-use water disinfection methods in the current context of global illness burden and development targets, and deduce some necessary next steps in future research.

9.1. Review of study design

We sought to answer two questions: if (i) the solar water disinfection method (SODIS) could prevent a diarrhoeal illness burden in the study children, and if (ii) this attributable preventive effect of SODIS could be maintained when projecting to population level. Choosing a study design that answers the right questions is not always straightforward and needs careful consideration (Habicht *et al.*, 1999). In our case, the randomised control trial approach would have been the method of choice for drawing accurate conclusions on the health effectiveness of the SODIS intervention. When resources are scarce and results are expected with a restricted time period, alternative valid methods and compromises must be considered (Habicht *et al.*, 1999). However, the study design alone is an inadequate marker of quality in public health interventions.

More importantly, the design should distinguish between the reliability of the evaluation process and the success of the intervention itself. Furthermore, the inclusion of descriptive data can considerably support the interpretation and transferability of the results (Rychetnik *et al.*, 2002). Rigorous observational studies can lead to valid alternative designs (to the randomised control trial), for deducing the effectiveness of an intervention and especially, when combined with additional design elements that complement and support the findings (Kirkwood *et al.*, 1997).

This is the first study to measure the health effectiveness of the SODIS method in a Latin American context. Other studies on different point-of-use methods have applied the controlled trial design, mostly randomised (Clasen *et al.*, 2004a, Quick *et al.*, 1999). We carried out various cross-sectional studies and applied qualitative research methods, to complement and inform a nested case-control study (details in chapter 1 and 7). Inherent to any observational study, we had to especially consider possible bias and confounding effects during the planning, implementation and analytical phase – such as selection bias, recall bias, information bias and misclassification bias (see below) –, in order to interpret the finding correctly.

We established a comprehensive list of possible *confounders* that we compiled from the literature and our pilot studies in Bangladesh and Bolivia, and which were included in the case-control questionnaire. As described in Chapter 7, the steps performed during the multivariate analysis, reduced confounding further to a maximum possible extent.

Due to the small number of children in the study and the concurrent study design of time-matched controls, we were not able to match cases and controls for age, sex or community. We adjusted for all confounders at the analysis stage. We cannot exclude residual confounding due to unknown factors.

Selection bias may have occurred if families would have been unwilling to participate at the time the visitor asked for an interview – these families could have been less likely to use the SODIS method. Such bias would have caused to over- or underestimate the measured effect (Hennekens and Buring, 1987). In our study, success rates of interviewing cases and controls were alike (69% vs. 61%). Eighteen families were not included in the case-control study, but data on the application of the SODIS method were nevertheless available. The families that were not interviewed were equally exposed to the SODIS method (i.e. observed use), as were the participating families. Furthermore, we could find a significant preventive effect of exposure to 'SODIS' in families not recruited for the study, comparable to that for participating families. In the light of these findings, it was not likely that selection bias had meaningfully influenced our results.

To avoid recall bias from systematic differences in reporting the status of exposure, we designed a semi-structured interview that combined open queries and spot observations as well as pre-coded questions allowing internal validity checks. To verify the consistency of the responses, we repeated key questions in different contexts, during the course of the interview. The data used to estimate the exposure to the SODIS method was assessed independently of the disease status of the child, and could therefore not have been influenced by recall bias. We cannot entirely exclude that an occurring diarrhoea episode in the child or any other motivation might have influenced responses of the mothers regarding other factors of interest.

The families' exposure status to the SODIS method was unlikely to be systematically flawed, as we estimated their exposure through the observations of independent staff during three unannounced household visits. This indicator was extensively studied and found to represent the best possible estimate for health assessment surveys (see chapter 4). Our outcome measure, diarrhoea, was based on extensive qualitative research that assessed reported diarrhoeal illness episodes using vernacular terminology (Weiss, 1988).

Our study design permitted us to effectively detect misclassification of cases and controls, which occurred despite careful training, adequate background information and a clear definition of the outcome. After the community health worker reported on the health status of the study children in his community, separate, "blinded" staff repeatedly evaluated the health status of the child during the case or control interview. The misclassification of the diarrhoeal episodes was equally distributed among SODIS-exposure groups and communities and therefore non-differential, which can only affect the result towards the null hypothesis. We detected misclassification in 21.5% of the selected cases and 15.1% of the selected controls. We resolved the misclassification of cases and controls directly in the field, by confronting the household with the discordant responses. If the household could not provide accurate information, we classified a child according to its reported health status during the interview. We detected consistent and known associations between different exposures and the outcome through the analysis, which strengthened the assumption, that misclassification did not notably influence our results.

In this study, all possible attempts were made to document known or suspected confounders and to adjust for them during the analysis stage; also, to minimise recall bias through careful training and interview technique, and by cross-checking repeatedly collected data in population sub-samples, as well as comparing information from different sources for reliability and consistency.

9.2. Variations in the health impact of home-based water disinfection methods

Study results on the health impact of point-of-use methods from independent research teams are likely to vary. Diarrhoeal disease burden could be reduced by half, following the introduction of home-based methods that guarantee the safe storage and quality of water (Pruess *et al.*, 2003).

Most findings to date agree that home-based interventions towards improved water quality and safe handling will significantly reduce the risk of diarrhoea (Gundry *et al.*, 2004). Some studies find rather consistent findings in the 40-50% diarrhoea risk reduction for methods based on chlorination and safe water storage (Quick *et al.*, 2002, Quick *et al.*, 1999). A recent trials detect an even higher risk reduction rates of 72% for ceramic filters in rural Bolivia (Clasen *et al.*, 2004a).

Other studies find comparatively low impact values of 16% diarrhoea risk reduction for solar heating (Conroy *et al.*, 1999). We detected an individual diarrhoea risk reduction of 75% (48% - 87%) in our study children applying the SODIS process, under the condition that they drank SODIS purified water at least five days per week (see chapter 7).

Reasons for these variations in risk reduction between studies certainly include differences in study designs, climate, season and cultural background of the area and the target population. The quality of the studies vary, due to using the same staff for implementation, evaluation of uptake and health monitoring (Clasen and Cairncross, 2004, Conroy *et al.*, 1996), which may significantly influence the validity.

Some studies assume the efficacy of the methods at field level based on previous investigations, and did not measure the actual drinking water quality at the time of the survey (Joyce *et al.*, 1996, McGuigan *et al.*, 1998, Conroy *et al.*, 1996). We measured the water quality of household drinking water at the time of the health assessment, and found high efficacies. The families that left their water exposed for at least *two* days, achieved a significantly better purification effect, approximating closely the WHO recommendations of zero-tolerance of indicator bacteria in drinking water (Chapter 5). Our experience in Bangladesh also showed that people were spared of diarrhoea episodes due to effective water disinfection, further indicating that the method functions under field conditions.

The variations in risk reduction are hardly attributable to differences between the promoted methods, as long as these methods guarantee both water quality and safe water storage. In the Kenyan trials on the effect of solar heating, however, the reported risk reduction refers mostly to an improvement in water quality alone: the control group was also told to store the water that was collected in bottles, but unlike the intervention group, did not expose the water to sunlight (Conroy *et al.*, 1996). This may explain the relatively low impact of solar heating compared with our study and other trials on point-of-use water disinfection methods.

Our study was performed under the Bolivian sun, at an altitude of about 2000 meters above sea level in a rural area, four months before the start of the rainy season. We found the health impact of solar water disinfection to be high, compared to findings from other studies.

We found that the method had a high efficacy (>90% reduction of contamination) under the present natural field conditions, which shows that families adopting the method drank cleaner water during the study period than other study families. In addition to the improved water quality, safe drinking water storage in the bottles was automatically introduced with the solar water disinfection method (Chapter 5).

We did not attempt to differentiate between the impact of hygiene behavioural change and water quality improvement. We can assume that the measured health impact of solar water disinfection it partly attributable to the introduction of safe water handling, as the improvement of water quality alone showed much lower impacts (Esrey *et al.*, 1985, Esrey *et al.*, 1991).

In evaluating the compliance of our target population, we were able to define determinants of adoption – e.g. people that maintained hygienic environments adopted the new method more readily – that led to a more comprehensive analysis of the impact and the effectiveness of solar disinfection.

This study used a multi-design approach to produce credible evidence of the efficacy and health effectiveness of SODIS as one the point-of-use method. The current result of significant risk reduction of diarrhoea in children under the age of five years is supported by further consistent evidence of efficacy, determinants for compliance and analyses of risk factors for the disease and infections. Repeated surveys, in different settings, could confirm the accuracy of the present result. We have already performed such study in an Asian context (Chapter 6).

A cluster-randomised control trial was launched in 2003, to measure the effectiveness of solar water disinfection in a similar rural area in Bolivia (Mäusezahl and Colford, 2003). The result of this trial will permit to verify the accuracy of the current findings and enable the first meta-analysis of the health impact of solar water disinfection based on the few studies published so far (Conroy, 1996, Conroy, 1999, Conroy, 2001, Chapter 7). This again will yield additional, valuable evidence for decision-making at local and global levels. Aspects other than the health impact of SODIS may also influence decision-making at policy level, and these need urgent attention from the implementers' side.

9.3. Critical aspects of the solar water disinfection method

Critical aspects of water purification methods in general are manifold and include their field efficacy and applicability, but are not restricted to the technical characteristics of the method. Shortfall can ultimately influence the methods' acceptability and sustainability of use in the population. The application of the method may be reduced and in the worst case may lead to the rejection of the method, because consumers are unsatisfied for various individual reasons. During the current research, we encountered features that could potentially hinder the further promotion of the SODIS method.

Adverse effects on consumers' health have never been reported. Chemical contamination of the water from sun-exposed PET (Polyethylene Terephthalate) bottles was clearly shown to be below the recommended threshold and would not represent a risk to consumers (Kohler and Wolfenberger, 2003, Wegelin *et al.*, 2001).

In Bangladesh, people showed no adverse health effects from changing drinking water sources from clean to contaminated – but purified with the SODIS method – water (Chapter 6). Direct consumer risks can therefore be assumed minimal if the method is applied correctly.

Environmental hazards may reduce the benefit of implementing SODIS in a community. Any new method should bring the desired benefit to people in need, without creating a new environmental hazard (United Nations, 1992). The SODIS method does not directly *create* a new hazard, as only available material and resources are used. Nevertheless, PET bottles are used, and need to be regularly renewed. In urban areas, used PET bottles are frequent, and add to the waste problem. Here, the SODIS method can contribute as a sort of "recycling" process.

In rural areas, however, conditions are different. PET bottles are often not present in vast amounts and may need to be imported from bigger cities to meet requirements for the SODIS application. We imported about 4000 PET bottles from the bigger city into the communities. Once we realised the waste problem, we started planning and digging waste pits in the study communities (Appendix 5). Solid waste disposal systems are frequently not installed in rural communities; once the bottles have served their solar disinfection purpose, they may be thrown away in the field or used as cooking fuel, without further consideration. In the light of a long-term, large-scale, and constant application of the SODIS methodology, this could become a local concern.

We calculated that over 25'000 one and a half litre bottles per year would be needed, to support the daily application of SODIS in our entire study population (10 communities; 429 households; five members/households; two bottles/member; two months' exchange rate). At the average weight of 40 grams per $1^1/_2$ litre bottle, this translates to about one ton of PET that is sooner or later accumulated as waste in the rural area. The weight of PET bottles that would have to be imported into a rural area points towards a need to include waste disposal strategies – centrally, at community or at household level – and waste management education, in parallel to the SODIS implementation.

We further observed that mothers would burn used bottles as fuel for cooking at household level. Burning at high temperatures will only create carbon dioxide (CO_2) and water (H_2O), and therefore be harmless to human health. Burning PET at low temperatures will produce carbon monoxide (CO), and possibly toxic PAHs (polycyclic aromatic hydrocarbons). The health risks associated with burning PET under such conditions have not been reported; however, indoor smoke is well known to increase the risk of acute lower respiratory infections in children (Ezzati *et al.*, 2002, Mishra, 2003, Smith *et al.*, 2000). Closer investigations of the environmental burden and the health risk of importing PET bottles into rural areas are needed, to estimate its importance in the long run.

Our study experienced that mostly women and children will be responsible for the application of solar disinfection in the households. In some settings (e.g. where no water disinfection practices are known) this may create an additional workload to women in the household. On the other hand, the SODIS method may also provide long-term relief to women's workload (e.g. less frequently collecting wood, increase time for child care during child illness). Gender issues should be carefully analysed in the planning phase of a point-of-use water disinfection method and incorporated in the promotion strategies.

Given a comprehensive implementation strategy, most of the health risks and possible environmental hazards may be considerably reduced, permitting a better acceptance and more regular application of SODIS in the population and at stakeholder level.

9.4. Lessons and recommendations regarding the implementation of solar water disinfection

Among other factors, the success of implementing the SODIS method will largely depend on the place, and its cultural setting. Our study produced important lessons on the determinants of adoption and on the choice for strategies that disseminate the knowledge for solar disinfection SODIS. The adoption of the lessons learnt could improve current and future implementation efforts. The feasibility of a large-scale implementation (e.g. simple, quick and effective social marketing through national radio and TV) of SODIS at this point in time, is questionable, due to missing evidence on key aspects of the method.

The efficacy of the solar disinfection method, following a specific instruction, has been recognised to vary depending on the local climate (McKenzie *et al.*, 1992). If instructions need to be adapted each time before implementation, large-scale dissemination through public media may not be suitable, as the instructions of use may differ according to the cultural setting and area.

The efficacy of the method – following current instructions – may be reduced at actual field level (Chapter 5), indicating that the current instructions (*www.sodis.ch*) probably require revision. More general, largely universal instructions must be formulated, incorporating the experiences of various settings and projects.

Another technical aspect concerns the provision of the necessary hardware for solar disinfection, namely, PET bottles. In urban areas, PET bottles are readily and freely available, and well-planned social marketing campaigns (e.g. providing instructions for use of SODIS on sold beverage bottles) may raise awareness and support people in the adoption of the method. A local markets for bottles could also be raised through public-private partnerships – e.g. PET bottle industry generates specific bottles for later SODIS use –, as is happening with hand-washing and the distribution of soap (Saadé et al., 2001, SDC, 2004). In rural areas, PET bottles are not usually readily available.

Networks for bottle provision may have to exist or be created – e.g. between local and city schools – which require "ad hoc" support. The easier availability of bottles through local small-scale providers may raise general compliance among the target population. On the other hand, the sustainability of small-scale bottle providers will be driven by the created demand in the population. A well-targeted social marketing campaign could be linked to the parallel establishment of bottle markets.

The acceptability of SODIS in the population is high, and people find it easy to apply. However, one of our key findings indicates that the majority of the targeted households did not perceive any benefit from applying the method. A missing *tangible* benefit leads to a low demand in the population and seems to explain the majority of the difficulties, also reported by other projects during different interventions (Meierhofer and Wegelin, 2002) – i.e., failure to believe in the SODIS disinfection process.

The importance of fine-tuning the intervention with local perceptions can only be emphasized (Curtis *et al.*, 1997), as it is not sufficiently taken into consideration in the field.

Inadequate messages – e.g. “SODIS kills pathogens” – may even generate doubt and criticism among the target population. Apparent inequity in the provision of service may result from not adapting the messages to all of the local educational and socio-demographic levels in the target population. Families that are least aware of underlying associations between germs and diseases, will not be able to understand, and therefore not perceive, the potential benefit of the method (see chapters 3, 4).

There are two possibilities for meeting this challenge. The first is to educate and convince people of the existence of germs that cause diseases. The presence of such a health concept in a population was shown to facilitate considerably the adoption of a home-based water disinfection method (Quick *et al.*, 2002). In areas where a high level of awareness is present, the implementation of solar disinfection should therefore be easier. However, the effort to introduce such health concepts into areas where the relation between germs and diseases is not perceived is likely to require considerable time and resources. However, such approaches may prove equally questionable as normative approaches (Nichter, 1991, Weiss, 1988).

The first step would be the development of a long-term information, education and communication strategy (IEC), in support of a family- centred approach for improving the understanding of disease prevention. This strategy would have to use multiple communication channels, in order to achieve best results.

Alternatively, the second approach could be to ensure sufficient time to investigate how SODIS could visibly benefit people – applying appropriate formative research – may be a promising approach at lower cost than the above (CDC, 2000, Unicef, 1999). The development of a properly adapted implementation strategy for the SODIS method in any situation, incorporating the essential information for that setting, becomes an interdisciplinary venture and challenge. Health education and formative research are not exclusive, and can be combined in the process of designing a SODIS intervention.

The choice of suitable implementation strategies will depend upon the resources available, the local partners and the characteristics of the area. Social marketing and the use of public media may be one of the least costly and most promising approaches. However, as reported elsewhere, people were mostly influenced by community- and household-based interventions in their adoption of the SODIS process (Chapter 3, (Quick, 2003)). Furthermore, different approaches affected specific factors of the population to a varying degree; e.g. awareness of germ/disease relation, extent of SODIS adoption (see Chapter 3).

To optimise the allocation of restricted funds and therefore obtain high benefits in health improvement at low cost requires a careful selection among different complementary implementation approaches, according to the local conditions and cultural setting.

As currently accepted, SODIS is a part-time method, that may require complementary methodologies in order to guarantee safe drinking water during the entire year. The method is therefore well-placed within programmes that promote a series of home-based water disinfection methods, from which families may choose the appropriate combination. The national ministry of health has recently launched a nation-wide programme, with the objective of strengthening the national health system in the rural areas of Bolivia; and this includes the promotion of solar water disinfection among other main targets (EXTENSA, www.sns.gov.bo).

The programme is a feasible example for wide ranging awareness building of the SODIS process in rural areas at relatively low cost. It is however not clear, to what extent such programme can increase the sustainable coverage of applying solar disinfection at national level. This would require a local follow up at district level and below (Harnmeijer, 1993).

In conclusion, at the current stage of available evidence, the broad (i.e. national), unsupervised, dissemination of the method may be justified on the basis of improving drinking water quality and health. The effective improvement in health may not always outweigh the investment, due to the relatively low adoption rates in target populations.

To reach the highest success rates through large-scale dissemination, it will first be necessary to revise user instructions in order to achieve best performances at field level; and also, to plan the organisation of necessary hardware (e.g. bottles) beforehand. Extensive formative research in different settings would provide a deeper understanding of the tangible benefits that SODIS could confer in the different contexts, which in turn could be communicated in large-scale implementation schemes, e.g. through social marketing campaigns. Following such a strategy might raise awareness of and compliance with the SODIS method and thus increase its health effectiveness at national and higher levels.

9.5. The role of home-based solar water disinfection in reducing the global burden of diarrhoea

At individual level, we measured a health impact of up to 75% in children under the age of five years that regularly drank SODIS-purified water. Assuming at least 20% uptake rate, as in our case, we estimated that the introduction of the SODIS method had reduced the risk of childhood diarrhoea by 14.5% at population level. Here, we focus on the prevention of diarrhoea, bearing in mind, that hygiene improvement in the home – a key feature of point-of-use methods – may also benefit the household by reducing other diseases, such as acute respiratory illnesses (Cairncross, 2003). The health impact can be expected to vary over time, as diarrhoea prevalence and risk factors are likely to fluctuate over an entire year.

We based our regional calculation on: our extrapolations of diarrhoea frequency in children (6.2 episodes/year, Chapter 7), the national census data (Instituto National de Estadístíca, 2002) and the estimated health effectiveness in this study. We calculated that at regional level, 3800 households in the Mizque area, containing on average 1.5 children under five years of age, suffer from about 35’000 diarrhoea episodes per year. The adoption of the SODIS method by 20% of the households would avert about 5000 diarrhoea episodes per year in this area. More generally, about 0.9 episodes of diarrhoea are prevented per child and year in this population, when the SODIS method is disseminated on a district-wide scale through the current approaches.

At global level, about four billion diarrhoea episodes occur, mostly in children under the age of five that live in developing countries, and the majority can be attributed to a lack of water, sanitation and/or hygiene (Schirnding von, 2003, Kosek *et al.*, 2003). These episodes cause approximately 2.5 million deaths (WHO, 2002, Schirnding von, 2003, Kosek *et al.*, 2003). Assuming, for example, that SODIS could be applied in 30% of the most affected areas. And based on the current experiences in Latin America and taking into account 50% less coverage for a global estimate, the global coverage of the use of the SODIS method is at about 0.001% (see Chapter 1). At a population health effectiveness of 14.5% about 200’000 diarrhoea episodes per year would be prevented through the implementation of the SODIS method.

This represents about 3200 disability adjusted life years (DALYs), including about 200 deaths that are prevented per year. On the other hand, if we assume best conditions, where all people in need are served and apply the SODIS method (100% coverage), solar water disinfection could prevent about 4.4% of the global diarrhoea burden, or 2.7 Million DALYs and about 110’000 deaths (WHO, 2002). In-depth global simulations, taking into account sufficient criteria for realistic estimation of the actual and potential global coverage of the SODIS method are needed.

The potential for solar water disinfection as a key intervention strategy is large. High individual effectiveness is lost due to low adoption rates in the fields (75% vs. 14.5%). Scarce information on where the method could successfully be disseminated is missing and this prevents an accurate estimate of its potential on a world scale. Global coverage needs to rise, to make a large impact on the overall burden of diarrhoea. The findings of our study support the advocacy of the SODIS method as a key strategy for diarrhoea prevention at household level, recognising, that it needs to be complemented with additional methods for guaranteeing safe drinking water for the entire year (Chapter 5, 7). Accurate estimates of the missing information should be made as a precursor to competent proposals for further large-scale dissemination of solar disinfection.

Ongoing research will provide whole-season estimates of the health effectiveness of the SODIS method (Mäusezahl and Colford, 2003). In the interim, the findings of a Cochrane review of the health impact of point-of-use methods should be available (Clasen *et al.*, 2004b). Both may provide further evidence for better acceptance and promotion for stakeholders and decision makers.

9.6. Positioning of solar water disinfection in regional settings and resulting priority research

The Millennium Development Goals (MDGs) are currently re-shaping development strategies. There is space for new ideas and approaches that can help people to break out of the poverty trap. Large-scale implementation projects, based on public-private partnerships, currently comprise the biggest hope for halving the population without access to safe water and improved sanitation by 2015 (Chapter 1, Appendix 1, *www.developmentgoals.org*).

Home-based (or point-of-use) water disinfection methods are especially interesting in areas where connections to infrastructure are not possible in the near term, or contaminated water is consumed, despite established water systems. The progress towards the achievement of target 10 of the MDGs, that point-of-use water disinfection methods could add is currently not monitored (Appendix 3). This is likely to change in the future, and indicators for estimating water quality are currently being field-tested (WHO/UNICEF, 2004). Apart from their effect on the health of the consumer, the awareness of the potential value of home-based water disinfection methods for stakeholders and policy makers is rising and may continue to rise given forthcoming endeavours provide further advocacy arguments for the SODIS method (Clasen et al., 2004b, Mäusezahl and Colford, 2003)

Most aspects of point-of-use methods are similar to solar water disinfection: they are applied in the home of the consumer; they act on the water quality; and they provide safe water storage. Processes may still need optimisation - before solar disinfection can effectively reach planners and decision makers at all levels.

Acceptance and easier implementation of solar disinfection may come from revised, more general instructions that guarantee WHO-acceptable water quality levels (Chapter 5). This may further reduce the cost of dissemination by making unnecessary the extensive research on the efficacy of the method in each new setting. A short test period for evaluating the methods' efficacy, however, will always be necessary, due to its strong dependence on at least three factors: UV-A, temperature and turbidity. Future research should therefore review, analyse and where necessary, complement efficacy findings from different places, to produce a consolidated, generally-applicable instruction protocol, for achieving highest efficacy under natural field conditions. As in our setting, a newer user instruction may fit peoples' perception better of whether the time investment for using the methodology is worth while (Acra *et al.*, 1984).

In light of future large-scale government or donor spending, the methods' cost-effectiveness is of growing importance. We could estimate that costs at individual level may quickly be inverted by the health benefits that the method delivers (Chapter 7).

Future research should carefully monitor the cost of solar water disinfection method and illness for the individual, but especially also compare programming cost for the dissemination of the method with health costs at system level.

Given that SODIS improves water quality, promotion activities have interpreted this as an improvement in the health of the consumer. We did detect a significant health improvement through introducing the SODIS method in a target population, but most of the effect may be due to the accompanying safer water handling. Evidence of health impact and effectiveness is based on many similar findings under different conditions and using different designs (Rychetnik *et al.*, 2004). The cluster-randomised control trial that is ongoing in a rural area of Bolivia, will show if the findings presented here can be reproduced (Mäusezahl and Colford, 2003). Nevertheless, more studies must be conducted under equally rigorous conditions and in various settings, to determine the effectiveness of solar water disinfection on a more general scale.

Current research is investigating the determinants of adoption of the SODIS method in Bolivia, and has as its objective, the design of computer models for optimising implementation strategies in a specific context (Mosler, 2004, personal communication).

In addition to this promising research, we suggest that an interdisciplinary research venture investigates the key benefits people would perceive from adopting the SODIS method, *before* any implementation takes place, through, for example, the application of formative research methods (Curtis et al., 1997, Harnmeijer, 1993)

Finally, cost- and health effectiveness measures will depend considerably on the perception of a family adopting the SODIS method. In addition, point-of-use methods may always require evaluations at household level, as the responsibility for use is entirely placed in the hands of the consumer. We suggested a feasible and rapid assessment approach at household level, through the application and combination of three indicators: reported use, frequency of drinking and observed use (Chapter 4). It is of eminent importance that standardised programme evaluation approaches are developed, as a basis for future work. The suggested approach could be validated during ongoing and planned programmes and research, in order to develop a rapid assessment ‘tool’ for the evaluation of a programmes’ success. It is expected that the accuracy of such indicators could change over time, as people are more frequently confronted with them. Constant re-evaluation of indicators for SODIS use may prove necessary, to measure the effectiveness of an ongoing programme over a prolonged time period.

Rapid collection of valid evidence of effectiveness is essential to make point-of-use methods available to people that have no other option than drinking contaminated water. Once enough evidence is assembled, several effective point-of-use methods can be compared and presented together as valid options, and stakeholders may choose a method according to their needs. Not only could this prove to be a promising scenario for the future of point-of-use technologies, but would also contribute to built global partnerships for development (8^{th} MDG). Home-based water disinfection methods may therefore temporarily relieve local governments from the worry and pressure to guarantee safe water for their population. The study in Zambia forms an interesting example - the local government was interested to test a point-of-use method to relieve people in certain city areas from drinking contaminated water (Quick *et al.*, 2002). Furthermore, providing different options to the target population is an empowering in itself and may result in higher acceptance.

A first step towards bringing together current evidence has been taken through the WHO review in 2002 (Sobsey, 2002), that is supposed to be revised regularly. Such central “library” can be useful in directing the needed research and available options.

Large scale, prolonged application and constant evaluation of the effect of point-of-use methods will evaluate the long-term benefits and possible adverse effects, i.e. the risk of introducing inequity in decision-making processes at stakeholder level, by introducing low-cost and effective methods under the responsibility of the local population. In-depth analysis and professional judgement of such risks in relation to the benefits will be required.

In conclusion, solar water disinfection can be positioned as one of several simple ways to relieve people temporarily from drinking contaminated water and from suffering frequent diarrhoea episodes. Various targeted research is suggested from the current research, to develop SODIS and other point-of-use methods to a level of high effectiveness, to promote the method among policy makers, and to raise awareness among countries and their populations. However, the ultimate decision-maker about point-of-use methods, will always be the consumer and potential beneficiary.

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APPENDIX 1: Millennium Development Goals (MDGs). *UN Millennium Summit, New York, September 2000. Source: www.developmentgoals.org*

Topics	*Targets*
Eradicate extreme poverty and hunger	Target 1: Halve, between 1990 and 2015, the proportion of people whose income is less than one dollar a day Target 2: Halve, between 1990 and 2015, the proportion of people who suffer from hunger.
Achieve universal primary education	Target 3: Ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling
Promote gender equality and empower women	Target 4: Eliminate gender disparity in primary and secondary education, preferably by 2005, and to all levels of education no later than 2015
Reduce child mortality	Target 5: Reduce by two thirds, between 1990 and 2015, the under-five mortality rate
Improve maternal health	Target 6: Reduce by three quarters, between 1990 and 2015, the maternal mortality ratio.
Combat HIV/Aids, malaria and other diseases	Target 7: Have halted by 2015 and begun to reverse the spread of HIV/AIDS Target 8: Have halted by 2015 and begun to reverse the incidence of malaria and other major diseases
Ensure environmental sustainability	Target 9: Integrate the principles of sustainable development into country policies and programmes and reverse the losses of environmental resources Target 10: Halve by 2015 the proportion of people without sustainable access to safe drinking water and basic sanitation Target 11: Have achieved by 2020 a significant improvement in the lives of at least 100 million slum dwellers
Build a global partnership for development	Target 12: Develop further an open, rule-based, predictable, non-discriminatory trading and financial system. It Includes a commitment to good governance, development, and poverty reduction - both nationally and internationally Target 13: Address the special needs of the least developed countries. Includes: tariff and quota-free access for least-developed countries' exports; enhanced programme of debt relief for HIPCs and cancellation of official bilateral debt; and more generous ODA for countries committed to poverty reduction

Topics	*Targets*
	Target 14: Address the special needs of landlocked countries and small island developing States (through the Programme of Action for the Sustainable Development of Small Island Developing States and the outcome of the twenty-second special session of the General Assembly) Target 15: Deal comprehensively with the debt problems of developing countries through national and international measures in order to make debt sustainable in the long term Target 16: In cooperation with developing countries, develop and implement strategies for decent and productive work for youth Target 17: In cooperation with pharmaceutical companies, provide access to affordable essential drugs in developing countries Target 18: In cooperation with the private sector, make available the benefits of new technologies, especially information and communications

APPENDIX 2: Comparison of Recommended Technologies for Household Water Treatment

Criterion	*Boiling with Fuel*	*Solar Disinfection with UV + Heat (SODIS or SOLAIR)*	*Solar Disinfection with Heat Only (Opaque Vessels and Solar Panels)*	*UV Disinfection With Lamps*	*Free Chlorine and Storage in an Improved Vessel ("CDC Safewater")*	*Chemical Coagulation-Filtration + Chlorine Disinfection*
Microbial reduction	Yes, extensive	Yes, extensive for most pathogens	Yes, extensive for most pathogens	Yes, extensive for most pathogens	Yes, extensive* for most pathogens	Yes, extensive
Diarrhoeal disease reduction	Yes	Yes, 9-26%; two Studies	None reported from epidemiological studies, but expected due to high temperature (55+oC)	None reported from epidemiological studies, but expected due to germicidal effects	Yes, 15-48%; many studies	None reported from epidemiological studies yet, but expected due to multiple treatments
Disinfectant residual	No	No	No	No	Yes	Yes
Quality requirements of water to be treated	No	Low turbidity (<30 NTU) for effective use; pre-treat turbid water	None	Low turbidity (<30 NTU) and low in UV absorbing solutes, such as NOM, iron and sulphites	Low turbidity (<30 NTU) and low chlorine demand for effective use; pre-treat turbid water	None; applicable to poor quality source water
Chemical changes in water	No, usually except deoxygenating and chemical precipitation	None or not significant	None or not significant	None or very little	Yes; may cause taste and odour and disinfection by-products	Yes, may cause taste and odour and disinfection by-products
Microbial re-growth potential in treated water	Yes, with storage beyond 1-2 days	Yes, with storage beyond 1-2 days	Yes, with storage beyond 1-2 days	Yes, with storage beyond 1-2 days	None to low if chlorine residual maintained	None to low if chlorine residual maintained
Skill level and ease of use	Low skill, easy use	Low skill; very easy use	Low skill; easy use with training	Moderate skill, training needed for maintenance leaning and lamp replacement	Low skill; easy use with training	Moderate, training needed in adding chemicals, mixing, decanting and filtering
Availability of needed materials	Requires a source of fuel	Requires plastic (PET) bottles and dark surface (on one side of vessel or on surface where vessel is placed	Requires black bottles of cook vessels and a solar reflector or solar cooker	Requires UV units and replacement lamps and a reliable source of electricity (power)	Requires source of free chlorine or chlorine generator and source of safe storage vessels	Requires a source of the chemical mixture (coagulants+chlorine disinfectant); may limit availability
Limits to water volume treated	Yes, difficult to scale up above usual cooking volumes	Yes, treats 1-1.5 litres per bottle; can simultaneously treat multiple bottles	Yes, treats 1-4 litres per container; can simultaneously treat multiple vessels with multiple solar panels or solar cookers	No, units can treat several litres per minute and much, depending on lamp size and number and reactor volume	No, easily scaled up	Yes, chemical mixture treats fixed volumes of 10-20 litres; repeated treatment of additional volumes
Performance verification requirements	Observe water for a rolling boil	Measure that target temperature is reached (thermometer or wax indicator)	Measure that target temperature is reached (thermometer or wax indicator)	Must verify lamp output; may be a limitation if unit lacks a UV sensor	Measure chlorine residual or microbial quality (indicators) or both	Observe (measure) turbidity reduction and measure chlorine residual
Costs per capita hardware	None	Cost of black paint for bottles or alternative surface	Cost of solar cooker / reflector & water exposure and storage vessels	cost of UV system: US$100-300), $20-60 Power (energy)	US$1.60	Use existing storage vessel or buy a special treatment and storage vessels (US$5-10 each)
Operation cost	Varies with fuel price; expensive	None	Replacement of above	Lamp replacement ($10-100) every 1-3 years	US$0.60	Chemical costs at about $US7-11, assuming about 2 ltrs/day

Criterion	*Boiling with Fuel*	*Solar Disinfection with UV + Heat (SODIS or SOLAIR)*	*Solar Disinfection with Heat Only (Opaque Vessels and Solar Panels)*	*UV Disinfection With Lamps*	*Free Chlorine and Storage in an Improved Vessel ("CDC Safewater")*	*Chemical Coagulation-Filtration + Chlorine Disinfection*
*Acceptability**	High	High to Moderate	High to Moderate	High	High to Moderate	High to Moderate
Sustainability	High, unless fuel is scarce	High, probably	High, probably	High, probably	High	High, probably; limited data
Length of treatment time	Minutes to tens of minutes	Hours (full sun), days (clouds), not effective if no sun	Hours (full sun), days (part sun), not effective if no sun	Seconds to minutes, depending on water volume treated and reactor design	Tens of minutes	Tens of minutes

Legend: *From: Sobsey M, Managing Water in the Home, WHO 2002; *High is >75%; moderate is 50-75%*

APPENDIX 3: Definition of indicators according to the WHO/UNICEF joint monitoring programme of water and sanitation.

From "Meeting the MDG drinking water and sanitation target: A mid-term assessment of progress. WHO/UNICEF 2004.

Existing surveys do not provide information on the quality of water, either at the source or in households. Improved sources may still contain harmful substances, and water can be contaminated during transport and storage. Although 'improved drinking water sources' provides a good indicator for progress, it is not a direct measure of it.

Extensive research in rural areas found that people satisfy their basic needs for water if the source can be reached in a round trip of 30 minutes or less. These requirements are determined locally, depending upon water availability, local customs, and the amount of water required to prepare food staples.

To resolve these issues and other issues, the JMP (Joint Monitoring Program) classified sanitation facilities and water supply sources as either 'improved' or 'unimproved', as defined below. In doing so, it makes the assumption that those classified as 'improved' are likely to be more sanitary than 'unimproved' ones.

Improved drinking water sources

Household connection
Public standpipe
Borehole
Protected dug well
Protected spring
Rainwater collection

Unimproved drinking water sources

Unprotected well
Unprotected spring
Rivers or ponds
Vendor-provided water
Bottled water*
Tanker truck water

Improved sanitation facilities

Connection to a public sewer
Connection to a septic system
Pour-flush latrine
Simple pit latrine**
Ventilated improved pit latrine

Unimproved sanitation facilities

Public or shared latrine
Open pit latrine
Bucket latrine

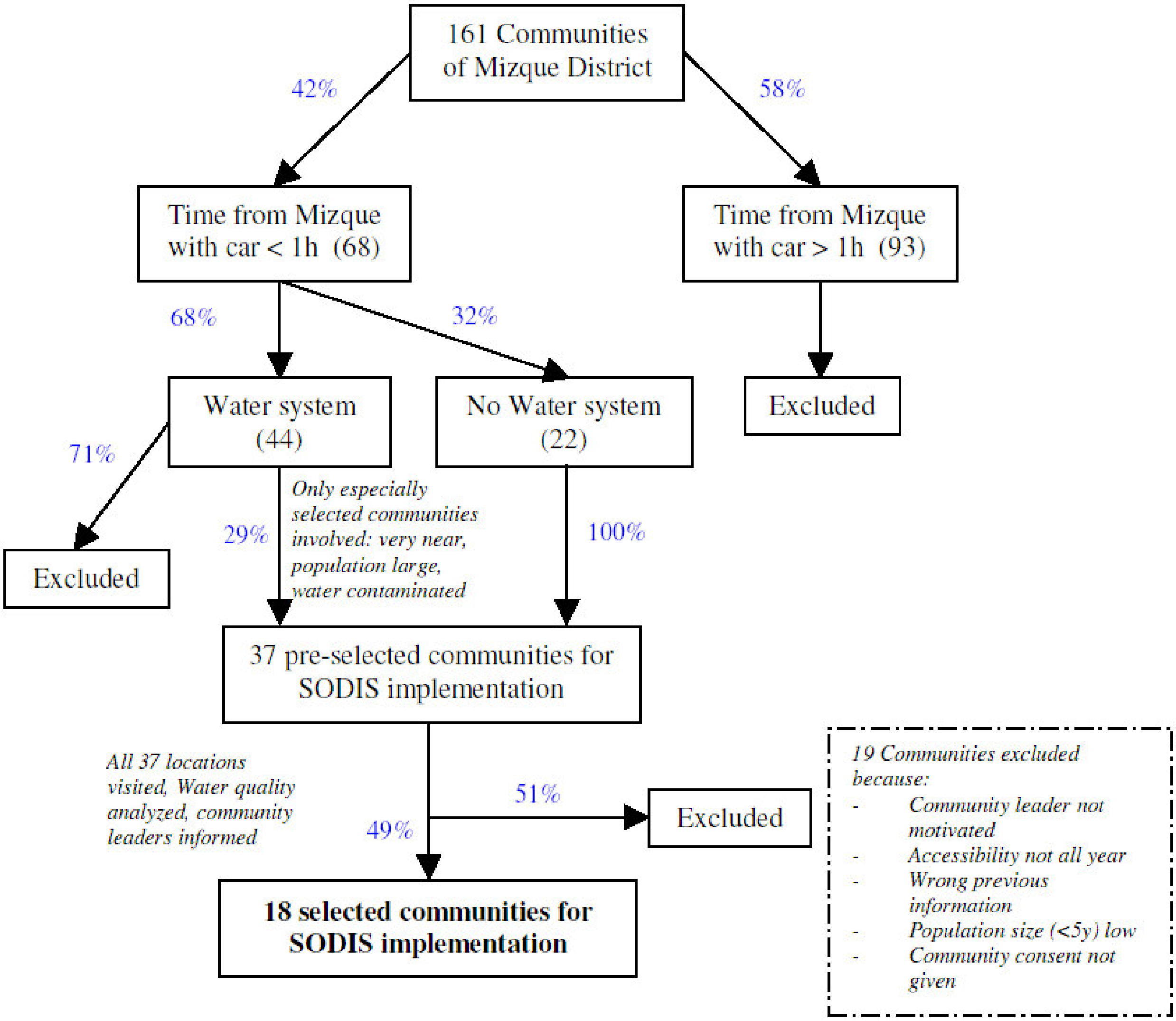
*Bottled water is not considered improved due to limitations in the potential quantity, not quality, of the water.
**Only a portion of poorly defined categories of latrines are included in sanitation coverage estimates.

APPENDIX 4: Community selection and informed consent

The project and study was reviewed and accepted by a WHO review board. The project was presented locally and accepted by the municipality.

We first applied normative criteria to select appropriate communities from 161 communities in the province of Mizque that were recorded in the annual plan of operations of the Municipality (POA: Plan de Operacíones Annuales) (Figure 2). Thirty-seven communities were visited to check the accuracy of the information (e.g. population size, number of children under 5 years, water sources etc.), operational feasibility of the area (e.g. all-year accessibility) and motivation and expressed need of the community leader. Eighteen communities were finally selected for the introduction of the SODIS method, where the project was first accepted by majority vote through the two-weekly community meetings. After a mid-year assessment, we decided on ten previously introduced communities with the highest motivation to apply the new SODIS technology and worst raw water quality to participate in the nested case-control study. All communities and households followed a standard informed consent procedure for the participation in the health assessment survey as described in detail in Chapter HEALTH.
Our field staff translated all data collection instruments into Quechua, the widely spoken local language. All translated documents and tools were back translated independently into Spanish to check the accuracy of the translation. Interactions with community people were always held in Quechua.

Figure 2: Decision tree of the community selection for the SODIS implementation



APPENDIX 5: Organisation of bottles & disposal

PET or plastic bottles were not new to the study population. Local markets existed – selling or giving bottles for free – but the quantity of bottles needed to supply the regular SODIS application of the target population was not sufficient. On average, families needed to exchange a bottle after 4-6 weeks. Ideally, the communities and households should have been supported by the project to organise their own bottles. The time and resource constrains did not allow such strategy. We therefore imported bottles from the big city and distributed them to the families on demand. The Fundación SODIS collected PET bottles through collaborating NGOs and fairs. We purchased bottles from private institutions, shops or schools in Cochabamba to a price of 20 Bolivianos (~ 2.8$) per 100 bottles and transported with lorries returning to Mizque. At the end of the projects, about 4000 PET bottles were transferred to the project area. All of these approaches were promising for future projects, but the sustainability of any supply strategy must be carefully examined and waste disposal facilities should be installed.

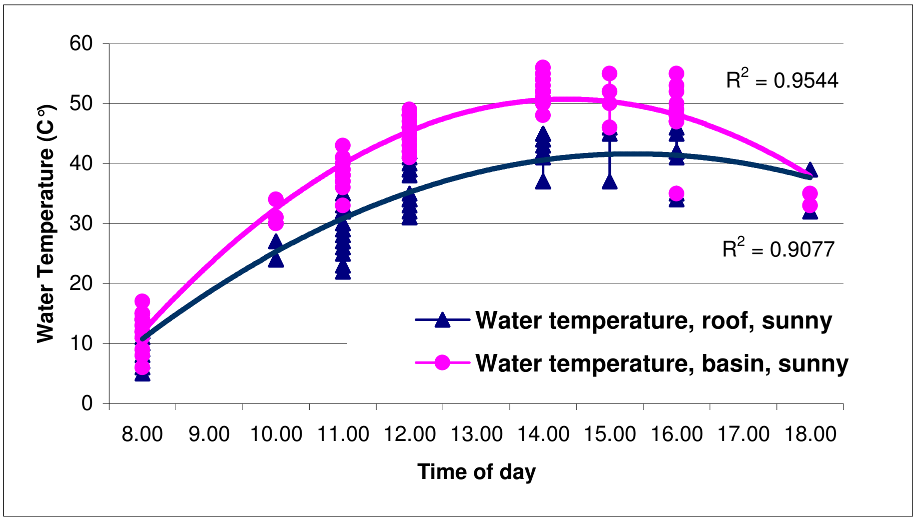
As in the communities around Mizque no public waste collection system is established, the implementation staff introduced the construction of inorganic waste disposal pits within the communities. The pits measured 1 x 1Meter and were approximately 1.5 m deep. We advised the community people to burn the bottles only inside these pits and not to use them for cooking purposes, because of the creation of toxic carbon monoxide when burnt at low temperatures or incompletely.

The establishment of such pits were only possible through the exchange of services:
For example, communities asked for T-shirts for their football team, which was provided on the condition that a waste pit was established. The use of these pits was not monitored or evaluated as they were built at the end of the survey.

APPENDIX 6: Temperature experiment to optimise the SODIS process

We monitored the air and water temperature in water-filled transparent PET bottles that were exposed to the sun at the central office. A cement-tile roof supported one bottle, and we put another bottle in a basin made of a corrugated iron sheet (“batea”) collocated on the floor and inclined toward north. The temperature difference was on average 8 °C, and the time of highest water temperature was determined, which lead to the conclusion that leaving bottles exposed for the entire day will secure that the process benefits from the highest water temperature (Figure 3).

Figure 3: Difference of Water temperature in exposed bottles dependent on support



APPENDIX 7: A pilot study to assess the feasibility of a health impact study in rural Bolivia

National and district level health, population and water and sanitation data were not complete or out of date, and information on water management, social context and cultural factors did not exist for this area. We therefore performed a pilot study to record the missing information and assess the feasibility to measure the effectiveness of the SODIS method in the rural area of Mizque, in the year 2001.

We conducted a cross sectional study in May 2001, where 142 families with children under the age of 5 years from 8 communities of the rural district in Mizque were surveyed at random. Water samples at household and community level and stool specimens were analysed in a sub sample of the study children under the age of 5 years.

The average household size was composed of 6.2 (SD=1.9) family members and 54.3% of the families had more than one child below five years. Water was collected on average 4 times per day, mainly in buckets (74.5%) and small canisters (17%) and more than 60% of all households were storing drinking water for more than 24 hours. Water from rivers, springs and irrigation channels was frequently used for drinking. All sources were contaminated with thermo-tolerant coliform bacteria, indicating faecal contamination.

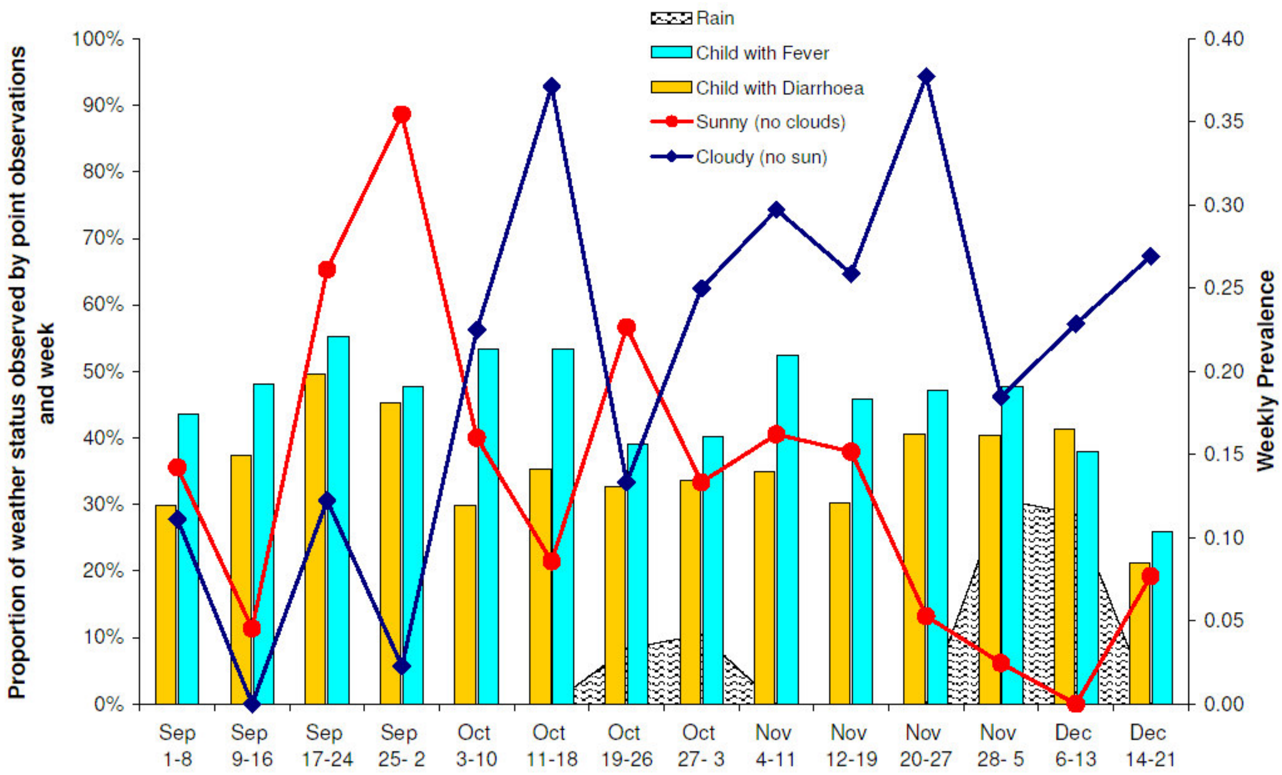
In-home drinking water samples were significantly more contaminated than community water sources, suggesting additional secondary contamination at household level and an additional elevated risk of water borne gastrointestinal illnesses.

In total, 35 mothers (24.6%) reported that one of their children under 5 years of age experienced an episode of diarrhoea at the time of the interview that compared well the DHS survey in 1998, which recorded a diarrhoea prevalence of 20.4% in children under three years of age in Bolivia. We found that among other factors, children under the age of five contracted diarrhoea due to their young age and because contaminated water was consumed from sources in the field. Mothers reporting to wash their hands with soap protected their children from diarrhoea.

In 36 of 74 stool specimens (48.6%), an intestinal parasite was detected (31% *Giardia lamblia*, 23% *Entamoeba hist/disp*, 11% Helminth). Parasitic infections were significantly less likely to be detected in younger children and were not associated with the occurrence of diarrhoea.

We concluded from the results that interventions targeting the disinfection and safe storage of water with accompanying hygiene behaviour messages were well-placed in an areas where indications for water borne diarrhoeal diseases were so marked.

APPENDIX 8: Weekly childhood illness prevalence in rural Bolivia and observed weather conditions, from September - December 2002



Legend: *Illness weekly prevalences from health monitoring activity Aug – Dec 2002, Mizque, Bolivia.*

APPENDIX 9: Terminology of childhood diarrhoea in rural communities of the rural province of Mizque, Bolivia. 2001/2002.

Nomenclature	Symptoms	Frequency / Consistency	Aetiology	Biomedical validity[#]	Severity	Treatment
K'echalera (Liquid stooling) ***Duration:*** *3 days - …*	*Belly aches, heat in belly *Makes *kaka* like water, constantly *Has fever, looses weight, weakens, loss of appetite *Some get cold *Watery stools	*Watery *Frequent	*From dirty water & dirtiness *When eating earth or bad meat *Worms inside, visible *When eating cold food and cold water	Valid; *general term including most other types*	*Very bad, child needs to be brought to the hospital *Not so bad, passes rapidly *The illness goes around like the pest *Drying out *Some get sick to die	*Herbal teas (of *Coca, Uri Uri, khoraciño*), rice water, avocado seeds, leaves/flour of Guayava, maize water or ORS *Traditional healer heals with "big" medicines *Pharmacy / doctor for pills, powders, anti-worm-remedy *Bring to hospital *Massage the back
K´echalera con sangre = Kecha pukay (Red Diarhoea)	*Fever *Bloody liquid stools *Abdominal pain	*Liquid stool w\ blood	*Interior warms *Mothers anger cooks the child's intestines through the breast milk *Intestines were cooked by the warms *Complication of Kecha Kellu	Valid, dysentery	*Is very bad *With this kind of diarrhoea children die *If they are vomiting as well they die within 1-2 days	*Juice of Cactus leaves *Traditional healer, consulting the mother earth
K´echalera k´omer (Green diarrhoea)	*Watery green diarrhoea with bad smell	*Watery with foam	*Because the breast of the mother is too cold *If diapers were washed and dried afterwards outdoors in wind and fog. *If the bottom becomes cold	Valid, *specification of the term "K'echalera" (self-limited diarrhoea)*	*Is not that bad	*Herbal teas (Paico and Muña) *Clean the bottom with the red corn stick (without the corns) and throw it away *Baths the belly and the bottom with alcohol *Grounded barley *Consultation by traditional healer
K'echa K'ellu (=Paskusqu'a)Yellow diarrhoea) ***Duration:*** *~1 week*	*Fever, vomit sometimes *Has blisters on lips and tongue *no inflation *Cries, looses weight	*3 – 4 liquid depositions / day *Stool is yellow and hot	*From heat *Mother's milk, if mother breastfeeds in the sun	Valid, *specification of the term "K'echalera" (Severe diarrhoea)*	*Very bad *Child can die in 1 week because the intestines get burned	*Bath the child in urine or cold water (to lower temperature) *Rub egg-whites on the child's body *Grounded white maize under the armpits *Give herbal tea
K'echa Yuraj (White diarrhoea)	*White diarrhoea very liquid *No inflation and no vomit *Has fever, cries *The tong is white and thick		*When breast milk is cold	Valid; *specification of the term "K'echalera" (Cholera-like diarrhoea)*		*Drink boiled eggshells *Apple in boiled water with egg white, whipped in a 1L bottle and given to the child.

Nomenclature	**Symptoms**	**Frequency / Consistency**	**Aetiology**	**Biomedical validity#**	**Severity**	**Treatment**
Cólera	*With gas and cramps *Body shivering, weakness *Vomit *Continuously passing watery stools	*Watery *Continuously (very frequent)	*Dirtiness *Came with the wind and people from outside	Valid; Cholera	*8 persons were killed	*Give them lots to swallow *SRO
Aykasan ***Age: 6-9 month*** ***Duration:*** *2-3 days*	*Liquid diarrhoea	*Colour is white and green *Duration of 2-3 days *1 deposition / day	*Not an illness, but a signal to the mother that the child is ready to start to creep, stand or walk	Not valid, *low depositions/day*	*Not severe *Mothers need to know	No specific treatment
Manch'ariska (afraid) ***Age:*** *2 – 12 months* ***Duration:*** *up to 2 months*	*Has diarrhoea, vomit or both *Fever *Low appetite	*Diarrhoea little by little *Vomits 2-3 times a day	*When child is frightened by something	Valid	*Not severe, but needs curing as child does not sleep well	*Consultation with natural healer
Oreja, Orejasqa =Ayaska (Cadaver-illness) ***Age:*** *3 – 24 months* ***Duration:*** *up to 1 months*	*Loosing weight like skeleton, then with diarrhoea *Fever, belly pain *Weak hands, bad eyes *Head and belly grows, body doesn't *Turn yellow, like cadavers *Cannot hold the diarrhoea *What he eats come out the same *Child is hungry	*Watery, undigested food *Not that liquid *Yellow diarrhoea *1 – 3 depositions per day	*Passing by dead rats, snakes or birds *When women is pregnant and passes above a dead animal with bad smell, the baby gets sick *Dead dog *Passing the cemetery *Bad smell passes into the blood *In general: caused through the smell of a cadaver	Not valid, *depositions / day low; Stool not liquid*	*Severe, needs rapid cure as looses weight *Can die in 10-12 days *Some die *Die like "out of control"	*Teas, plasters, bath and vapour of herbs, especially *Uri Uri* *Rub in the earth, which was removed from a grave, at the time when it is thrown onto the dead. After, bath in a mixture of colours. After this, cover the body with hot sheets, when there is sun. Should not get cold. *With various herbs and boiled human bones (drinking); also for bathing *Collect the faeces of a recently killed sheep, wrap it around in hot sheets and leave it like this to sweat. *To cure, carry the baby 3 kilometres, walking, such as the child sweats *In covers put it in the sun, such as it falls a sleep, then cover it, and let it sweat. Change and wash its cloth when wet. Don't do it in the wind *Do not bring the child to the hospital as they do not understand

Nomenclature	**Symptoms**	**Frequency / Consistency**	**Aetiology**	**Biomedical validity#**	**Severity**	**Treatment**
Siki Chirisk'a (Cold bottom) ***Age:*** *5 – 12 months* ***Duration:*** *3 days*	*Has cold bottom, soles and hands *Cannot sleep	*Liquid whitish stool *2 – 5 depositions per day	*From the cold *When child is not well dressed	<u>Valid</u>	*Not very severe *Cannot sleep	*Needs rapid treatment as child cannot sleep *Not necessary to bring the child to the hospital
Siki Chupasqa (Shrunken buttock) ***Age:*** *5 – 12 months* ***Duration:*** *3 days – 2 weeks*	*Bottom hurts *Soundly diarrhoea *Turn pale and yellow *Vomit	*Liquid like water *With phlegm *Small frequent depositions *2 – 5 depositions per day	*When falling on the floor, during learning how to walk *When his "tail" (coxis) is crooked, or gets bend by the fall	<u>Valid</u>	*Severe illness *Needs rapid cure as child looses weight rapidly and can die *Affects the children from 3month to 2 years *If tremble, will die	*Rub (Massage) its bottom with oil **khaqudoras* make it cry until it is silent, like dead *Rub it with *khaqudoras* ;straighten his "tail", then it is healed *Massage the whole body and care well for the child *Reposition of the Coxis, entering with the finger in the anus *No use to take him to the hospital as they do not understand
Uma Quiwicha ***Age:*** *2 – 10 months* ***Duration:*** *~ 1 week*	*Diarrhoea *Child is passive	*Liquid *Whitish-yellow colour (Stool) *2 – 3 depositions per day	*Bad accommodation of the child's head during carrying *When child gets used to a certain bad accommodation	<u>Valid</u>	*Serious, as the nerves of the child can get "harder"	*Bring to a natural healer who knows how to massage the child's head and neck with oil or alcohol

biomedical validity: WHO-definition of diarrhoea: 3 or more loose stools per 24 hours or 1 loose stool with blood

Curriculum Vitae

Name: **Michael André <u>Hobbins</u>**
Nationality: Swiss (Buerger von Zug) / British (EU)
Date & place of birth: 21 November 1973, London, UK
Profession: Epidemiologist

<u>LANGUAGES</u> German, English, Spanish, French; solid verbal and written knowledge

PROFFESSIONAL EXPERIENCE

Jan 2001 – May 2003 **Project manager / director** *Cochabamba, Bolivia*
Swiss Tropical Institute: Directed a team of 22 staff to realise a water intervention trial in collaboration with three institutions in a rural Bolivian population

Jan 2000 – Oct 2000 **Consultant** *Basel, Switzerland / Bangladesh*
Swiss Tropical Institute, for CARE-Bangladesh: Evaluating the promotion of a water purification method in the SDC-funded international partnership project (WPP)

Aug 1999 – Dec 1999 **Project coordinator** *Basel, Switzerland / Bangladesh*
Swiss Tropical Institute, in Bangladesh: Assessed the feasibility of implementing an intervention trial in a multi-institutional, international Bangladeshi setting

ADDITIONAL PROFESSIONAL EXPERIENCE

2004/2005 **Expert** *Switzerland*
Schweizer Jugend Forscht (sjf), category: Medicine, Biochemistry, Chemistry

PROFESSIONAL MEMBERSHIP

Since 2000 **Aguasan group**: Community of practice for the water and sanitation development sector; impact on policy formulations; based at the Swiss Agency for Development and Cooperation (SDC) in Berne, Switzerland

EDUCATION

Oct 2004 **PhD** in Epidemiology at the University of Basel on solar drinking water purification

Jul 1999 **Diploma** in Integrative Biology (Biology I) at the University of Basel; thesis on Noroviruses in Switzerland

Jun 1993 **Matura certificate** (Mathematical coursework) at the Institut Dr. Pfister (ZG); since 2001, member of the association for former pupils (start of the association)

OTHER ACTIVITIES

February 2003 — **Scientific contribution** to a documentary on solar water disinfection in Bolivia; by MTW (Mensch-Technik-Wissenschaft): 'SODIS: Solare Trinkwasserdesinfektion', 13.3.2003.

March 2002 — **Title role** in a documentary on the Austrian scientist Thaddäus Haenke in Bolivia and Chile ("Söhne der Wüste: Durch die Atacama", by Stefan Köster); transmitted by ZDF, ORF, Arte.

October 2000 — **IT installer** at "Roche" for short term assignment of 3 weeks to exchange computer equipment in different departments of the firm

Jul - Oct 1996 — **Assistant** to a research project at the Scripp's Institute for Oceanography (SIO), California, USA

PUBLICATIONS

Hobbins M & Maeusezahl D, Wegelin M, Uddin Z, Motaleb A, Tanner M: The Health benefits of solar water disinfection in a special setting in rural Bangladesh. Manuscript to be submitted to *Environmental Health Perspectives in 2005*

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