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

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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.*

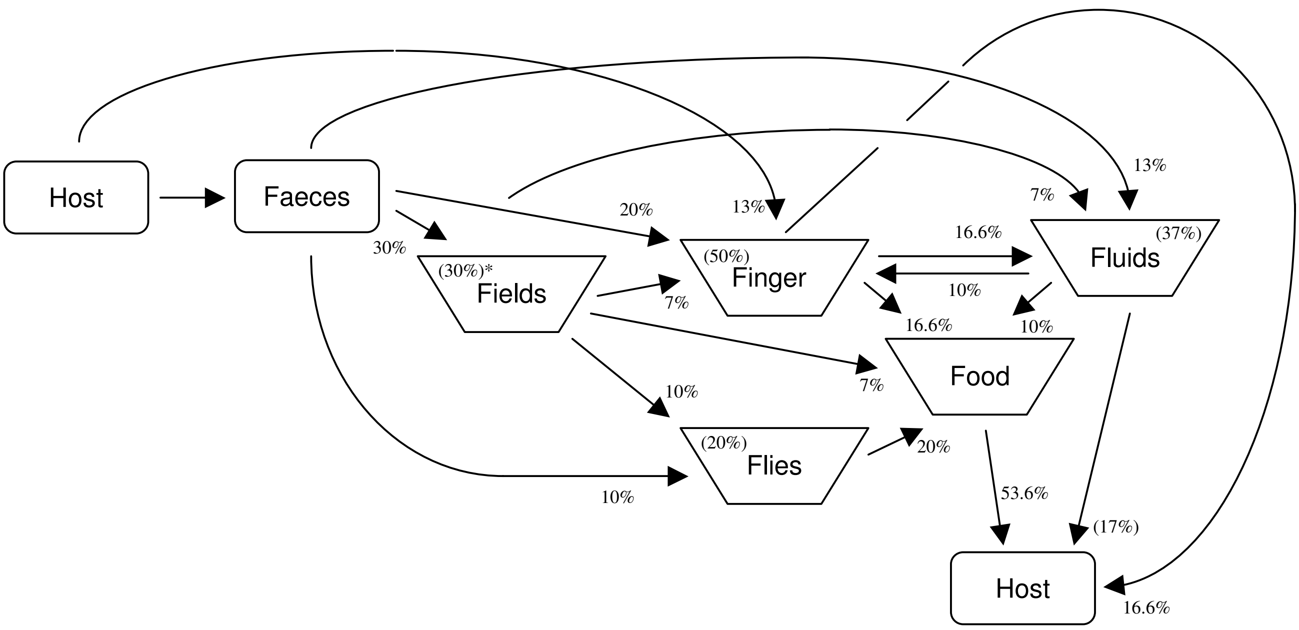
1.2. Diarrhoeal diseases prevention

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.

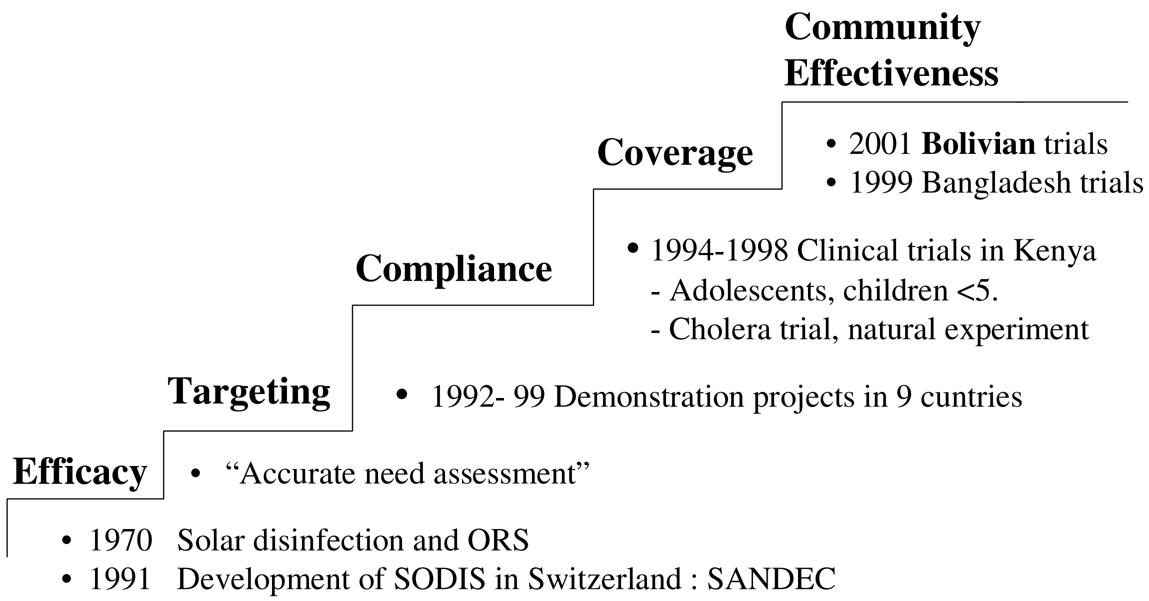
Study	*Intervention*	*Control-intervention*	*Study group, Place*	*Time follow up*	*Measured reduction in diarrhoea*
Clasen et al. *(Clasen et al., 2004a)*	Ceramic filters	None	Households, Bolivia	6 mths	64% (prevalence)
			Children<5y, Bolivia	6 mths	72% (prevalence)
Quick et al. *(Quick et al., 1999)*	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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