Water, Sanitation, and Health in Developing Countries

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Relevant Publications

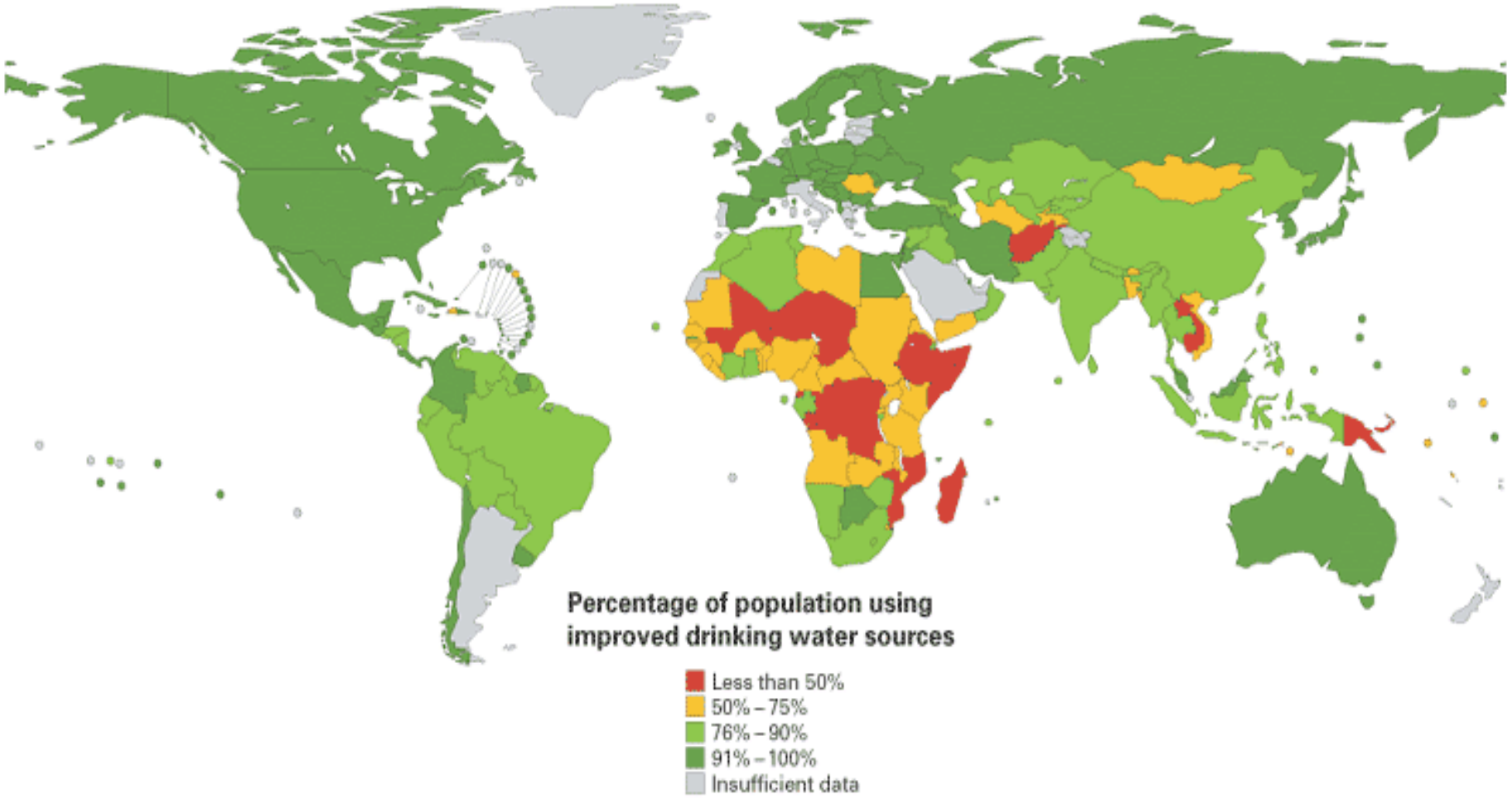
- Montgomery, M.A., and Elimelech, M. “Water and Sanitation in Developing Countries: Including Health in the Equation”, *Environmental Science and Technology*, Volume 41, January 2007, pages 17-24.

- Elimelech, M. “The Global Challenge for Adequate and Safe Water”, *Journal of Water Supply: Research and Technology – AQUA*, Volume 55, February 2006, pages 3-10.

The Gloomy Facts

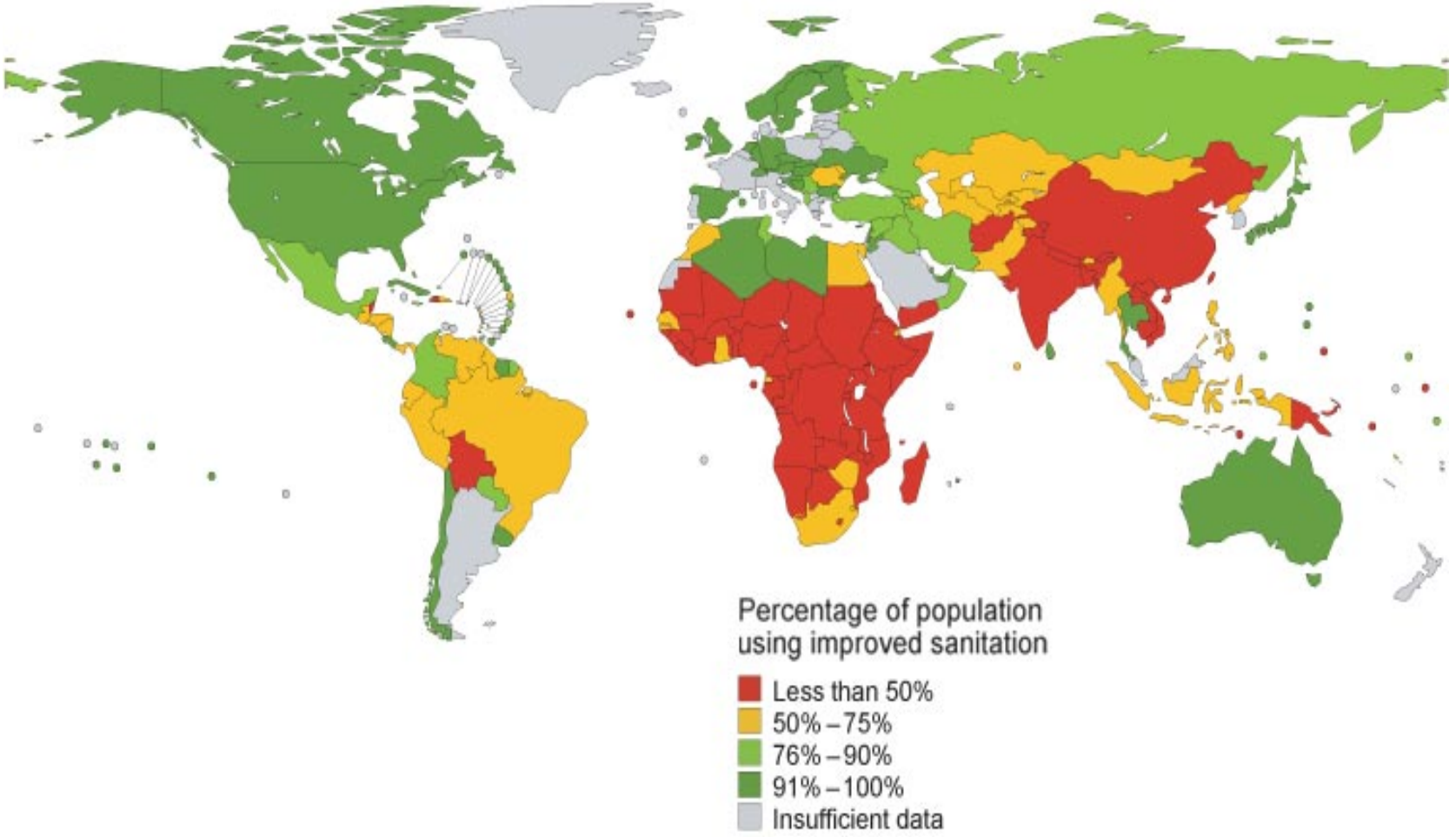
- 1.1 billion people — or one sixth of the world's population — lack access to safe water
- 2.4 billion are without adequate sanitation
- Between 2 to 4 million deaths a year are attributed to unsafe water, mostly due to water-borne preventable diarrheal diseases
- 90% of those who die from diarrheal diseases are children under 5 in developing countries

More than 1 Billion without "Improved" Water



UNICEF/WHO, Meeting MGD Water and Sanitation Targets, 2004.

More the 2 Billion without Sanitation



UNICEF/WHO, Meeting MGD Water and Sanitation Targets, 2004.

The UN Millennium Declaration (2000)

- Set the Millennium Development Goals with an ambitious agenda for improving the human condition by 2015

- Goal 4: Reduce child mortality
  - By 2015, reduce by two thirds the mortality rate among children under five

- Goal 7: Ensure environmental sustainability
  - By 2015, reduce by half the proportion of people without sustainable access to safe drinking water and sanitation

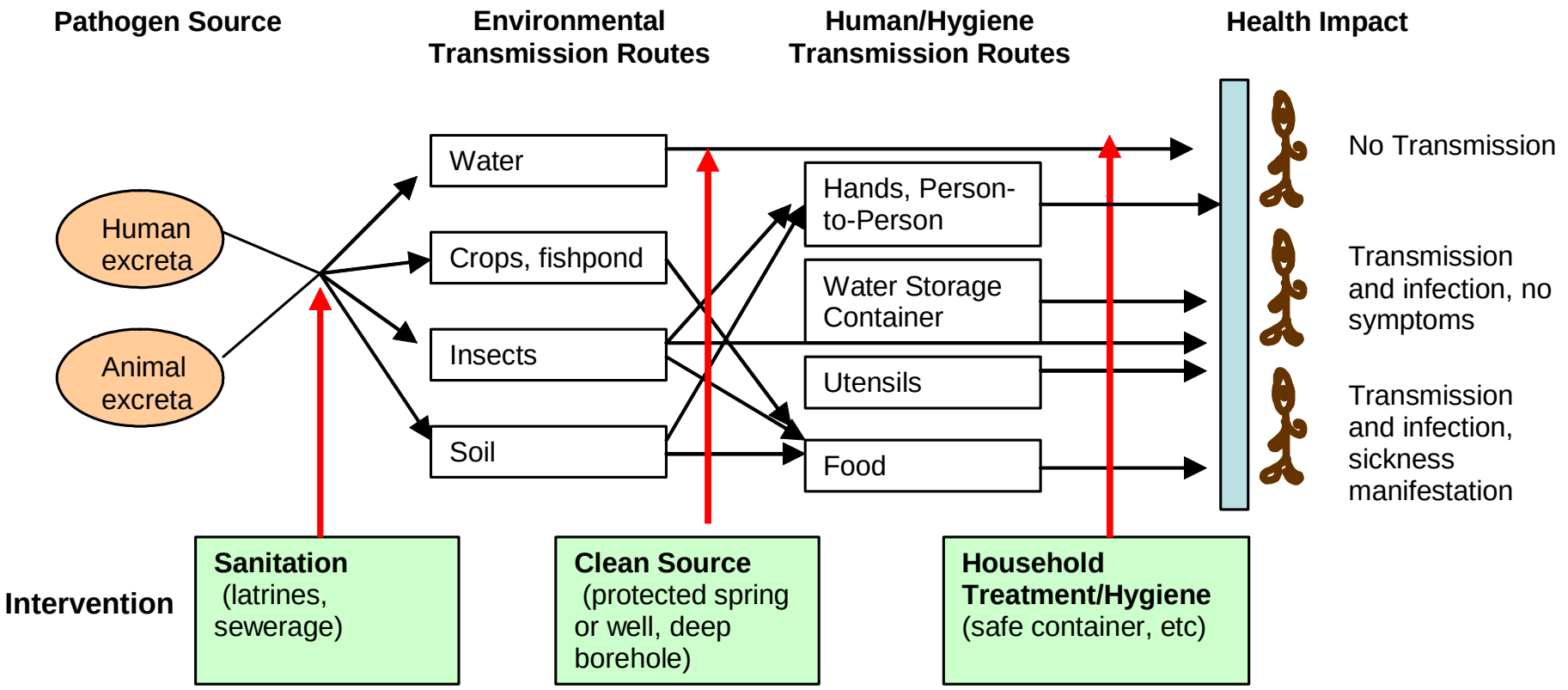
The Situation is not Improving Fast and we will Miss the MDG Targets

- At the current pace, by 2015:
  - 2.4 billion people will lack access to improved **sanitation**
  - 920 million will lack access to improved **water**
  - The problem is most severe with **rural populations**
  - Least progress has been made in **Sub-Saharan Africa**

Deaths of children under 5 yrs old per 1000

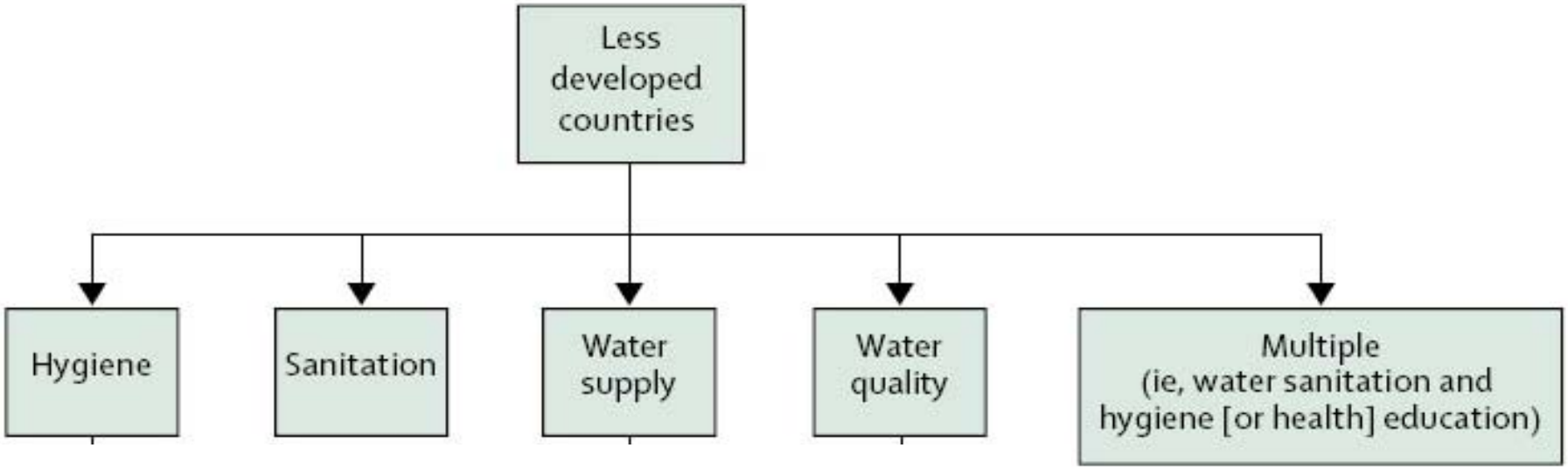
% of population with access to safe drinking water

Transmission Pathways of Water-Related Pathogens are Complex



What is the Cause of Diarrheal Diseases?

- Analysis of intervention/epidemiological studies
- Such studies have provided contradictory and often confusing results and conclusions



The Former Dominant Paradigm for the Prevalence of Diarrheal Diseases

From Esrey et al. (1985), *Bulletin of the WHO*

Intervention	Avg. Reduction
Water and Sanitation	30%
Sanitation	**36%**
Water Quality and Quantity	17%
Water Quality	**15%**
Water Quantity	20%
Hygiene	**33%**

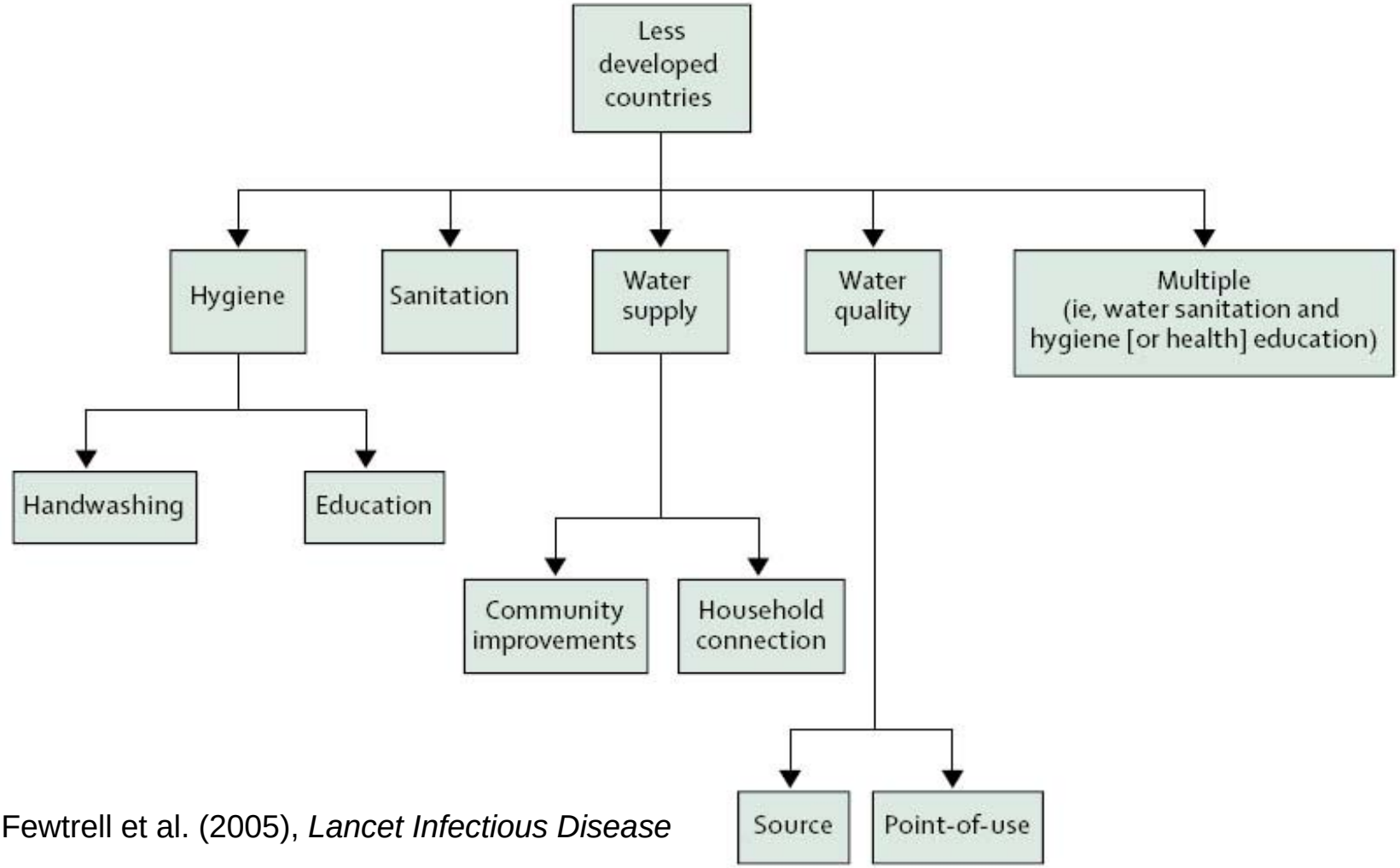
Note: Point-of-use (POU) interventions were not included

Conclusion: **Sanitation** and **Hygiene** are the Major Causes for Diarrheal Diseases

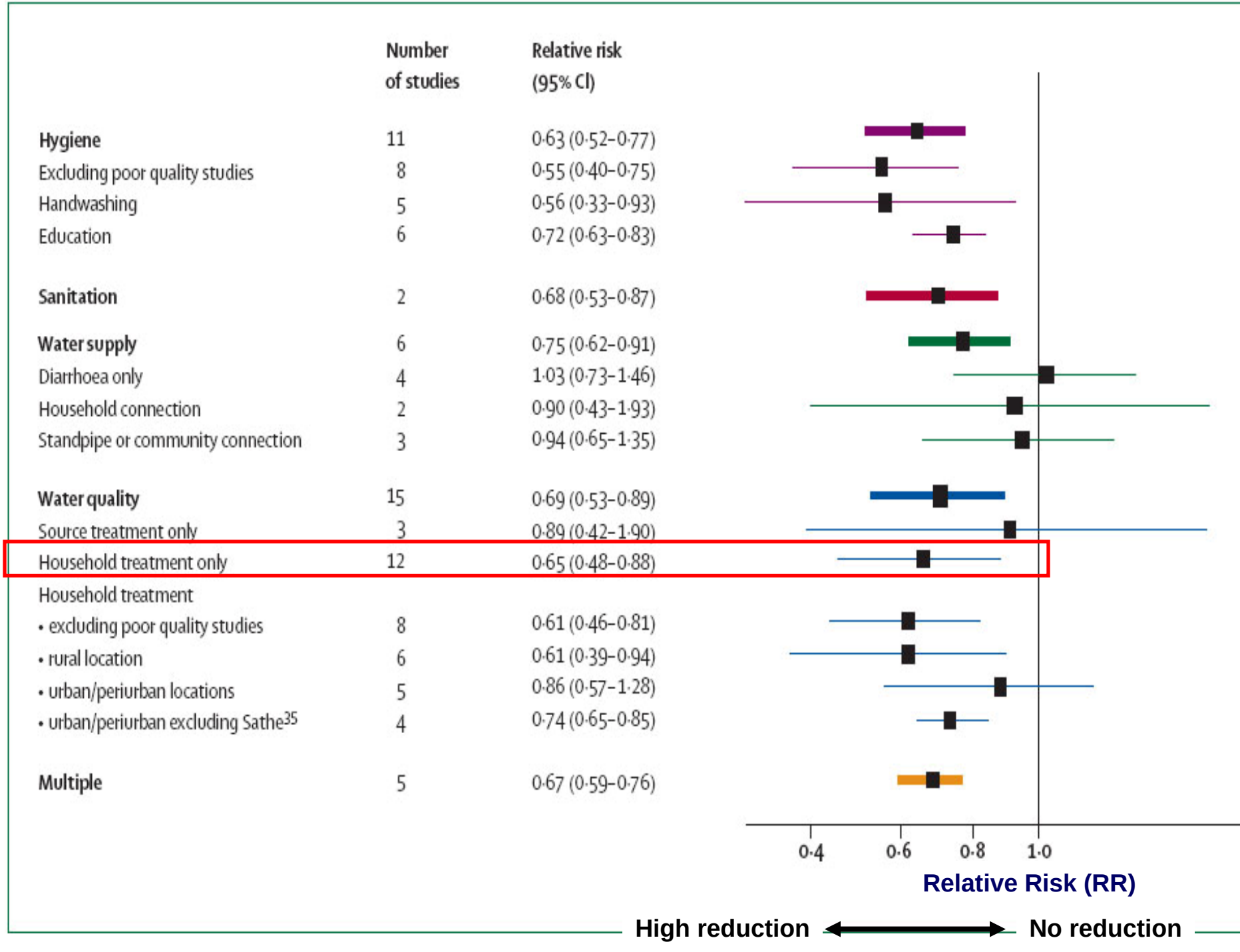
A Refined Paradigm

- Fewtrell et al. (2005) in the journal *Lancet*: An extensive meta-analysis of past studies
- Demonstrated the importance of point-of-use (POU) treatment in reducing diarrheal disease morbidity
- The variable compared is the relative risk (RR) of contracting diarrhea between control and intervention groups — the greater the effectiveness of an intervention, the lower the RR

Fewtrell et al. Statistical Analysis of Intervention Studies



From Fewtrell et al. (2005), *Lancet Infectious Disease*


Number of studies
Relative risk (95% CI)
Hygiene 11 0·63 (0·52–0·77)
Excluding poor quality studies 8 0·55 (0·40–0·75)
Handwashing 5 0·56 (0·33–0·93)
Education 6 0·72 (0·63–0·83)
Sanitation 2 0·68 (0·53–0·87)
Water supply 6 0·75 (0·62–0·91)
Diarrhoea only 4 1·03 (0·73–1·46)
Household connection 2 0·90 (0·43–1·93)
Standpipe or community connection 3 0·94 (0·65–1·35)
Water quality 15 0·69 (0·53–0·89)
Source treatment only 3 0·89 (0·42–1·90)
Household treatment only 12 0·65 (0·48–0·88)
Household treatment
• excluding poor quality studies 8 0·61 (0·46–0·81)
• rural location 6 0·61 (0·39–0·94)
• urban/periurban locations 5 0·86 (0·57–1·28)
• urban/periurban excluding Sathe[35] 4 0·74 (0·65–0·85)
Multiple 5 0·67 (0·59–0·76)
0·4
0·6
0·8
1·0
Relative Risk (RR)
High reduction
No reduction

Summary of Fewtrell et al. Study

Intervention	Reduction in Diarrheal Disease
Water Quality (at Source)	11%
Water Supply	19%
Multiple Interventions	30%
Hygiene	37%
Water Quality (POU)	**35%**
Sanitation	32%

Why Hasn't POU Treatment Played a Bigger Role Until Now?

- Previous studies did not include data on POU treatment, suggesting that hygiene and sanitation were more important than water quality interventions
- Note: It is still unclear whether these measures can achieve levels of scale and sustainability to make a significant dent in the global disease burden

Centralized versus Decentralized Solutions?

Mintz et al. *Am. Jour. Public Health*, 1991:

- "Approaches that rely solely on time- and resource-intensive centralized solutions will leave hundreds of millions of people without access to safe water far into the foreseeable future"
- "A radical reorientation toward interventions to support these populations is urgently required."

"Cellular phones and satellite dishes revolutionized the telecommunications industry in developing countries, bypassing the expenditures and delays associated with traditional wire-based systems . . . . . Similarly new scientific research . . . offers dramatic opportunities to introduce ***new decentralized (point-of-use) approaches for improving water quality****"*

Mintz, et al., *American Journal of Public Health,* 2001, 91:1565

Quick Overview of Point-of-Use Methods at the Household Level

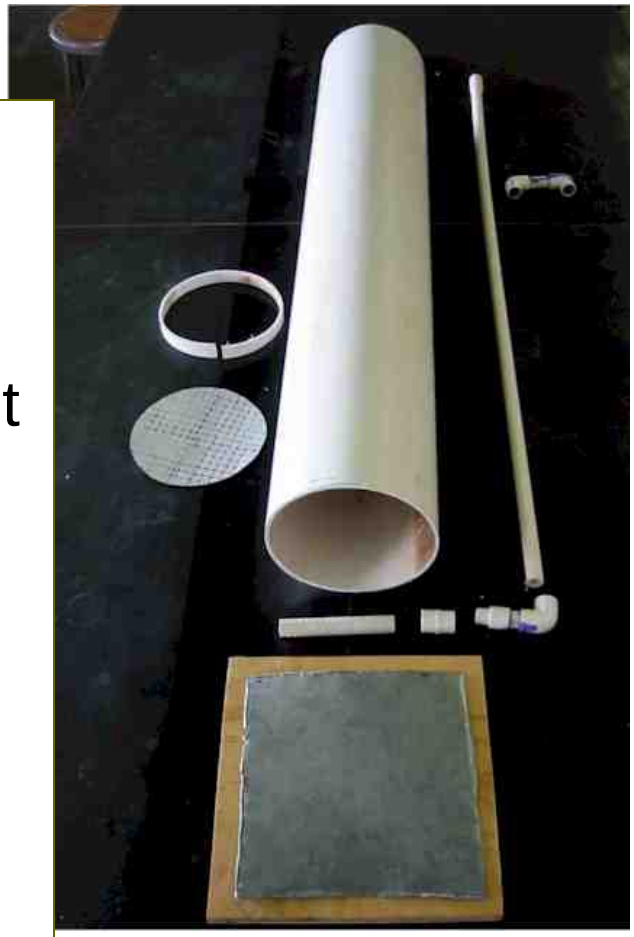
Note: Several of the slides on POU technologies were provided by Jeff Albert, Aquaya.

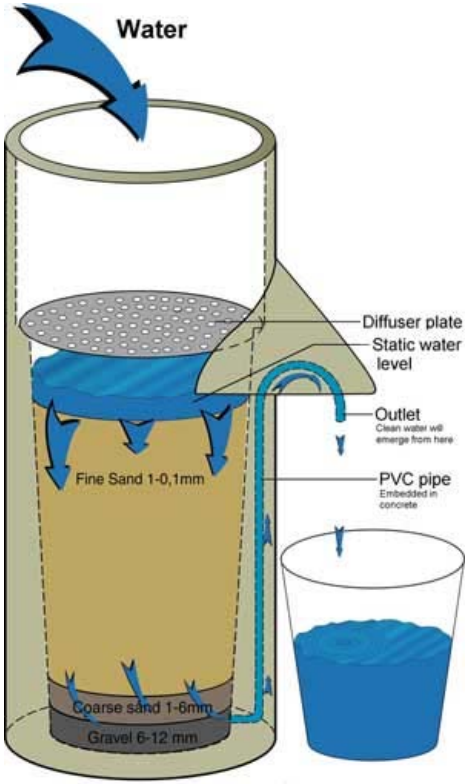
Boiling

- <$1/capita/yr to $10s /capita/yr, depending on fuel source
- Roughly, 1 kg of wood needed to boil 1 liter of water
- Fuel costs can be prohibitive, and smoke can cause respiratory disease

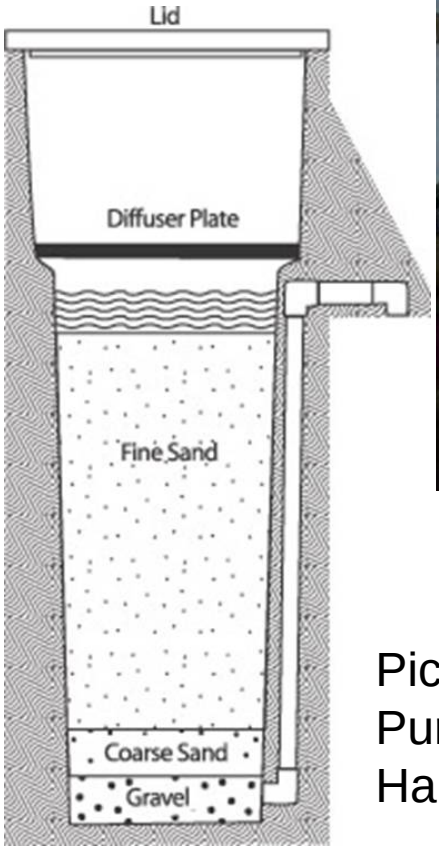
Biosand Filter

- <$1/capita/yr
- Proven effective in the lab; no published field health studies yet
- High front-end capital costs: $10-30/unit for single family
- Pathogen removal may not be high enough





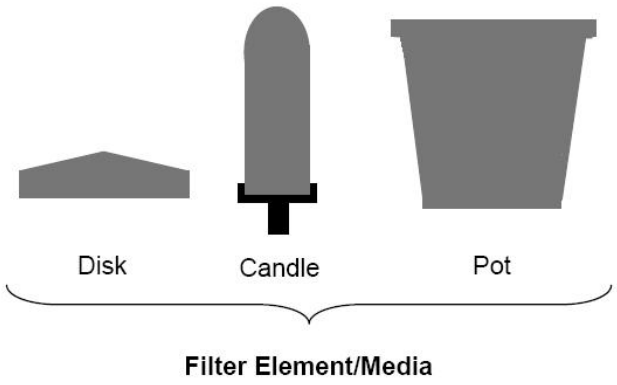
Biosand Filter



Pictures obtained from: South Asia Pure Water Initiative, Inc., Hamden, Connecticut

Ceramic Filter

- <$1/capita/yr
- Not enough data on performance in developing countries
- High front-end capital costs: $10-50/unit for single family



Chemical Disinfection (Chlorine)

- <$1/capita/yr
- Chlorine residual addresses storage concerns
- Chlorine odor/taste is a major adoption obstacle

Inexpensive Sodium Hypochlorite (Bleach) Solutions

Madagascar
Sûr'Eau ("Safe Water")
0.5% solution, 0.5 L, treat 2000 L

Kenya
"Klorin"
1 % solution, 0.5 L bottle

Zambia
"Clorin"

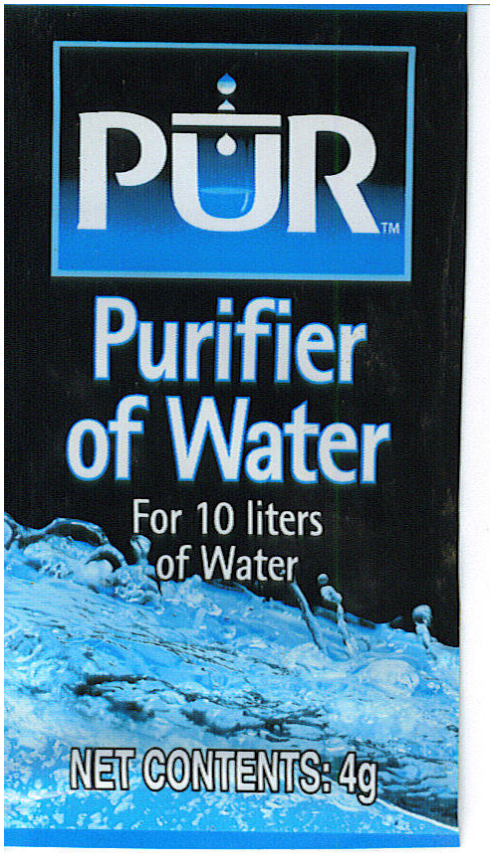
Solar Disinfection (SODIS)

- <$1/capita/yr
- proven bacterial inactivation
- Turbidity inhibits UV penetration and limits effectiveness

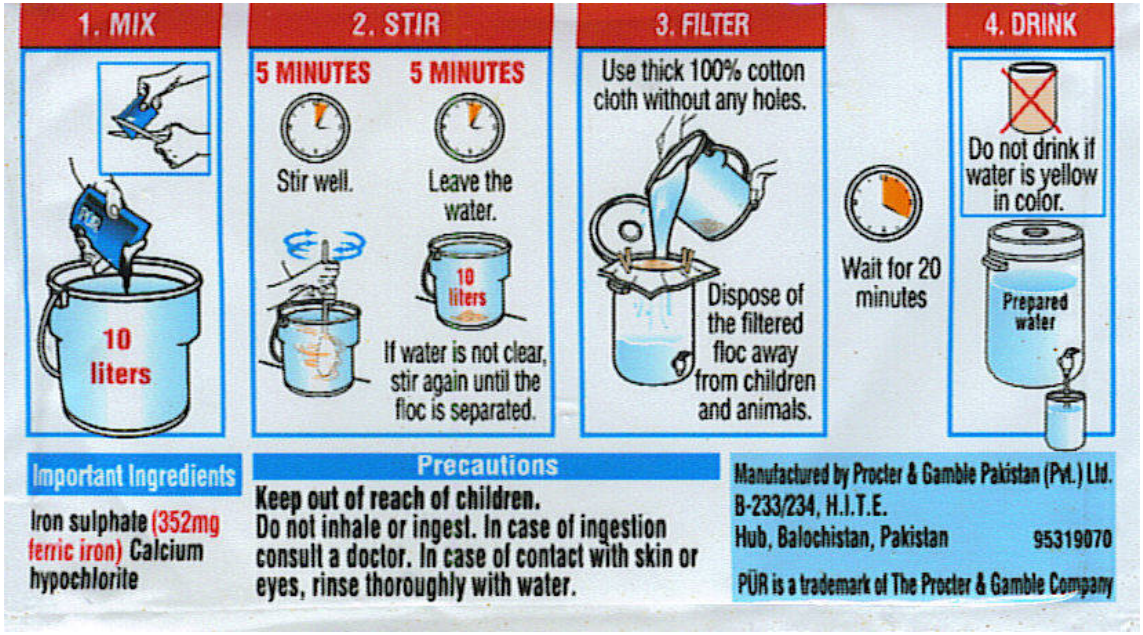
Flocculation/Disinfection (PUR®)
(ferric sulfate plus calcium hypochlorite)

- ~$6/capita/yr at 4 liter/day for drinking water
- Significant removal of all microbial pathogens (and arsenic)
- Chlorine taste and odor

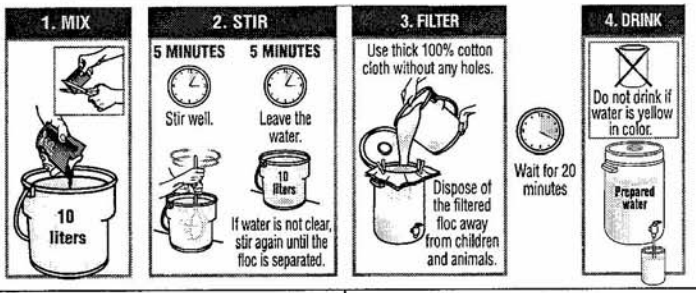
Procter & Gamble PuR® for Point-of-Use



Powder containing ferric sulfate and calcium hypocholrite



Used successfully in the Philippines, Indonesia, Guatemala, Morocco, Pakistan, Haiti, Liberia, Bangladesh, Kenya, Uganda, Chad, Botswana, Malawi, Zimbabwe, Sudan, Iran, Ethiopia, Iraq, and South East Asia.



PUR Purifier of water
Product Demonstration Guide
(American English)

1. Open a sachet using a pair of scissors.
2. Add the contents of the sachet to a clean mixing vessel containing 10 liters of water.
3. Agitate the powder vigorously in the water for 5 minutes. Be sure a vortex is created when mixing. Then, let the water stand until it clarifies.
4. After adding the powder to the water, the water will become colored. The color indicates that the product is working. When the process is finished, the water will be crystal clear.
5. If you see the water is still colored, you can mix again and let it rest for another few minutes.
6. Once the water looks clear, and the floc is at the bottom of the bucket, filter the water through a clean cloth filter into a clean storage container and cover it with a lid.
7. The filter must be a cotton cloth that prevents the floc from passing through.
8. Wait **20 minutes** before drinking the water.
9. Do not drink water if it is colored or cloudy after treatment. If the floc accidentally gets into the treated water, use another cloth to filter the floc out of the treated water. The water is still good to drink.
10. The treated water should be preferably consumed within 24 hours after its preparation. Water that is left over should be used for cooking, washing, watering animals or otherwise discarded.
11. **ALWAYS** dispense the water from the storage container into another container, such as a cup or glass for drinking.
12. Discard the floc from the water treatment process in the latrine, or on the ground away from children and animals.

Do not ingest the powder.
Maintain out of children's reach.
Contents: $Fe_2(SO_4)_3$: 352 mg Fe(III); $Ca(OCl)_2$

PUR Purificador de agua
Guía para la demostración del producto.
(Venezuelan Spanish)

1. Abra el sobre con unas tijeras.
2. Añada el contenido del sobrecito a un recipiente limpio que contenga 10 litros de agua.
3. Agite el polvo vigorosamente en el agua por 5 minutos aproximadamente. Asegúrese de que cree un embudo al revolver el agua. Luego deje que el agua repose hasta que esté clara.
4. Luego de añadir el polvo en el agua, el agua se coloreará. El color indica que el producto está funcionando. Cuando el proceso termine, el agua estará cristalina.
5. Si nota que el agua aún tiene color, luego de revolver y reposar, puede revolver de nuevo y dejarla reposar por segunda vez.
6. Una vez que el agua se vea clara, y que los grumos estén en el fondo, cuele el agua a través de un filtro de tela limpio a una cubeta de almacenamiento limpia y cúbrala con una tapa.
7. El filtro debe ser una tela de algodón, sin agujeros, para evitar que pasen los grumos al agua.
8. Espere **20 minutos** antes de beber el agua.
9. No beba el agua si ésta tiene color o está turbia después de ser tratada/purificada. Si los grumos cayeran accidentalmente dentro del agua tratada/purificada, use otro filtro de tela para filtrar de nuevo los grumos del agua tratada. El agua todavía se puede utilizar.
10. El agua tratada/purificada debe consumirse preferiblemente dentro de las 24 horas siguientes a su preparación. El agua que quede, después de ese período, deber utilizarse para cocinar, lavar, darle de beber a los animales o descartarse.
11. **SIEMPRE** debe dispensar el agua de la cubeta de almacenamiento a un nuevo recipiente, como una taza o un vaso.
12. Deseche los grumos del agua tratada/purificada en la letrina, o en la tierra, lejos de los niños y de los animales.

No ingiera el polvo.
Manténgase alejado del alcance de los niños.
Contiene: $Fe_2(SO_4)_3$: 352 mg Fe(III); $Ca(OCl)_2$

PUR Purificateur d'eau
Guide de démonstration du produit
(France French)

1. Ouvrir le sachet du produit avec des ciseaux.
2. Ajouter le contenu du sachet dans un seau propre contenant 10 litres d'eau.
3. Mélanger vivement la poudre dans l'eau, durant environ 5 minutes. S'assurer de créer un tourbillon lors du mélange. Laisser ensuite reposer le mélange jusqu'à ce que l'eau se clarifie.
4. Une fois la poudre additionnée à l'eau, celle-ci se colore. Cette couleur est une indication du bon fonctionnement du produit. Lorsque le processus de purification de l'eau est terminé, l'eau devient limpide.
5. Si une fois cette procédure terminée, l'eau reste colorée, recommencer à mélanger et laisser l'eau se poser une nouvelle fois.
6. Une fois limpide et le floc accumulé au fond du seau, laisser l'eau se décanter à travers un filtre de coton, dans un récipient propre réservé au stockage de l'eau purifiée, et le couvrir.
7. Le filtre doit être en coton, sans trous, afin d'éviter que le floc ne passe au travers.
8. Attendre **20 minutes** avant de boire.
9. Ne pas boire l'eau si elle reste colorée ou trouble après purification et traitement. Si l'eau traitée contient du floc, la re-filtrer avec un autre filtre, afin d'éliminer le floc. Cette eau reste potable.
10. Une fois purifiée, l'eau doit être consommée dans les 24 heures suivant son traitement. Passé ce délai, le reste d'eau peut être utilisé en cuisine, pour le ménage, ou pour l'abreuvage des animaux.
11. **TOUJOURS** verser du récipient de stockage dans un autre récipient (tasse ou verre).
12. Jeter le floc restant suite au traitement de l'eau dans les latrines ou l'enfouir dans la terre, loin des enfants et des animaux.

Ne pas ingérer la poudre.
Conserver hors de la portée des enfants.
Contient : $Fe_2(SO_4)_3$: 352 mg Fe(III) ; $Ca(OCl)_2$

PUR مطهّر الماء
طريقة الاستعمال
(Classic Arabic)

1- افتح الغشاء بمقص

2- افرغ محتوى الغشاء في دلو نظيف (10 لترات من الماء).

3- خلّط المسحوق بالماء برشاقة لمدة 5 دقائق. تأكد من خلق زوبعة أثناء التخليط. اترك الخليط يرتاح حتى يصبح الماء صافياً.

4- خلال عملية الخلط، سيصبح الماء ملوناً. هذا اللون هو دليل على نجاح مفعول المسحوق. عند الانتهاء من عملية التطهير سيعود لون الماء صافياً.

5- إذا بقي الماء ملوناً، عاود عملية الخلط واترك الماء يرتاح مرة أخرى.

6- عندما يصبح الماء صافياً، ويتكوّن راسب إلى قعر الدلو، صفّ الماء عبر ثوب قطني نقي وبدون أي ثقب في سطل نظيف وغطيه.

7- يجب أن تكون المصفاة من ثوب قطني بدون أي ثقب حتى لا يمر الراسب عبر المصفاة.

8- انتظر 20 **دقيقة** قبل شرب الماء.

9- لا تشرب الماء إذا كان ملوناً أو غير صافٍ بعد عملية التطهير. إذا كان الماء المطهر يحتوي على بعض الرواسب فيجب إعادة تصفية الماء بثوب آخر. سيظل هذا الماء صالحاً للشرب.

10- يجب استعمال الماء خلال اليوم الذي يلي عملية التطهير. أما بعد ذلك فيستحسن استعمال الماء لأغراض أخرى مثل الطبخ، التنظيف أو تروية الحيوانات.

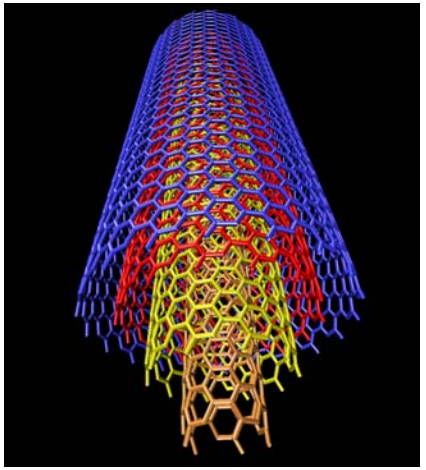
11- يجب **دائماً** صب الماء من مكان التخزين إلى الكوب.

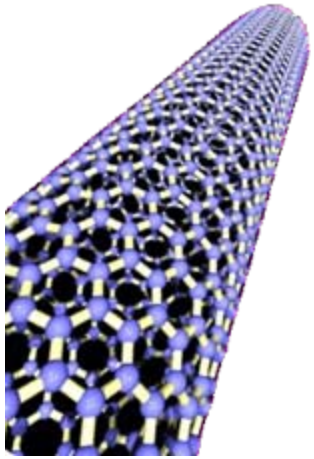
12- ارم الأوساخ الناتجة عن عملية التطهير في المراحيض أو ادفعها بعيداً عن متناول أيدي الأطفال والحيوانات.

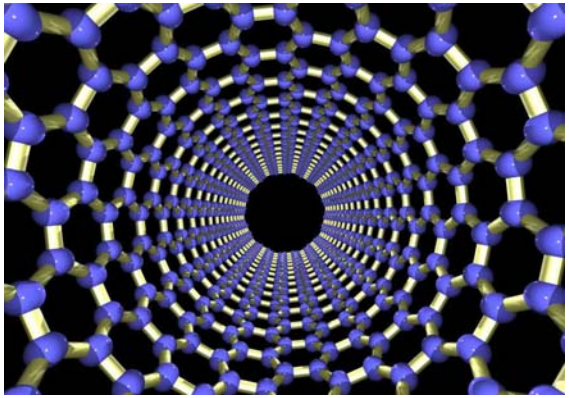
المسحوق ليس للأكل
أبعدوا المسحوق عن متناول الأطفال
يحتوي على: $Fe_2(SO_4)_3$: 352 mg Fe(III); $Ca(OCl)_2$

Carbon Nanotube (CNT)-Based Hybrid Filter for POU Treatment

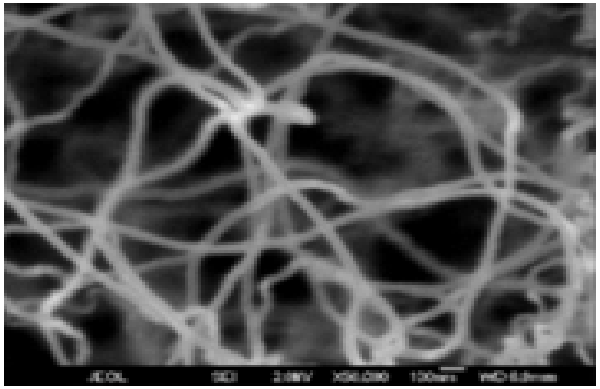
"These nanotubes are so beautiful that they must be useful for something. . .", Richard Smalley







CNT Hybrid Filter



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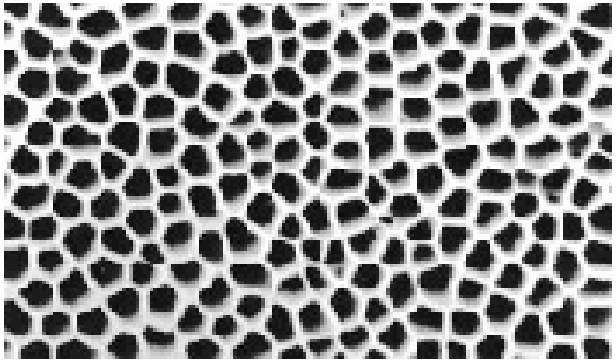
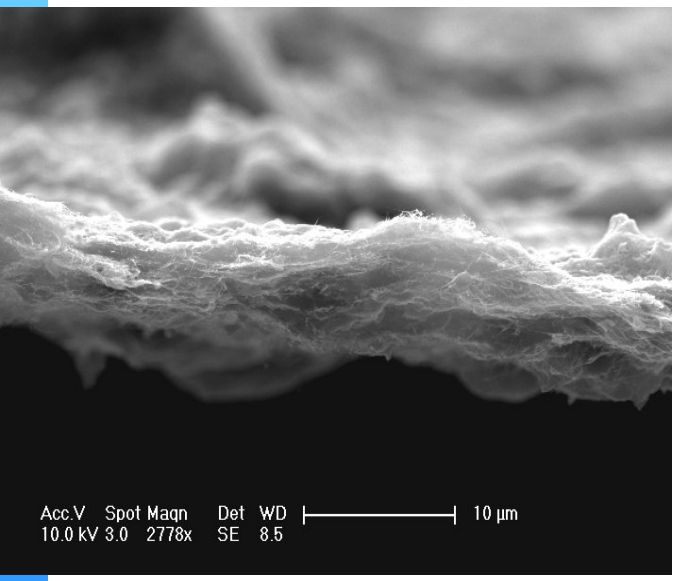
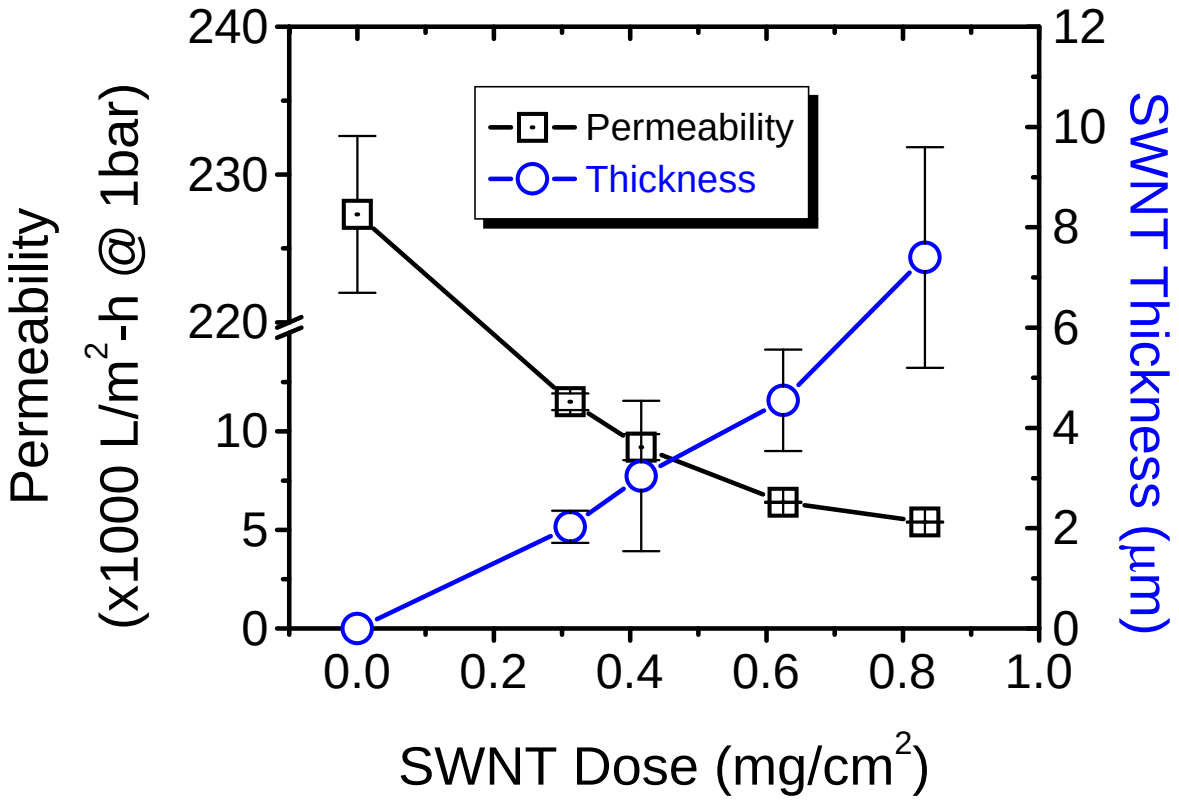


- Antimicrobial
- High permeability
- Very high surface area (adsorption, filtration)
- Can be regenerated at high temperatures/harsh conditions

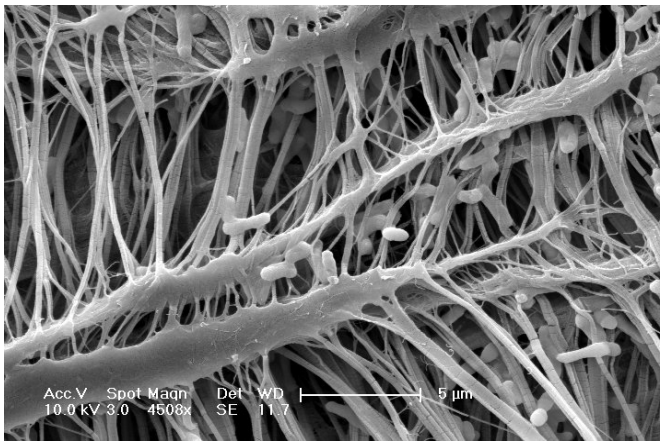
- High permeability
- Secondary barrier to pathogens
- Can be regenerated at high temperatures/harsh conditions

Characteristics of SWNT Filter

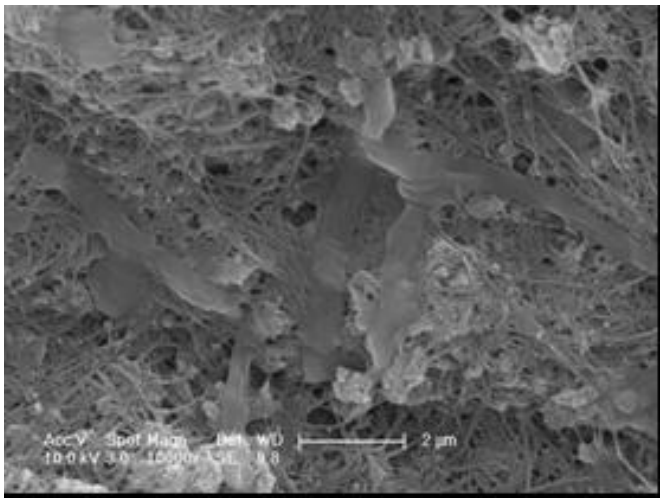




Complete Retention and High Inactivation of Bacteria



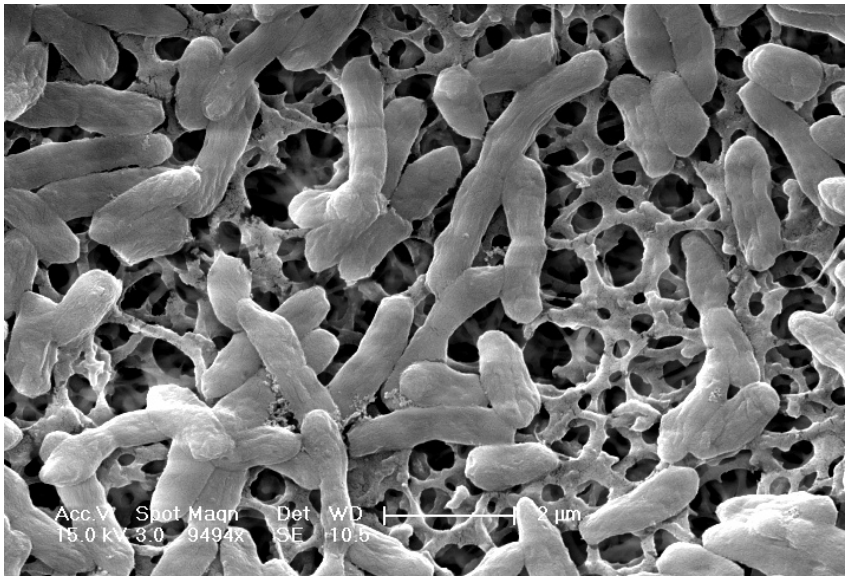
Base filter
(PVDF)



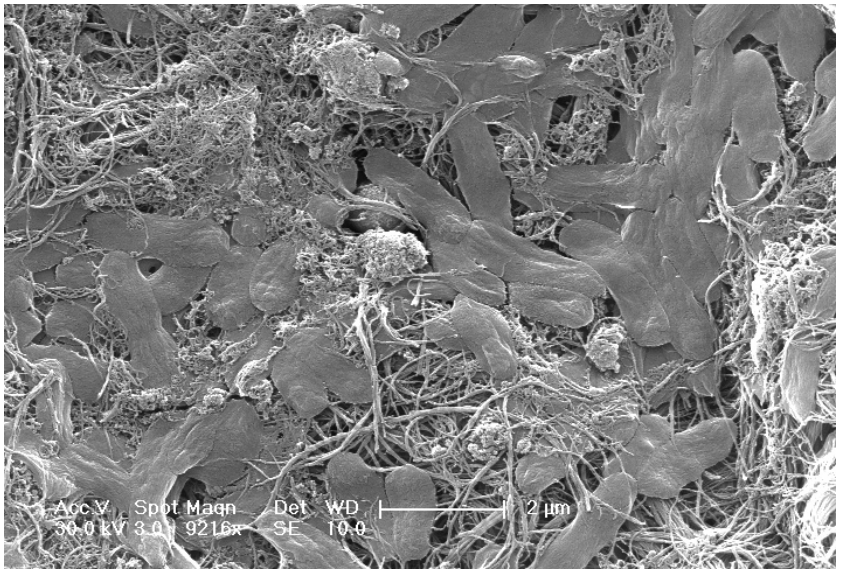
Hybrid
(SWNT layer)

- *E. coli* K12
- $N_0 \approx 5 \times 10^5$ cells
- pH 5.7
- 0.9 % NaCl
- 22 ºC
- Flow rate, 125 LMH

Severe Cell Membrane Damage

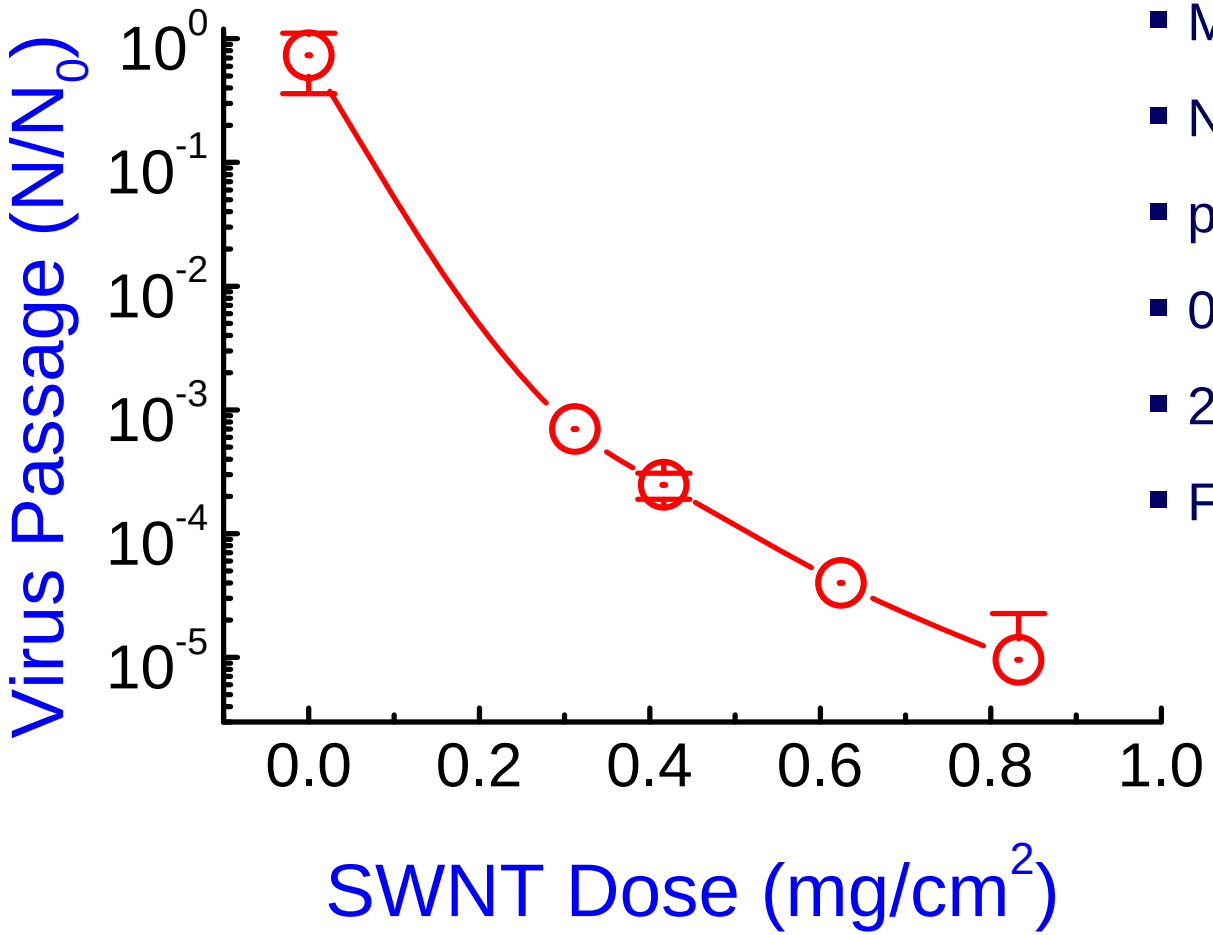


Control (without SWNT)



SWNT

Can Achieve Over 5 Log Removal of MS2 Viruses



- MS2 virus
- $N_0 \approx 1.5 \times 10^6$ virus
- pH 5.73
- 0.9 % NaCl
- 22 ºC
- Flow rate, 125 LMH

Sanitation!
Sanitation!
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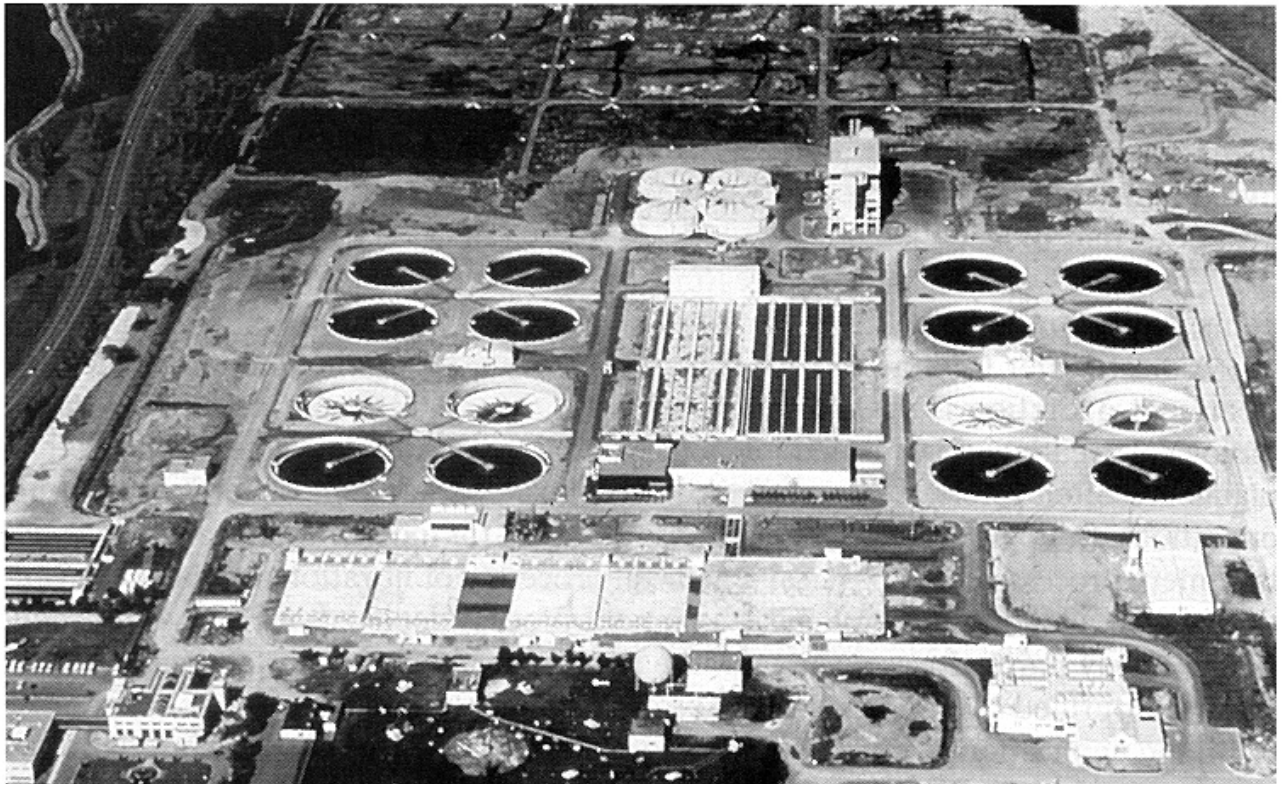
Centralized Treatment is not Realistic (Long-Term Goal)



Short Term: Decentralized Household Sanitation

Basic Latrine

VIP Latrine

Composting Latrine

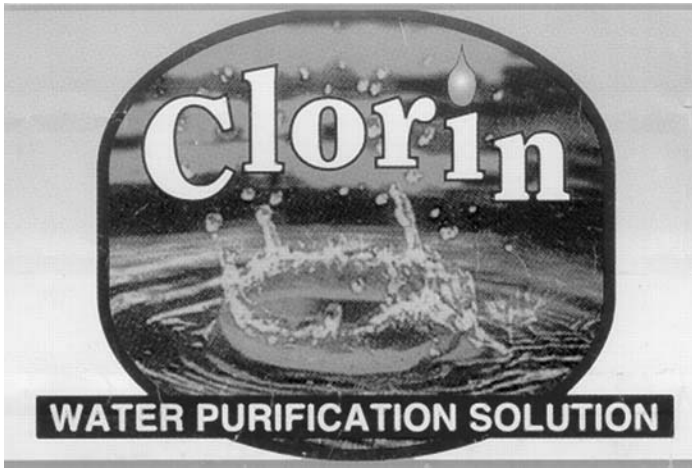
Super VIP Latrine

Closure

Mungu atupelekea mgonjwa

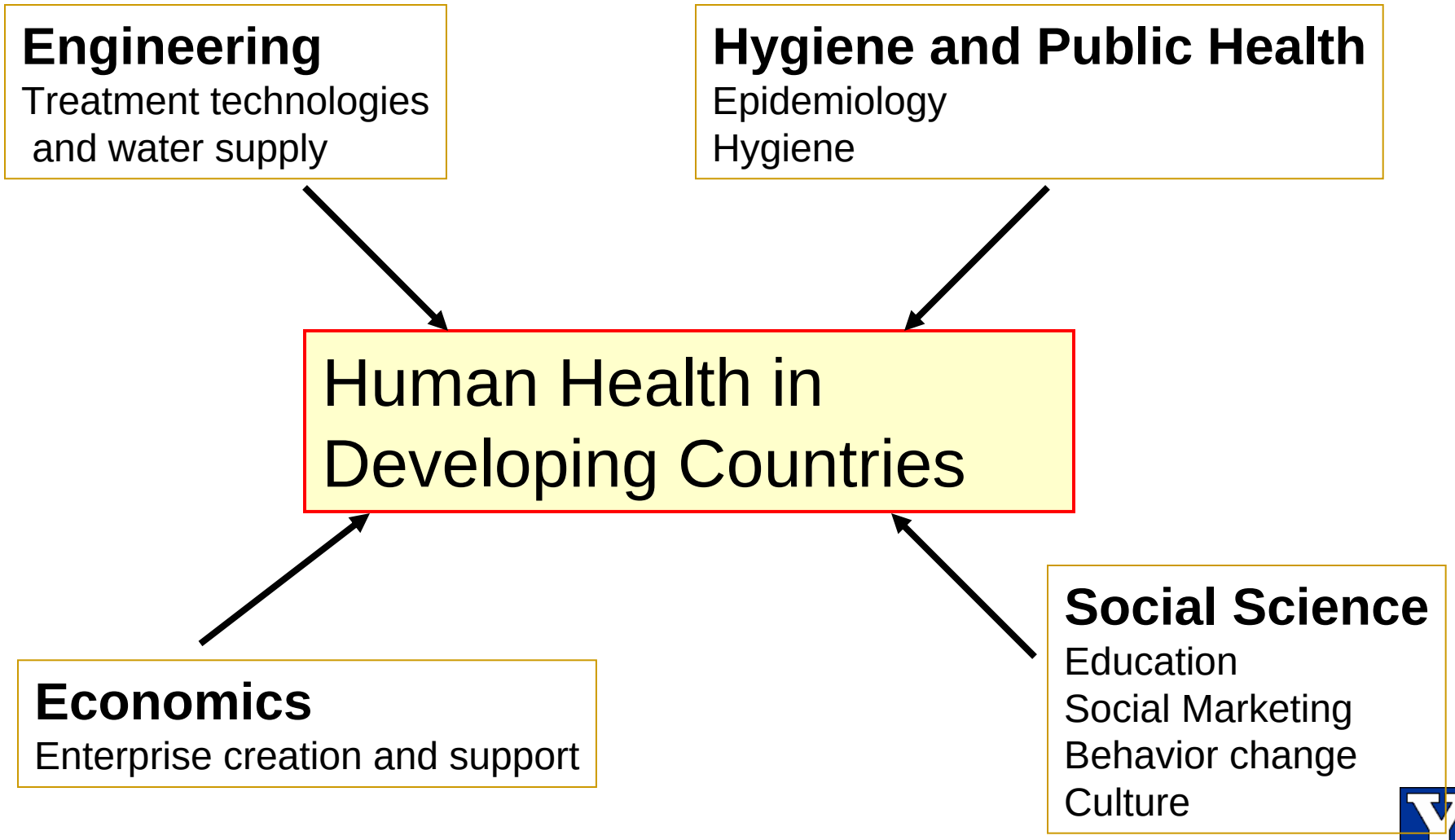
(in Swahili: "*God is the one that delivers us illness*")

Education, Social Marketing, and Promotion are Most Important



- Public health interventions must involve behavior changes
- The process by which new water treatment practices are promoted is as critical as the treatment process itself

Need for an Integrated Approach



Beyond Textbook Equations

- Value of local knowledge and wisdom
- Developing culturally, socially, and environmentally specific solutions

Culture, Education > **Engineering, Technology**