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LOCAL ACTION WITH INTERNATIONAL COOPERATION TO IMPROVE AND SUSTAIN WATER, SANITATION AND HYGIENE SERVICES

Adaptable drinking-water laboratory unit for decentralised testing in remote and alpine regions

A. Diener (Germany), A. Schertenleib, D. Daniel, M. Kenea, I. Pratama, M. Bhatta, M. Bhatta & S. Marks.

BRIEFING PAPER [2743]

Our project introduces an adaptable drinking-water laboratory unit to promote decentralised drinking-water quality testing in remote and alpine regions. We outline product-design and handling requirements for analyses in remote areas as a basis for the development of do-it-yourself setups that fill the gap between field test-kits and professional laboratory facilities. In a collaborative effort between international researchers and local water experts, a setup was developed in the alpine region of Mid-Western Nepal. The unit's main element, a solar-powered incubation system proved technically reliable, suitable for cold climates and easy-to-handle in mobile and stationary application. The setup can support the extension of water safety planning and water quality surveillance to so-far underserved rural or unreached remote regions. Long-term implementation will require a careful look at effective solutions for training, supervision, supply chains and integration into existing structures.

Introduction and Background

Safe management of drinking-water requires the initial assessment, regular verification and operational monitoring of microbial and chemical parameters. This paper outlines an adaptable laboratory unit for drinking-water quality testing. It is a result of a two-year collaboration between Nepalese practitioners and international researchers - with over 3000 processed water samples. The laboratory unit was designed to fill the gap between simple field-test kits and more sophisticated laboratories (Figure 1). Adaptable water quality testing facilitates are particularly lacking in rural communities, where 80% of the global population consuming unsafe water reside (Bain et al. 2014). Rural alpine regions of Nepal are precisely the areas suffering most from contaminated drinking-water supplies and, based on our project experience, also from a lack of water quality testing and risk-based management based on testing results

The Sustainable Development Goal (SDG) Target 6.1 calls on governments to facilitate access to safe water for the 1.8 billion people currently consuming faecally contaminated supplies by 2030 (Bain et al. 2014). The United Nations General Assembly recognised access to safe water as a human right and thus empowered consumers to request water quality improvements and certification. Hence, the safety of drinking-water must be verified and operationally monitored through regular water quality monitoring, the values which can also guide installation, treatment upgrades and day-to-day management of supplies (Ainsworth 2014; Amrose et al. 2015).

Our project focused on the water quality testing element that is most critical in terms of health risks and infrastructural requirements: microbial analysis for faecal contamination. The presence of faecal matter containing pathogens in drinking-water can cause diarrhoea, typhoid, polio and cholera; water-borne diseases that cause an estimated half million deaths annually. Laboratory protocols for microbial contamination call for rapid processing, strict hygiene measures and laboratory incubation under controlled temperatures (World Health Organization (WHO) 2014). Microbial parameters are known to be dynamic in time and space calling for reliable access to dependable (and affordable) testing facilities. In rural settings, water samples are usually transported in refrigerated containers to distant central laboratories or processed on-site with commercial field-test kits (MacDonald et al. 2016, WHO 1996).

Limited access to laboratory facilities and basic infrastructure are main factors for the underutilisation of drinking-water quality testing in rural areas. However, national regulations often require laboratories to comply with standard operating procedures or international standards as a precondition for water quality surveillance. Field-kits commonly used in remote areas are likely to be excluded. The WHO's Guidelines for Drinking-water Quality (WHO 1996) recommends at least one monthly sample for surveillance purposes for piped schemes serving less than 5000 people. This paper explores how decentralised water laboratory units can be set-up to support day-to-day water supply management, development of new water supplies and national water quality surveillance.

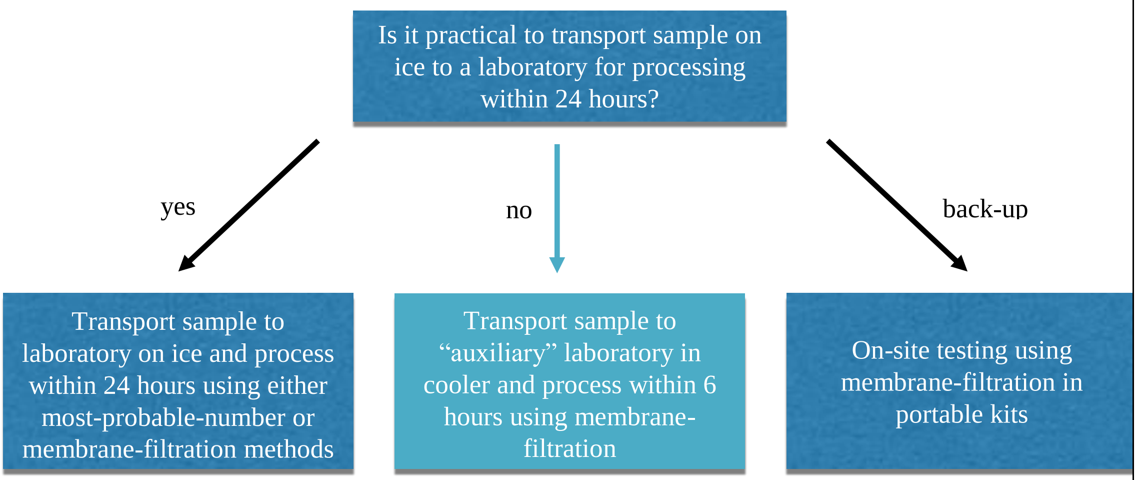

Figure 1. Water quality testing method depending on central laboratory access
Source: Adapted from World Health Organization 1997, page 64

Project and laboratory setup

Collaborative research project

The project was collaboratively set-up by two water research institutes (Swiss Federal Institute for Aquatic Science and Technology (Eawag), UNESCO-IHE Institute for Water Education), the water programme of a technical development agency (HELVETAS Swiss Intercooperation), and water supply practitioners in selected communities of Mid-Western Nepal. The project was funded by the Swiss Agency for Development and Cooperation (SDC) and led by Eawag's Water Supply and Treatment group in the Department of Sanitation, Water and Solid Waste for Development (Sandec). It was initiated after a review of water quality field-testing kits and upon request for advice on drinking-water treatment and testing by Nepalese water specialists.

Between 2014 and 2016, a three-phase research project on household water treatment, intermittency in piped-supplies and water safety plan review were conducted in selected districts of Mid-Western Nepal. It is a rural setting that represents the challenges of many underserved regions with inadequate transportation infrastructure, hindering timely access to distant national laboratories and grid-electricity largely unavailable. The International Energy Association's World Energy Outlook for 2016 stresses the low access to electricity in rural regions of developing countries. In Nepal, about 7 million of 27 million people remain without access to electricity, while in rural areas only 18% of households have access to improved water on their premises (IEA World Energy Outlook 2016,).

Requirements for laboratory equipment and consumables

The laboratory unit combines elements of field laboratory equipment with a solar-powered incubation system. During field missions, the laboratory unit was continuously reviewed, and incubator design and field procedures improved accordingly (Figure 2). The equipment was used both as a mobile laboratory transported by vehicle, mule or local carriers and as a stationary laboratory set-up adjacent to a rural health post. In collaboration with local water experts, the study team devised the following design criteria for a drinking-water laboratory unit for the alpine regions of Nepal:

- The incubator for microbial tests must reach and steadily maintain a standard incubation temperature (35 °C) with sufficient volume for 50 daily samples, and consuming a limited amount of energy (< 500 Watt-hours / day) at low ambient temperatures (5 °C).
- The electrical setup must be suitable for the permanent operation of the incubator and the periodic charging of water disinfection devices and hand-held probes. It must rely on renewable energy

(requirement by local community) and align with the common electrical setup in Mid-Western Nepal (12 volt direct current, 50 watt solar cells).

- The water sample collection process must meet hygienic requirements (100% negative controls) using an uninterrupted cooling chain that does not rely on refrigeration or ice, and transportation time must not have a significant impact on measured contamination levels.
- The laboratory setup must be adaptable to different consumable types or brands and microbial analysis methods, based on changing local requirements and/or supply chains.

The laboratory unit was set-up with the following basic equipment applicable for most microbial and physico-chemical testing purposes: A solar-voltaic array for electricity supply (50 Watt, 60 Ah), an incubator (self-assembled), a water sample processing set (membrane filtration set by DelAqua), insulated sample transport containers (locally available thermos units), a UV disinfection device (SteriPen™), and probes for physico-chemical parameters (various). This setup allowed the use of various consumable types, with basic consumables including: hand sanitiser (local products), laboratory gloves (non-sterile), record sheets and markers, calibration fluid (for physico-chemical testing equipment), and water sample bags (WhirlPak™). For membrane filtration in addition: filter membranes (45 µm pore size, 47 mm diameter), bacteria culture petri-dishes (compact dry plates), and methanol (disinfectant). Supply chains for laboratory consumables can be routed via pharmacies or health posts to guarantee proper handling and timely delivery.

Do-it-yourself incubation system

The authors addressed the gap between field-kits designed for occasional operation in remote areas and the professional setup of regional or central laboratories by combining elements of both setups into a do-it-yourself setup. The incubation system is amenable to different types or brands of microbial analysis consumables and supports testing of *E. coli*, *Enterococci*, *vibrio parahaemolyticus* and other common microbial contamination indicators. In principle, an incubator is simply an enclosed device with a controlled temperature level designed for optimal growth of bacteria cultures. A typical incubation temperature of 35° C is applicable for various microbial testing methods (Gruber et al. 2014). Except in regions with an ideal ambient temperature range (25-40 °C), incubators are necessary for culture-based microbial water analysis (Brown et al. 2011). Incubation at constant temperatures enables comparisons of microbial contamination levels in different places or points in time.

The incubator setup is based on an insulated chamber with a thermostat regulating the inside air temperature via heating units and ventilation for uniform temperature distribution. The heating units were split into a permanent and an auxiliary heater, the latter being connected to a manual switch to allow laboratory staff intervention in case of very low ambient temperature conditions or rapidly dropping temperatures (Figure 3). The incubator was designed for an electrical power of 6-9 Watts as compared to 30 Watts for similar-sized commercial systems with less insulation. The basic setup is applicable for ambient air temperatures between 5° and 35° C. The setup can be modified for use in colder environments with additional insulation and heat plates, or for warmer environments with simple cooling elements such as a Peltier device or thermoelectric cooler. The material costs for the construction of the incubator unit are estimated at around 100 US-Dollars depending on supplier choice.

Figure 2. Incubator prototypes (from left to right: 2014, 2015, 2016)

The energy supply was based on the typical solar-voltaic array available locally, with a 50 Watt solar panel, a battery charger and converter, and a deep-discharge battery (12 V, 60 Ah). A DC/DC voltage regulator was placed in-between the battery input and the active components (controller, fan) to guarantee a stable voltage of 12V and increased equipment lifetime. The converter also integrates a short-circuit protection for the active components in the case of damaged cables or defective heating foils.

The collection of water samples in mountainous and remote terrain encounters the challenges of a lack of electricity for refrigeration or ice production for cooling, as well as large distances between households and between water supply points for transport and access. Sampling made use of light-weight sterile bags (WhirlPak / ThioBag) and thermos containers for transport. Thermos containers were sterilised daily and filled with cool (below or around water sample temperature), sterilised water for each round of collection. This setup may not inhibit bacterial growth, but simulates a pro-longed residence of the sample in the water system or storage container. The maximum holding time between sample collection and processing by membrane filtration was set at 6 hours.

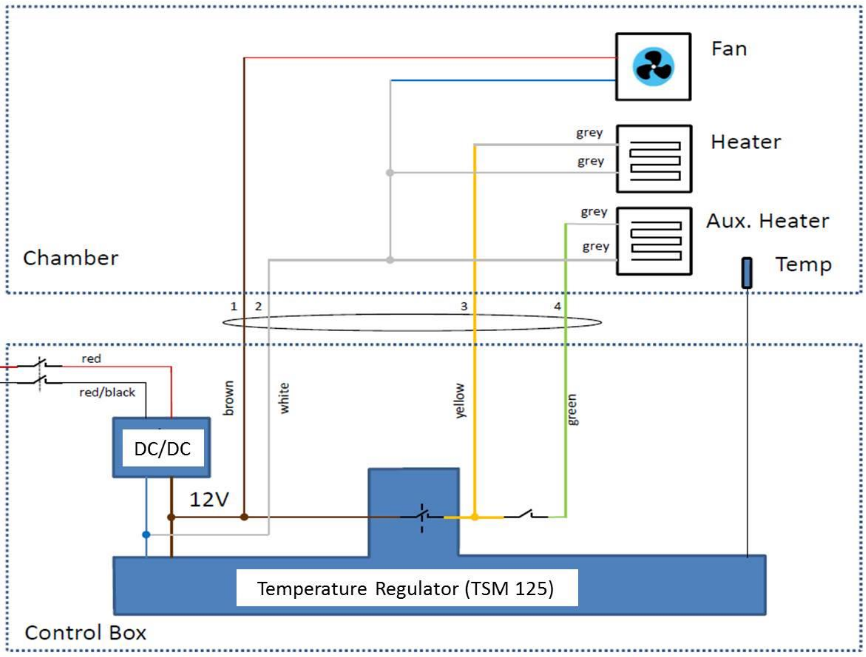

Figure 3. **Electrical wiring for a two-step temperature control of the incubator.**

Lessons learned

Technical laboratory functionality

The functionality of the incubator was monitored in an approach inspired by the guidelines for laboratories set by ISO 17025, using three temperature sensors (iButton) that temporally log the air temperature inside and outside the incubator. Special attention was paid to critical timespans during the 24 (or 48) hour incubation process: the opening and closing of the incubator door for placing and/or removing petri-dishes and the phases with the lowest or most rapidly dropping ambient temperatures. The first prototype observed temperature drops of up to 10 °C during early morning hours at ambient temperatures of around 0° C. Additional insulation minimised temperature drops in closed operation. The heat loss during loading of the incubator was minimised by a side-door design instead of the common top-loading setup often found in commercial incubation systems. Temperature fluctuations after opening (<1 minutes) were measured at a maximum of +/- 3 ° C with stabilised temperature levels within an hour. The temperature distribution within the incubation chamber was measured at around 1° C between the lowest and the highest sample. Overall, the solar-powered incubation system worked reliably throughout the three testing periods accounting for five months of field operation. On cloudy days with low solar radiation and during cold winter periods requiring maximum heating power, back-up batteries and/or auxiliary, non-electric heating may be required.

Training requirements and hygienic procedures

The laboratory unit was generally operated by experienced researchers. In an initial assessment of training requirements, the study team instructed two unskilled members of a rural community on water samples processing for microbial analysis and measurement of physio-chemical parameters. The two-day training proved sufficient for trainees operating the laboratory, however, on-site supervision was still required for quality control. Also, several community members were trained in water sample collection. In the process, the study team tested different procedures for water sampling. Minor mistakes in handling of water samples at the onset of the project caused field and laboratory blanks to be contaminated. These experiences reinforce previous research reporting that the validity of testing using even simplified laboratory setups or field kits largely depends on staff training and on- or off-site supervision (Crocker und Bartram 2014). It should be evaluated to what extent the training burden could be reduced by integrating the drinking-water laboratory unit into existing facilities where staff possess basic knowledge in laboratory operation. Decentralised setups may in many cases require the fostering of supply chains for laboratory consumables and spare-parts, and the setup of local disposal facilities with safety measures for hazardous materials such as bacteria cultures on used plates.

Integration of decentralised rural laboratories into national surveillance strategies

The setup of permanent drinking-water laboratories in remote and infrastructurally underdeveloped regions is clearly ambitious. A do-it-yourself setup may save investment and operating costs, but obviates neither the need for basic training and backstopping services, nor for an institutional integration of the drinking-water testing services. The trade-offs to comparable investments in infrastructure and health services are complex. On our study site, the tested water supply schemes were not consistently meeting drinking-water quality standards despite adhering to standard engineering practices for gravity-fed schemes and WHO’s water safety planning approach (World Health Organization 2014). In the development and day-to-day management of investigated schemes, water quality testing was not, or only partially, integrated. In some cases microbial testing had been conducted as a one-off analysis, as sometimes done for chemical tests with presence assumed to be reasonably constant over time. Especially in untreated water supply systems with possibly impacted seasonally by high surface run-off , one-off tests ignore the variable temporal and spatial distribution of microbial contaminants. In the studied region, the lack of local expertise and capacity for drinking-water quality monitoring limited potential public health benefits of drinking-water supply investments. In terms of financial sustainability, decentralised fixed laboratories in rural settings are relatively low-cost in operation, as salary levels are typically lower and sample transport distances are shorter as compared to urban laboratories (Crocker und Bartram 2014). Consumable costs remain comparable with urban laboratories, as the flexible laboratory setup allows for the use of different types and brands of microbial testing consumables. Local circumstances will determine to what extent savings in transportation and staff costs can off-set investments in laboratory equipment, consumable and maintenance costs.

Conclusion and outlook

The findings show how simplified laboratory units can be functional even under the challenging circumstances of remote, alpine regions. The drinking-water laboratory unit for alpine regions described here priortizes the adaptability required to facilitate access to safe drinking-water under circumstances of extreme climate conditions and inadequate infrastructure or technical capacities. This setup supports testing of various microbial indicators using a wide selection of consumables. Similar sized solar-voltaic arrays are available in many regions. Together with the microbial laboratory unit they make possible the integration of additional various tools for operational monitoring, for example rechargeable water-probes and spectrophotometers for turbidity or chlorine residual. The simplified setup that allows maintenance and repair in similar fashions as common electrical devices used in remote areas can contribute to the sustainability of water quality testing interventions in underserved regions. The laboratory units shall be points of departure for introducing not only decentralised water quality verification, but also operational monitoring both for day-to-day water parameter testing and regular inspections by small system operators. Before laboratory units establish as monitoring or surveillance facilities and water supply management professionalizes, the units can support awareness raising in communities having no previous water quality management experience. Additionally, in the context of SDG 6.1 new water supply schemes will be established, and decentralised laboratories can support the initial explorations of water sources in an area.

In a subsequent project, decentralised water laboratory units will be installed in several districts of Mid-Western Nepal to pilot access to water quality testing for community-managed piped water schemes as well as households. The project will evaluate how effectively and reliably the units can be installed and operated, serving as an integral element of water safety planning, supply management, and regional water quality surveillance.

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References

AINSWORTH, Richard (2014): Safe Piped Water Managing Microbial Water Quality in Piped Distribution Systems. The Netherlands: IWA Publishing. Retrieved from http://www.iwaponline.com/wio/2013/pdf/wio2013RF9781780405841.pdf

AMROSE, Susan; Burt, Zachary; Ray, Isha (2015): Safe Drinking Water for Low-Income Regions. In: *Annu. Rev. Environ. Resourc.* 40 (1), S. 203–231. DOI: 10.1146/annurev-environ-031411-091819.

BAIN, Robert; CRONK, Ryan; HOSSAIN, Rifat; BONJOUR, Sophie; ONDA, Kyle; WRIGHT, Jim et al. (2014): Global assessment of exposure to faecal contamination through drinking water based on a systematic review. In: *Tropical medicine & international health : TM & IH* 19 (8), S. 917–927. DOI: 10.1111/tmi.12334.

BROWN, J.; STAUBER, C.; MURPHY, J. L.; KHAN, A.; MU, T.; ELLIOTT, M.; SOBSEY, M. D. (2011): Ambient-temperature incubation for the field detection of Escherichia coli in drinking water. In: *Journal of applied microbiology* 110 (4), S. 915–923. DOI: 10.1111/j.1365-2672.2011.04940.x.

CROCKER, Jonny; BARTRAM, Jamie (2014): Comparison and cost analysis of drinking water quality monitoring requirements versus practice in seven developing countries. In: *International journal of environmental research and public health* 11 (7), S. 7333–7346. DOI: 10.3390/ijerph110707333.

GRUBER, Joshua S.; ERCUMEN, Ayse; COLFORD, John M., JR (2014): Coliform bacteria as indicators of diarrheal risk in household drinking water: systematic review and meta-analysis. In: *PLoS ONE* 9 (9), S. e107429. DOI: 10.1371/journal.pone.0107429.

INTERNATIONAL ENERGY AGENCY (2016): World Energy Outlook 2016. Paris, France. International Energy Agency. Retrieved from http://www.iea.org/publications/freepublications/publication/WorldEnergyOutlook2016ExecutiveSummaryEnglish.pdf

MACDONALD, Morgan C.; JURAN, Luke; JOSE, Jincy; SRINIVASAN, Sekar; ALI, Syed I.; ARONSON, Kristan J.; HALL, Kevin (2016): The impact of rainfall and seasonal variability on the removal of bacteria by a point-of-use drinking water treatment intervention in Chennai, India. In: *International journal of environmental health research* 26 (2), S. 208–221. DOI: 10.1080/09603123.2015.1089532.

WORLD HEALTH ORGANIZATION (2014): Water safety in distribution systems. Geneva, Switzerland: World Health Organization. Retrieved from http://apps.who.int/iris/bitstream/10665/204422/1/9789241548892_eng.pdf

WORLD HEALTH ORGANIZATION (1997): Guidelines for Drinking-water Quality. Vol. 2. 3rd ed. Geneva, Switzerland. World Health Organization.

Contact details

About the authors: Arnt Diener is a technical consultant for EAWAG and WHO focussing on drinking-water risk management and water safety planning in small systems. Dr Sara Marks is a group leader at EAWAG and coordinates international research programs on water supply and treatment in developing contexts. Ariane Schertenleib is a project officer at EAWAG and focuses her research on the impacts of water supply interventions in Africa and Asia.

Arnt Diener
An der Windmühle 4, 53111 Bonn, Germany
Tel: +49 176 646 446 91
Email: arnt.diener@outlook.com

Dr Sara Marks
Überlandstrasse 133, Dübendorf, Switzerland
Tel: +41 58 765 5631
Email: sara.marks@eawag.ch
www.eawag.ch/en/aboutus/portrait/organisation/staff/profile/sara-marks