



Tons of excreta and ways to treat them

U. Heinss and M. Strauss, Switzerland, S.A. Larmie, Ghana



IN MOST CITIES in developing or newly industrialised countries, collection, haulage and treatment of faecal sludges (FS) from latrines, aqua privies and septic tanks pose a multitude of problems.

Due to excessive haulage distances and to a lack of suitable treatment options, the sludges are normally dumped untreated within the shortest possible distance. To illustrate the quantitative aspect of the problem, e.g. Manila and Bangkok, where 65 per cent of the population are served by septic tanks, will have to deal daily with the haulage and treatment of 300 and 500 tanker loads, respectively, in the near future; i.e., when emptying services will have been improved (Veroy, Arellano and Sahagun 1994; Stoll 1995). Only in a few countries (e.g. Ghana, Thailand, Indonesia, and Argentina), purposely designed treatment plants exist to treat septage and nightsoil. In some countries (e.g. Botswana, Tanzania, South Africa), FS are added to the urban wastewater stream for co-treatment in wastewater treatment plants; generally waste stabilisation ponds (WSP). These are frequently overloaded and malfunctioning as they are not originally designed to receive the additional load.

Field research objectives

The lack of appropriate options for the treatment of faecal sludges (FS) in developing countries has lead SANDEC to

initiate an R+D project on selected FS treatment processes and technologies. The aim of the project is to provide planners and engineers with recommendations on the design of selected medium to low-cost treatment options. The recommendations will be based mainly on the results of field research conducted on full or pilot-scale treatment plants.

Faecal sludge characteristics and treatment objectives

High and low-strength FS

Faecal sludges may be classified into two broad categories (Heinss, Larmie, Strauss 1997): high-strength sludges from bucket privies or unsewered public toilets, and sludges of weak strength, such as septage. Table 1 lists the main characteristics of the two FS types based on a large number of reported values, as well as on our own observations.

Truncating FS into the two categories is important when selecting treatment processes e.g. for solids-liquid separation (sedimentation/ thickening; sludge drying beds), or for pond treatment.

Ammonia – the tricky variable

Faecal sludges may contain very high ammonium (NH_4) and, hence, also ammonia contents (NH_3) which may be toxic to algae at $> 20 \text{ mg/l}$ levels. This is of particular relevance to the treatment of FS in pond systems where the development of facultative pond conditions and growth of algae are desirable. We recommend the maximum allowable NH_4 concentration in the influent to a facultative pond not to exceed 400 mg/l for temperatures of $25 - 28^\circ\text{C}$ and $\text{pH } 7.5 - 8$. At lower temperatures, the value may be increased. According to the table above, septage may thus often be treatable in facultative ponds, whereas high-strength FS would have to be diluted first (e.g. by co-treating it with domestic wastewater). NH_3 may also hinder anaerobic processes if occurring at excessive concentrations. Specific field research is needed to determine threshold limits and conditions under which this may occur.

BOD – a reliable design variable?

BOD, routinely used in pond design, is difficult to be determined reliably for faecal sludges. BOD bottles should be continuously stirred or periodically shaken over the entire 5-day testing period, particularly when analysing FS

Table 1. Important characteristics and classification of faecal sludges

Item	High-strength	Low-strength	Sewage as comparison
Example	Public toilet or bucket latrine sludge	Septage	Tropical sewage
Characterisation	Highly concentrated, mostly fresh FS; stored for days or weeks only	FS of low concentration; usually stored for several years	
COD	20, - 50,000 mg/l	$< 10,000 \text{ mg/l}$	500 - 2,500 mg/l
COD : BOD	2:1 - 5:1	5:1 - 9:1	2:1
$\text{NH}_4\text{-N}$	2, - 5,000 mg/l	$< 1,000 \text{ mg/l}$	30 - 70 mg/l
TS	$\geq 3.5 \%$	$< 3 \%$	$< 1 \%$
Helminth eggs	20, - 60,000 /l	$\leq 4,000/l$	300 - 2,000 /l

from public toilets or pit latrines rich in settleable solids. BOD analysed in stirred bottles is on the average 1.4 times higher than the BOD determined in unstirred bottles. BOD may also be determined via COD analyses. Reported and measured COD/BOD ratios are listed in Table 1.

Treatment objectives

The decisive criterion in establishing treatment objectives is whether the effluent and treated solids from the faecal sludge treatment plant (FSTP) are to be discharged into the aquatic or the terrestrial environment, or whether they are meant for agricultural or aquacultural use. Variables such as COD or BOD and NH₄ are of prime importance for discharge into receiving waters. If treated FS is to be reused, hygienic characteristics such as helminth eggs used as parasite indicators, and faecal coliforms as bacterial indicators, are the key variables.

Furthermore, nitrogen and heavy metals are important criteria: compared to phosphorus, nitrogenous compounds are not retained/stored in the soil matrix. Therefore, groundwater will be contaminated by nitrogenous compounds if the use of FS exceeds the plants' nitrogen requirements. Septage collected from cottage or larger scale industrial premises may contain heavy metals. They will accumulate in soils and plants. Recommended accumulation tolerance limits must be taken into consideration (U.S. EPA 1984). Effluent and plant sludge quality guidelines for selected variables are listed in Table 2.

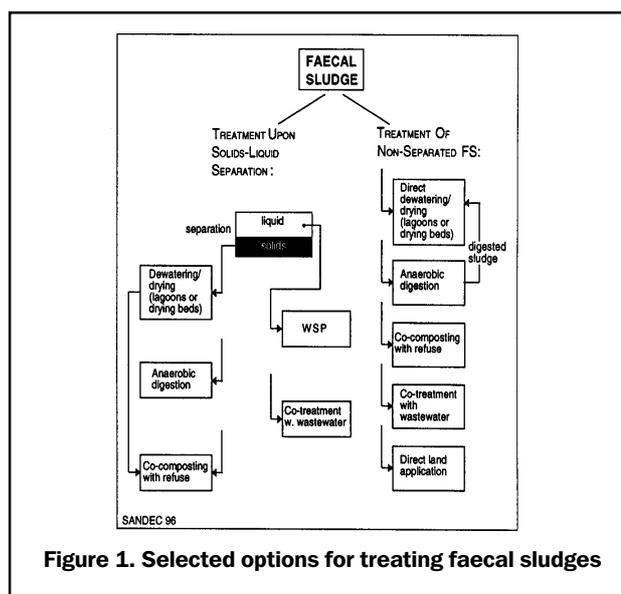


Figure 1. Selected options for treating faecal sludges

Treatment options

Current focus in field research

Figure 1 offers a selection of faecal sludge treatment options which may be composed of medium to low-cost technologies, especially for developing and newly industrialised countries (Strauss and Heinss 1995). The selection is not exhaustive as more sophisticated technologies may prove feasible in specific situations.

The following treatment processes and technologies are currently being investigated by SANDEC and its partners in Ghana (Water Research Institute), Thailand (Asian Institute of Technology) and the Philippines (University of the Philippines/ National Engineering Centre):

- Solids-liquid separation, viz.:
 - Sedimentation/thickening
 - Sludge drying beds (unplanted and planted)
- Anaerobic ponds
- Facultative ponds (conventional and with attached-growth media)
- Land treatment/soil reclamation

To date, recommendations for preliminary design have been elaborated for solids-liquid separation processes, anaerobic ponds, facultative ponds, and for options combining these processes. In addition to these field-tested options, recommendations have been formulated for the co-treatment of FS with municipal wastewater in waste stabilisation ponds and in activated sludge plants. Field research comprising septage treatment by planted sludge drying beds, attached-growth facultative ponds, and soil reclamation using septage have only recently been initiated.

Selection of treatment options

Low-strength (e.g. septage) and mixtures of low and high-strength FS should be subjected to solids-liquid separation

Table 2. Suggested effluent and plant sludge quality guidelines for the treatment of faecal sludges (Heinss, Larmie, Strauss 1997; WHO 1989; Xanthoulis and Strauss 1991)

	COD [mg/l]	NH ₄ -N [mg/l]	Helm. eggs	Faec. coliforms [No./100 ml]
A: Liquid effluent				
<i>Treatment for discharge into receiving waters:</i>				
• Seasonal stream or estuary	≤ 300-600	10-30	≤ 2-5/1	≤ 10 ⁴
• Perennial river or the sea	≤ 600-1,200	20-50	≤ 10/1	≤ 10 ⁵
Treatment for reuse				
• Restricted irrigation	n.c.	1)	≤ 1/1	≤ 10 ⁵
• Vegetable irrigation	n.c.	1)	≤ 1/1	≤ 10 ³
B: Treated solids				
• Use in agriculture	n.c.	n.c.	≤ 3-8/g TS	Safe if egg standard level is met
n.c. - not critical				
1) Nitrogen loads not to exceed the crops' requirements of 100 - 200 kg N/ha-year.				
2) WHO 1989 3) Xanthoulis and Strauss 1991				

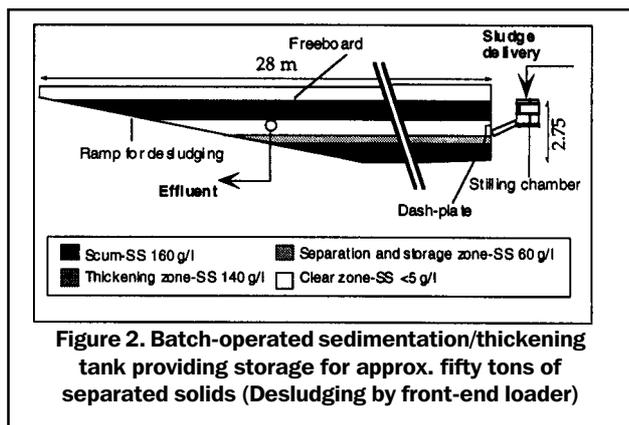


Figure 2. Batch-operated sedimentation/thickening tank providing storage for approx. fifty tons of separated solids (Desludging by front-end loader)

prior to pond treatment (high-strength sludges are hardly or not at all conducive to solids-liquid separation). This is likely to lead to considerable land savings as compared with direct pond treatment. Furthermore, technical and operational difficulties associated with the emptying of large quantities of separated solids from primary ponds could be avoided.

High and low-strength sludges should be treated separately in places where significant amounts of high-strength sludges are produced (e.g. from unsewered public toilets or from bucket latrines).

Pond treatment of *high-strength, rather fresh FS* is not recommended due to the reasons outlined above and possible ammonia (NH₃) toxicity problems. Anaerobic digestion with biogas utilisation followed by sludge drying beds may constitute a technically feasible option. Co-composting with e.g. municipal refuse (LaTrobe and Ross 1992), wood chips or sawdust may offer another alternative. Finally, high-strength FS if produced in relatively small quantities may be co-treated with low-strength sludges (as practised e.g. in Accra, Ghana) or with wastewater.

Recommendations for preliminary design

Solids-liquid separation – sedimentation/thickening

Batch-operated, non-mechanised FS settling/ thickening tanks might be the option-of-choice where continuously operated settling tanks equipped with mechanical sludge scraping installations may not be appropriate.

Annoh and Neff (1988) and Annoh (1989; 1994) have conceived and implemented batch-operated FS settling/

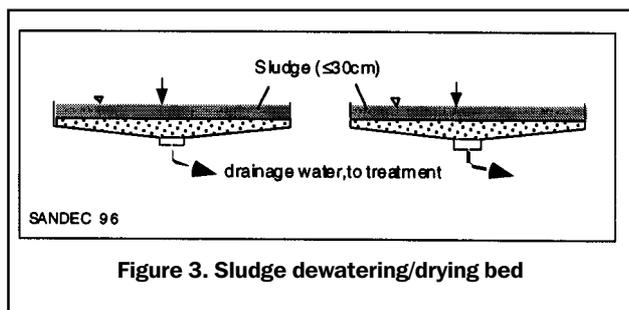


Figure 3. Sludge dewatering/drying bed

thickening tanks in Accra (Ghana). The tanks are accessible and can be emptied by front-end loaders to remove the separated solids. Figure 2 shows an improved version of the tank which comprises FS loading at the deep end and effluent draw-off near the shallow end (Heinss, Larmie, Strauss 1997).

The required storage volume for the separated solids is the decisive design variable for batch-operated FS settling/thickening tanks, in contrast to wastewater sedimentation tanks which are designed on the basis of the liquid and solids surface loading rates. Guidance on tank design and expected contaminant removals in the liquid fraction are presented in Figure 5.

Solids-liquid separation – unplanted sludge drying beds

Drying beds are or have been widely used throughout Europe and North America for dewatering sludges from wastewater treatment plants. Similar to lagoons, drying beds also require much space. Therefore, in many industrialised countries, this treatment option had to be replaced by less land-intensive dewatering processes such as chemical-aided centrifuging or filter pressing.

In unplanted sludge drying beds, application or loading depths should amount to max. 30 cm as shown in Figure 3. With solids loading rates of 100-200 kg TS/m².yr., 40 per cent TS content in the dewatered sludge may be attained within 8-12 days. The dewatering/drying rate is dependent on the type of sludge and its solids content, on weather conditions, loading rate, application depth, and on the operating 'age' of the bed. The hygienic quality of the dewatered or dried sludge (best expressed by the residual concentration of nematode eggs) is dependent on the combined effect of time, dryness and temperature.

Table 3. Comparison of the land area required for settling/thickening vs. drying bed treatment for solids/liquid separation of faecal sludges

	Attainable TS %	Assumed loading cycle	TS loading kg TS/m ² .yr	Required area m ² /cap. ¹⁾
Sedimentation/thickening tank	≤ 14	8-week cycle (4 weeks loading + 4 weeks resting; 6 cycles per year); two parallel settling tanks	1,200	0.006
Sludge drying bed (unplanted)	≤ 70	10-day cycle (loading-drying-removing; 36 cycles per year)	100 - 200	0.05

1) Assumed parameters: FS quantity = 1 litre/cap.day; TS of the untreated FS = 20 g/l

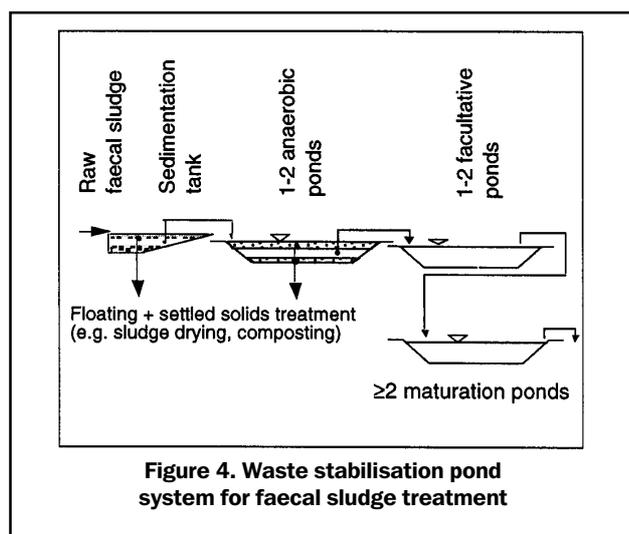


Figure 4. Waste stabilisation pond system for faecal sludge treatment

Sedimentation/thickening vs. drying beds

Table 3 contains the per capita surface area required for the two solids/liquid separation processes described above, viz. sedimentation/ thickening and drying beds (Heinss, Larmie, Strauss 1997). A sedimentation/thickening tank requires a much smaller area (approx. ten times) to treat FS than a sludge drying bed. However, FS treatment in dewatering/drying beds may yield a sludge product with a TS content ranging from 25-70 per cent after 10 days of drying. The solids separated in settling/ thickening tanks may be thickened to TS contents of ≤ 15 per cent only, and require further dewatering or co-composting. Since the COD, SS (suspended solids) and helminth egg concentrations in the effluent from drying beds are significantly lower than in the effluent of sedimentation/thickening tanks, they require less polishing treatment.

Complete helminth egg inactivation may be achieved if the sludges are allowed to dry for 10-12 months at water contents > 5 per cent. Egg survival periods are greatly reduced by sun drying to water contents < 5 per cent, below which nematodes are unlikely to survive.

The drained liquid will amount to 50-80 per cent of the raw sludge volume loaded into the beds. Substantial reductions of suspended solids (≥ 95 per cent), COD (70-90 per cent) and helminth egg counts (100 per cent) are achieved in the percolating liquid. Inorganic nitrogen ($\text{NH}_4\text{-N}$; $\text{NH}_3\text{-N}$) removal ranges from 40-60 per cent. The drained liquid may then be treated in waste stabilisation ponds.

Stabilisation pond (Lagoon) treatment with preceding solids-liquid separation

Waste stabilisation ponds (WSP) present a low-cost, potentially sustainable technology with increasing worldwide application in treating liquid and semi-liquid waste. Substantial knowledge has been accumulated in recent decades on the design and operation of WSP schemes treating wastewater (Mara and Pearson 1986; Mara et al. 1992). However, scarcely any R&D work on pond systems treating faecal sludge has been done so far.

The authors are aware of the existence of separate pond treatment of faecal sludges (septage mainly) currently

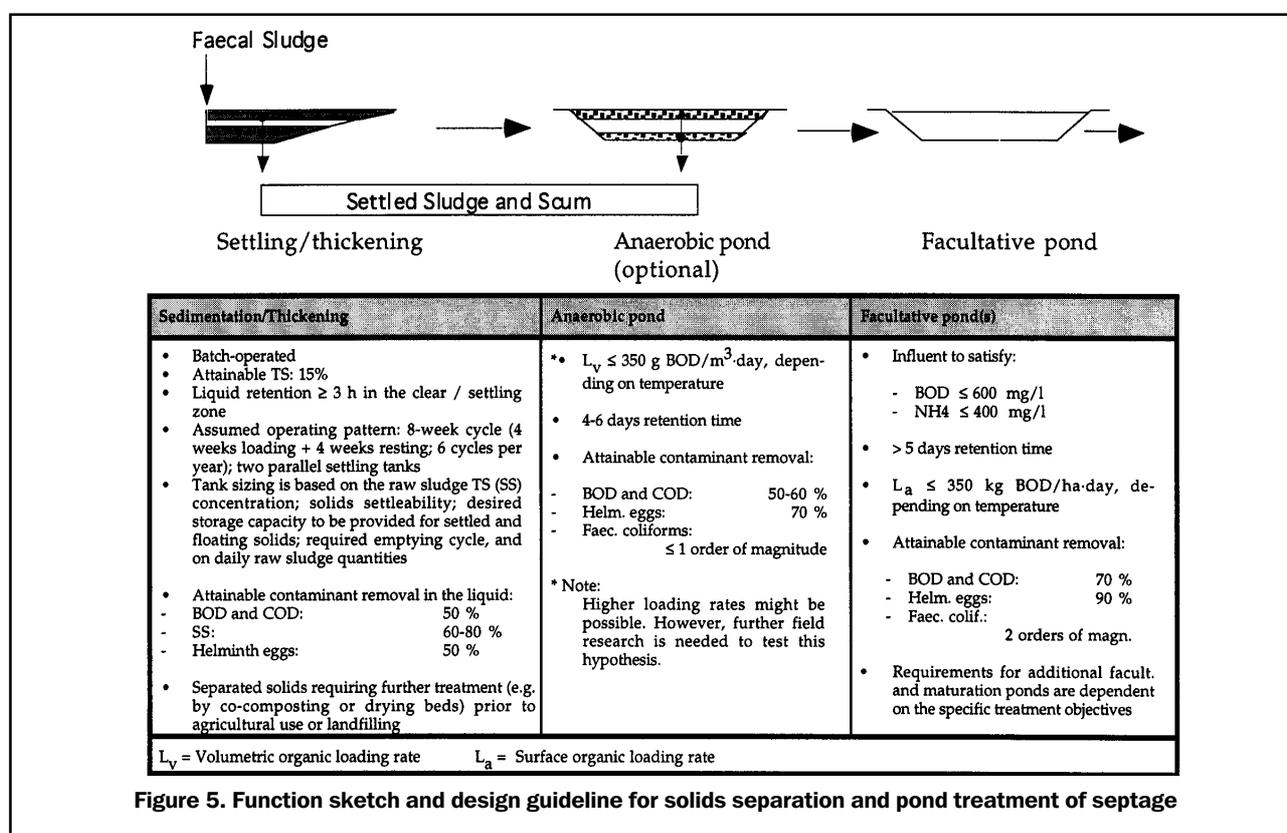


Figure 5. Function sketch and design guideline for solids separation and pond treatment of septage

being practised in Indonesia, Ghana, Benin, Argentina, and the United States.

Figure 4 is a functional sketch of a pond system treating presettled septage. Figure 5 provides a *design guidance* for treating *septage* by settling/thickening followed by an anaerobic/facultative pond system in warm climates (Heinss, Larmie, Strauss 1997). The recommendations are based on field research conducted by the Ghana Water Research Institute and SANDEC at a full-scale FSTP in Accra, and on related literature.

Co-treatment with wastewater in waste stabilisation ponds

Where waste stabilisation ponds (WSP) treat municipal wastewater, the pond systems are often used to co-treat faecal sludges.

Organic loading rate, solids load and ammonium/ammonia nitrogen concentrations are the critical variables (Heinss, Larmie, Strauss 1997). The guidance given above for separate FS treatment can also be applied to co-treatment.

Planning aspects for faecal sludge management: centralised vs decentralised treatment

The haulage of relatively small faecal sludge volumes (5-10m³ per truck) through congested streets over long distances in large urban agglomerations is not sustainable neither from an economic nor from an ecological viewpoint. New concepts of excreta collection, transport and treatment will, therefore, have to be developed in conjunction with sanitation systems adapted to the varying socio-economic segments of urban populations.

Faecal sludge haulage volumes and mileage are to be minimised. Planning and installing small to medium-sized decentralised FS treatment plants could contribute to easing the haulage problem. Such a decentralised treatment system may consist e.g. in faecal sludge dewatering and subsequent treatment and discharge (or reuse) of the separated liquid. Assuming that the dewatering process (e.g. by sludge drying beds) yields a reduction in water content from 98 per cent to 75 per cent, the dewatered sludge volume to be transported would be 12 times smaller than the raw FS volume. Compared to wastewater treatment, the advantage of FS treatment is its adaptability to any type of topography.

References

ANNOH, C., 1989 and 1994, *Project Designs for the Koforidua and Teshie (Accra) Faecal Sludge Treatment Plants*. Unpublished documents.
 ANNOH, C., and NEFF, R., 1988, Personal communication.
 DE SALES, L., 1997, *Land Reclamation Using Septage*. University of the Philippines - National Engineering Center. Interim field research report. Unpublished.

HEINSS, U., LARMIE, S.A., STRAUSS, M., 1997, *Anaerobic and facultative Pond Systems for the treatment of Septage and Public Toilet Sludges in Tropical Climate - Lessons Learnt and Recommendations for Preliminary Design*. EAWAG/SANDEC. To be published.
 MARA, D.D., and PEARSON, H., 1986, Artificial Freshwater Environment: Waste Stabilisation Ponds. In: *Biotechnology* (Rehm and Reeds, eds.). VCH Verlagsgesellschaft, Weinheim, Germany.
 MARA, D.D., ALABASTER, G.P., PEARSON, H.W., MILLS S.W., 1992, *Waste Stabilisation Ponds*. Leeds: Lagoon Technology International Ltd.
 MINISTRY OF PUBLIC WORKS, GOV. OF INDONESIA, 1992, *Guidelines for the Survey and Design of Faecal Sludge Treatment Plants (Pedoman Survey Dan Perencanaan Instalasi Pengolahan Lumpur Tinja)*. In Indonesian. Unpublished English translation.
 STALDER, I., 1996, *BOD Analyses of Accra Septage and Public Toilet Sludges*. Internal Report, SANDEC.
 STOLL, U., 1994, Master Plan on Treatment and Disposal of Sewage and Nightsoil Sludges Including Oil and Grease Residues for Bangkok Metropolitan. In: *Proceedings, Workshop on Management of Sewage and Nightsoil Sludges: Treatment, Reuse and Disposal*. Bangkok, 18-19 October.
 STRAUSS, M., and HEINSS, U., 1995, Faecal Sludge Treatment. *Sandec News* No. 1, May 1995, Duebendorf/Switzerland: EAWAG.
 U.S. EPA, 1984, Handbook: *Septage Treatment and Disposal*. EPA 625/6-84-009, U.S. Environmental Protection Agency, Center for Environmental Research Information, Cincinnati, Ohio.
 VEROY, L.S., ARELLANO, F.L., SAHAGUN, V.A., 1995, Septage Management Plan for Metro Manila. In: *Asia Pacific Regional Water Supply Conference Exhibition*. Manila, 6-10 November.
 WHO, 1989, *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture*. Report of a WHO Scientific Group. Technical Report Series 778. WHO Geneva.
 XANTHOULIS, D., and STRAUSS, M., 1991, *Reuse of Wastewater in Agriculture at Ouarzazate, Morocco* (Project UNDP/FAO/WHO MOR 86/018). Mission reports.

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