Effluent and Sludge Management in Yemen

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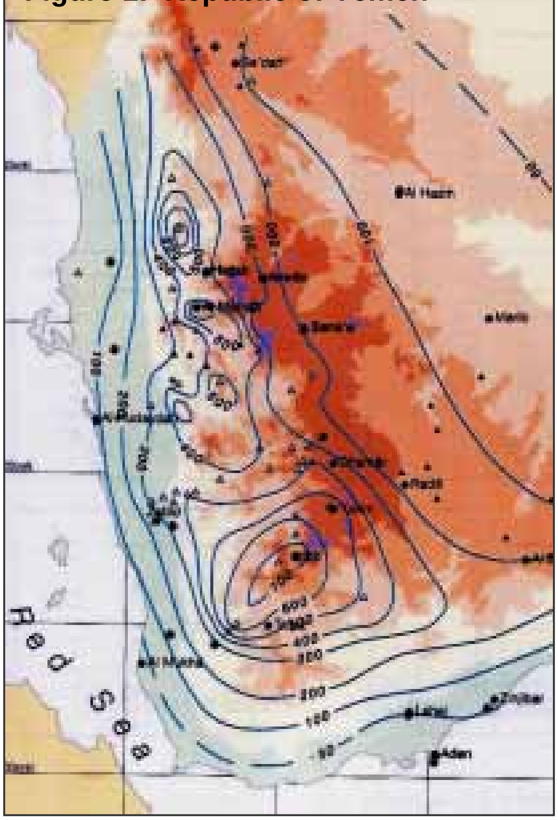
Abstract

Yemen has rapidly declining water resources and high incidence of water-borne diseases. Significant improvements to public health have been achieved in recent years through the construction of sewerage systems and wastewater treatment plants in some towns, but none of the wastewater projects have considered how effluent and sludge should be managed safely. This paper describes the strategy, now being developed in Yemen by MHW Arabtech Jardaneh, to achieve sustainable reuse of effluent and sludge, by adopting simple and pragmatic measures that ensure maximum recovery of the resource value of wastewater and protection of human health, within the limited financial resources available.

1. The Need for Effluent and Sludge Reuse

Yemen is a water-scarce country with a rich natural environment and agricultural diversity due to its varied terrain and climatic conditions. The natural resources are the basis of the national economy but the depletion and degradation of these is undermining sustainable development and Yemen is facing a water crisis. Figure 1 shows the principal towns, topography and rainfall in the most populated and productive western part of Yemen.

Figure 1: Republic of Yemen



The annual renewable water resources in Yemen are estimated at 2.5 billion m^3, but this falls well short of the current annual consumption of 3.4 billion m^3, a deficit approaching 1 billion m^3/year. This is due to the rapid expansion of groundwater exploitation for agricultural irrigation since the 1980s, resulting in aquifers being depleted at a much faster rate than natural recharge. This is exacerbating an already difficult situation for potable water supplies. At the present rate of consumption, fresh groundwater resources may be exhausted in 50 – 100 years in some regions, and as little as ten years in the Sana'a basin where groundwater decline is the greatest at up to 8 m per year.

Annual per capita water availability in Yemen has progressively fallen from 1,098 m^3 in 1955, to 460 m^3 in 1990 to a current level of 137 m^3, and could fall to 66 m^3 by 2026. Compared with the average for the MENA region of 1,250 m^3/day or the global average of 7,500 m^3/day, the amount water available per capita in Yemen is amongst the lowest in the world.

With agriculture consuming the most water (over 90%), only 40 l per capita per day remains on average for domestic consumption, well below the level regarded as the minimum necessary for human needs. Public health and clean water supplies are also at risk from the poor provision of sewage collection and treatment systems. Currently, only 57% of the population has public water supply and only 6.2% have sewerage, mostly in the urban centres.

These difficult conditions are not going unchallenged. Prior to, and since the reunification of Yemen in 1990, there have been numerous development programs in all sectors involving many international donor organisations. Recent important developments in the water and environment sectors have been the adoption of water and environmental laws; the creation of a combined Ministry of Water and Environment (MWE); and the progressive decentralisation of the water supply and sanitation services. There is an ongoing programme of rehabilitation and installation of water supply and sanitation systems in the cities and provincial towns, and Millennium Development Goals sets targets of halving the unserved urban population by 2015.

A consolidated strategy, action plan and investment program has recently been devised as the National Water Sector Strategy and Investment Program (NWSSIP, May 2004) for the water sector as a whole, addressing water resource management, urban and rural water supply and sanitation, irrigation and the environment, with an investment program of $1.54 billion for 2005-2009.

The provision of wastewater treatment inevitably results in the production of treated effluent and sludge, and these products should be regarded as valuable resources for agricultural irrigation and soil fertilisation, particularly under the conditions in Yemen. The current water-scarce conditions emphasise the need and urgency of reusing all treated wastewater, and the NWSSIP considers reuse as a means of substituting fresh water resources. This raises new issues for the management and control of effluent and sludge that hitherto have not been addressed in Yemen at national or local levels. While it has been stated government policy for some years to reuse effluent as a resource substitution for agricultural irrigation, there has been no clear strategy, particularly in relation to institutional responsibilities, appropriate legislation and practical knowledge of the ways and means of realising the resource value of effluent and sludge in a sustainable and safe manner. Standards for effluent reuse have been adopted, based on WHO and FAO, but the means of compliance, both institutionally and practically, is absent. So far, the issues relating sludge quality and control have been ignored.

There are few laboratories in Yemen capable of analysing the comprehensive list of parameters required by the effluent reuse standards. Since heavy industries are absent from all catchments, heavy metal concentrations in effluent and sludge are trivial, but the major challenge is ensuring that the microbiological quality of effluent and sludge is suitable for the reuse conditions, due to the high prevalence of enteric diseases in the population. Most WWTPs, even the most recent, are unlikely to achieve the microbiological quality standards necessary for unrestricted reuse.

Through the German Financial Co-operation with the Republic of Yemen, the general and specific issues arising from the need for managed reuse of treated effluent and sludge in Aden, Amran, Hajjah, Ibb and Yarim are addressed through a feasibility study, being undertaken by MWH Arabtech Jardaneh. While providing specific solutions for these five towns, this study will also provide the strategic and practical framework on which the management of effluent and sludge reuse in other towns in Yemen can be based.

2. The Potential Benefits of Effluent and Sludge Reuse

Effluent and sludge must be treated and managed appropriately to avoid potentially adverse impacts on the environment and human health, so that the resource value of using these products can be realised safely. The use of effluent and sludge must also be practicable and economic to ensure operational reliability and affordability under the local conditions.

The use of effluent and sludge has a number of direct and indirect benefits. Agriculture can utilise lower quality water than that required for potable purposes, and so effluent reuse for crop and tree irrigation can release precious clean water resources for more sensitive uses. In many countries, there is a shortage of animal manure traditionally used to maintain soil fertility. Sludge (and other organic wastes) can have a strategic role in soil management and conservation, to enhance soil productivity and to help control the loss of soil through erosion, an important issue in Yemen.

Both effluent and sludge contain nutrients that have direct benefits for the farmer by increasing crop yields and cropping intensity. Traditional rain-fed crop production is low yielding and high risk, limiting cropping to the rainy season, but the continuous flow of effluent allows reliable cropping throughout the year. Fertiliser consumption in Yemen is low, applied only to high value irrigated crops, and agricultural improvements are slow to be adopted, largely due to traditional land tenure conditions. The nutrient content of effluent and sludge can provide a low cost means of enhancing farm profitability as well as allow import substitution of both fertiliser and food. Although this will be small at the national scale, this will be important at the local level.

Because of this, demand for effluent and sludge is likely to be high where the benefits are realised and this may make it feasible for the water utilities to charge farmers for supplies, thus generating revenue. Also, agricultural diversification and forestry may be possible, providing rural development opportunities arising from suitably developed and focused effluent and sludge management strategies.

The agronomic values of treated effluent and sludge are well recognised internationally, and reuse in agriculture is usually the most sustainable option. However, the whole process must be considered holistically, encompassing wastewater quality, treatment and reuse/disposal options, and with a long-term view to potential impacts and overall sustainability. This process also necessarily requires appropriate policies, strategies, legislation and institutional structures with adequate resources for implementation and control, so that the maximum benefits from effluent and sludge reuse can be realised at the lowest cost whilst protecting the environment and human health.

3. Wastewater Production and Treatment

Wastewater problems occur when communities expand to the point that the natural assimilation capacity of the environment cannot deal with traditional methods of disposal. Most towns in Yemen have grown very rapidly since the first Gulf War due to the return of migrant workers and refugees, and this resulted in rapid degradation of water quality from the existing town wells. This situation was exacerbated where piped water systems were installed, resulting in higher water consumption and overloading of cesspits.

Sewerage systems were subsequently installed in a number of towns and the first of the existing WWTPs was constructed in Aden in the 1970s. However, the rapid rate of expansion of many towns has resulted in overloaded and inadequate collection and treatment systems, resulting in the discharge of raw and partially treated sewage.

In recent years, the number of sanitation projects has grown rapidly, mostly financed by World Bank and German (KfW) funds. There are now more than 20 WWTPs in Yemen, either operating, under construction or at the design stage, with a total treatment capacity that will reach about 200,000 m^3/day (73 million m^3/year) – see Table 1. The majority of WWTPs are waste stabilisation pond systems, which is the most appropriate treatment for the local conditions, and if designed correctly, should produce high quality effluent suitable for unrestricted reuse. Conventional treatment is provided in Sana'a and Ibb by extended aeration, and in Hajjah by Imhoff tank and percolating filter, and these WWTPs produce relatively poor quality effluents but the lack of space precluded the use of pond treatment.

Table 1 Existing and Planned WWTPs in Yemen

Location	Design capacity (dwf m^3/d)	Type of treatment	Date commissioned
Aden (Ash Shaab)	11,000	3 stage stabilisation ponds	1970s, extended 1989
Ash Shaab (upgrade)	30,000	3 stage stabilisation ponds	Designed
Aden (Al Arish)	70,000	3 stage stabilisation ponds	2002
Amran	1,480	3 stage stabilisation ponds	2002
Bait El Faqih	2,544	3 stage stabilisation ponds	Under construction
Bajil	4,151	3 stage stabilisation ponds	Under construction
Dhamar	11,000	3 stage stabilisation ponds	1992
Hajjah Main	2,428	Imhoff tank / 2 stage trickling filter	1998
Hajjah LS6	724	Imhoff tank	1998
Hajjah LS8	253	Imhoff tank	1998
Hodeidah (existing)	12,000	3 stage stabilisation ponds	1983
Hodeidah (upgrade)	51,500	3 stage stabilisation ponds	Under construction
Ibb (current)	5,200	Activated sludge	1991
Ibb (upgrade)	10,000	Imhoff tanks / activated sludge	Under construction
Mukalla	14,000	Stabilisation ponds	Under construction
Al Qa'edah	2,650	Imhoff / trickling filter	Designed
Rada	1,880	2 stage stabilisation ponds	1996
Sana'a	50,000	Activated sludge	2000
Seiyun	9,300	Stabilisation ponds	Designed
Taiz	17,500	3 stage stabilisation ponds	1982
Tarim	8,000	Stabilisation ponds	Designed
Yarim	1,771	3 stage stabilisation ponds	2003
Zabid	1,146	Imhoff tank / 2 stage stabilisation ponds	Under construction

While it is easy to be critical of the designs of wastewater treatment plants (WWTPs) after the plants have commenced operation, our evaluation of eight WWTPs revealed a number of design weaknesses due to inappropriate design parameters and the lack of some basic design considerations. One reasons for this may be due to limitations on construction budgets available from the international donors and, whilst the Government of Yemen (GOY) contributes to costs, this has been limited to a percentage of the total costs. Designing WWTPs down to a price is unlikely to result in the best long-term investment, as the WWTPs may not treat sewage to the necessary standards for reuse, thus requiring subsequent investment to rectify the deficiencies and improve effluent quality, which may not be physically or financially feasible after the WWTP has been constructed.

In recent recognition of this and the Government's commitment to effluent reuse, the MWE now states that the Government will make up any shortfall in investment to ensure effluent quality standards for reuse are achieved. The technical competence of the Local Corporations and at the Ministerial level clearly needs to be enhanced so that WWTP designs made by foreign consultants can be critically reviewed to ensure that best long-term value for money is realised and that the required effluent and sludge quality standards for reuse can be achieved.

A consistent shortcoming in WWTP designs is the assumption made on water consumption and sewage strength, resulting in designs that do not adequately balance organic and hydraulic loads. Sewage strengths in Yemen are high due to low per capita water consumption – the introduction of cost-recovery tariffs reduced domestic water use. As a result, WWTPs generally exceed their organic loading well before their hydraulic capacity. For existing stabilisation pond treatment systems, the simplest and lowest cost solution is to increase the retention time in the anaerobic ponds (i.e. build additional ponds), as this will enhance overall treatment efficiency by reducing the organic loading of the facultative ponds.

Optimistic assumptions are also made for the faecal coliform (FC) load in the sewage, generally 10^7 MPN/100 ml, when higher values are more likely (10^8 or more) due to the high strength of the sewage. This will result in greater FC numbers in the treated effluent compared with the modelling of the design assumptions. Achieving FC counts of less than 1,000 MPN/100 ml in the effluent is the standard necessary for unrestricted reuse, and well-designed stabilisation ponds should be able to achieve this: few WWTPs are be able to do so in practice. Where space for additional ponds is limited, effluent polishing and disinfection by sand filters and chlorination may be the most practicable means of achieving appropriate effluent quality for unrestricted reuse. Ibb WWTP is the only plant in Yemen with effluent chlorination, but this is not sufficiently effective due to the current overloaded condition of the treatment plant.

Sludge from anaerobic ponds and Imhoff tanks have undergone digestion, but this is not effective at reducing pathogen numbers to sufficiently low levels in the sludge to be safe for manual handling of the sludge. Most WWTPs are provided with an area for temporary storage of sludge after removal from anaerobic ponds or drying beds, prior to being collected by farmers. However, the design of the storage areas does not usually permit the long-term storage necessary to reduce the usually high pathogen and parasite contents of the sludge to levels that will comply with the proposed standard. Under local conditions, storage for six months with sludge spread in a thin layer (~15 cm) to maximise exposure to solar radiation is regarded as the most practicable and lowest cost means of achieving hygienic sludge (approaching USEPA Class A).

The issues of WWTP design, referred to above, concern the final quality of effluent and sludge in relation to their intended outlet. The additional costs of ensuring that reuse standards can be met reliably add little to the overall cost of WWTP construction if they are designed for at the outset. However, the development of effluent and sludge management plans is done after the WWTP is constructed, rather than before. This can lead to either, reuse of effluent and sludge that does not comply with the standards, or effluent and sludge are disposed of in less sustainable ways. For effluent, this would be discharge to the local wadi, where farmers would use the effluent in any case. For sludge, this would most likely dumped haphazardly as there are no sanitary landfills in Yemen, creating a significant environmental and health hazard.

In designing a new WWTP, it is logical that the best practicable and sustainable options for effluent and sludge management should be identified first, so that the WWTP can be designed to achieve reliably the necessary quality requirements for the identified effluent and sludge outlets. However, in practice, this is rarely happens in a systematic manner. The international donors and design consultants need to consider a holistic approach to the development of management strategies and WWTP design in order to achieve the most cost-effective and sustainable treatment and reuse in the long-term.

4. Effluent Reuse Practices and Prospects

With the introduction of sewerage systems, farmers were quick to exploit this new resource, either by diverting new perennial wadi flow or by blocking sewer mains to flood irrigate their land, totally unconcerned about the health risks to them, their families or consumers of the crops. As observed in many developing countries, where farmers have experienced the crop yield benefits (and profits) from using raw sewage, it is often then difficult to persuade them to use treated effluent, to the extent that repairs to sewage mains cannot be made easily as water utility workers may be threatened by armed farmers.

If all of the treated effluent produced at the design capacities of the current and planned WWTPs (Table 1) could be used for irrigation, this would service the needs of about 3,650 ha, assuming an irrigation duty of 20,000 m^3/year. This rate is suggested as an average to meet the requirements of two crops grown per year under the general arid climatic conditions of Yemen, assuming a low irrigation efficiency (<50%) resulting from the common use of long earthen distribution channels. The potential area that could be irrigated with effluent is equivalent to about 0.3% of the cultivatable land in Yemen, but could be increased by the adoption of improved pipe distribution systems. While the quantity of effluent is very small in relation to overall water requirements, this will be significant within the localities of effluent production.

The effluent irrigated areas for each WWTP will generally be limited to that which can be reached by gravity flow as pumping should be avoided where possible, so as to minimise costs and reliability problems. In most circumstances, this will be land immediately downstream of the WWTP and alongside the wadi into which the treated effluent is likely to be discharged. In some situations, effluent irrigated land would be a narrow strip of land alongside the wadi, stretching for several kilometres. However, farmers are increasingly using portable pumps to lift water (and effluent) to irrigate higher ground where they have sufficient land and yield potential to justify the costs, or can share equipment with neighbouring farmers.

With the exception of one formal effluent reuse scheme (Hodeidah Green Belt), effluent is discharged to the nearest wadi (or to sea). Wadis normally experience periodic infrequent flows, but effluent discharge inevitably results in perennial flow and this presents both opportunities and risks. Farmers are presented with a reliable source of water for crop irrigation so that they can increase their cropping intensity and income, but they utilise the effluent without any knowledge of its risks. Usually, there are wells near wadis, and wadis are also commonly used as roads, so there are potentially high indirect and direct exposure risks to local inhabitants. The perennial flow of effluent in wadis may also make the wadis impassable for traffic, an issue commonly disregarded in the design of WWTPs where contractors are required merely to provide ‘discharge to wadi’.

Achieving reuse of treated effluent and sludge depends crucially on farmer acceptance, and many farmers are equivocal about reuse, principally due to concern of damage to their land (salinisation). Once there has been some local experience of effluent and sludge reuse, and the benefits are apparent to the local farming community, demand usually increases rapidly. There is a clear need for demonstration field trials to show farmers: how to maximise benefits and minimise potential problems such as salinity; safe handling practices to minimise risk of infection to themselves; and the most appropriate crops to grow to avoid risks to consumers. This should be a function of the agricultural extension authority, but this service does not operate effectively and their staff are not trained in modern irrigation practices or the reuse of effluent.

There will always be a proportion of effluent that cannot be used for crop irrigation due to the seasonality of crop production, even when two or more crops are grown per year. Effluent not reused will eventually infiltrate in the receiving wadi bed to provide indirect recharge but there is considerable scope for formal aquifer recharge where discharge to wadi is inappropriate, and this could be targeted to reduce the rate of decline of groundwater in specific areas. As most aquifers are deep, the soil cover will provide good filtration and adsorption of pathogens and pollutants in the effluent (with the exception of nitrate), so the impact of groundwater quality should be minimal. Monitoring of the local wells would be necessary as these are often used as potable supplies, as well as for crop irrigation.

The reuse of effluent (and sludge) for trees (forestry and amenity) is well established in many countries, and this is a potentially attractive option for Yemen, where natural forests are limited and declining rapidly due to over-exploitation for fuel wood and animal fodder. The green belt scheme in Hodeidah is the only formal ‘forestry’ effluent reuse project, designed to control sand dune encroachment of the urban area. This is also being considered for Aden. Effluent is also used to irrigate urban planting of trees in Sana’a, transported by tanker, and this may be an attractive option in other towns to enhance the urban environment. There has been no development of commercial forestry in Yemen, principally due to limited water resources, but this may be a feasible option where it could stimulate economic development of associated industries, such as furniture manufacturing, as well as provide fuel wood and fodder.

The assessment and development of effluent management strategies are highly site-specific, and as a consequence, it is not a simple matter to categorise common conditions under which particular effluent management approaches would be recommended. Each WWTP has to be assessed according to the local conditions, following a systematic and objective approach, as adopted in this study.

Our study of five towns has shown clearly the problem, that sources of effluent do not always coincide with easily accessible land for irrigation, and would require investment to maximise direct reuse. For the same reason, it will be difficult to achieve substitution of fresh water by effluent, as envisaged by NWSSIP, since the majority of farms are based on rain-fed crop production. Consequently, in most cases, effluent reuse is more likely to result in expansion of crop irrigation, rather than conservation of groundwater.

Following the principle that the simplest and most pragmatic approaches are generally the most achievable and sustainable, the minimalist approach is to discharge the effluent to the nearest wadi, and allow farmers to use the effluent as they wish, as current practice, but with more control and monitoring. Improvements can be achieved by encouraging the formation of Water User Associations (WUA), to provide a forum for the farmers, WWTP and the local authorities (agriculture, water resources, etc.) to ensure appropriate coordination, investment and safe practices.

Formal irrigation schemes tend to be expensive, but provided the land is close to the WWTP, the capital costs, are unlikely to be large, provided the system is kept simple. Farmers have already shown that they are willing to invest in small pumps and pipelines to utilise effluent on an ad hoc basis, but operated through a WUA, the costs of schemes can be shared and will benefit more users. While the government could part finance schemes as an incentive to conserve groundwater, the operation of the system should be entirely the responsibility of the WUA. The financial commitment of the farmers is considered essential to ensure that they have a sense of 'ownership' and a vested interest in the system, thus ensuring its sustainability.

5. Sludge Use Practices and Prospects

Soils in Yemen are characterised by low organic matter and nutrient contents, resulting in low levels of agricultural production. Manures are used to supplement soil fertility, usually from the farmer's own animals but there is an active market for cow and chicken manures that supplies the larger farmers. Fertiliser consumption in Yemen is low, and restricted exclusively to nitrogen (urea) applied only to high value irrigated crops: phosphorus and potassium fertilisers are unknown. Due to the uncertainty of rainfall and consequential financial risk, fertiliser is not applied to rain-fed crops.

Under these conditions, sludge offers a cheap and effective alternative to manure and fertiliser to provide organic matter and nutrients, at the cost of the farmer loading and transporting sludge from the WWTP. Currently, arrangements between the WWTP and farmers are ad hoc, with no control or recording of user and the land to which the sludge is applied.

For the current and proposed WWTPs (Table 1), it is estimated that the total sludge production in Yemen may exceed 40,000 tds/y within ten years or so. About 10,000 ha (0.9% of total cultivatable area of Yemen) would be required annually to use this quantity of sludge, assuming an annual rate of application rate to land is 4 tds/ha. While this area is small in relation to the overall cultivatable area of Yemen, sludge is produced in only a few locations and so will require a significant proportion of the land locally. Unlike effluent reuse, where the area of reuse is usually constrained to land immediately downstream of the WWTP, the principal limitation for sludge reuse is transport distance (i.e. the cost to the farmer of collecting sludge from the WWTP). While the main sludge reuse area would normally be expected to be within a few kilometres of the WWTP, there are exceptions; for instance farmers from Tihama and Amran have taken sludge from Hajjah WWTP, a distance of more than 50 km, as they see a value in sludge in excess of the transport cost.

For the small stabilisation pond WWTPs, finding sufficient farmers in the locality to take the sludge is unlikely to be a problem, but for the major sludge production centres of Sana'a, Ibb, Aden and Hodeidah, this could be much more difficult as the WWTP would be reliant on a much larger proportion of the farming community to take sludge. For Aden and Hodeidah, this is made more difficult with the WWTPs being located on the coast with only limited agricultural land nearby.

The sludge storage facilities on the WWTPs are limited, and in some cases, WWTP designs made no provision. Consequently, there is anxiety about sludge handling, storage and disposal, particularly as stabilisation pond systems are desludged only periodically. Clearly, sufficient storage must be allowed for in the design but also, the demand by farmers must be encouraged through demonstration trials, marketing and provision of appropriate agronomic advice.

All sludges currently produced in Yemen are air-dried, either in situ in anaerobic ponds or on drying beds. However, at Ibb, which experiences the highest rainfall in Yemen, the WWTP has a seasonal problem due to low demand during the wet summer season when air drying of sludge is difficult, and currently exacerbated by the over-loaded condition of the WWTP. Sludge accumulates to the extent that the WWTP is obliged occasionally to discharge liquid sludge to the wadi. The current proposal is to install mechanical dewatering, which should alleviate the immediate problem but could result in more difficult issues. Mechanical dewatering is not only expensive (recurrent costs for polymer and power), but also the physical quality of the sludge (sticky) will be unattractive to farmers, being impossible to handle and spread on the land manually. This will also increase potential health risks to the farm labourers. Expanding the drying beds and improving their efficiency (e.g. solar drying, reed beds, etc.), with additional sludge storage space, are considered more sustainable and lower-cost options.

The principal concern of sludge reuse is the high exposure risk of WWTP and farm labourers handling sludge and the potential for acquiring infection. Farmers can be adequately protected by long-term storage of sludge to reduce the pathogen load to acceptable levels for manual spreading on the land. However, WWTP are highly exposed as sludge is lifted from drying beds by hand, and ensuring workers to take elementary precautions (i.e. gloves, boots, personal hygiene) has proved difficult, resulting in high levels of infection and absenteeism.

Sewage treatment results in most of the pollutants in sewage being retained in the sludge, but with the limited quantity of industrial effluents discharged to sewer, heavy metal concentrations in sludges are very low and typical of domestic catchments. However, the long-term environmental concern is that use of sludge on land results in accumulation of heavy metals in soil. Modelling of potential accumulation, based on the natural background concentrations of heavy metals in the soil, indicates that it would take at least 200 years of regular use before precautionary limit values for protecting soil quality would be approached. Consequently, heavy metals in sludge are not an immediate environmental or health concern, with the benefit of reducing the need for frequent and costly monitoring programs.

6. Strategy Development

International experience shows that the key to successful and sustainable effluent and sludge reuse programs is to control the potential risks to human health and the environment, and to create and maintain farmer and public confidence in the effectiveness, safety and benefits of wastewater treatment and effluent and sludge reuse.

While there is a general acceptance in Yemen that the reuse of effluent (and by implication, sludge) is an integral component of water resource and pollution control policies, there is no cohesive implementation strategy. There is no clear definition of the institutional responsibilities or the mechanisms for implementing and controlling reuse projects.

Regulations on the treatment of wastewater and effluent and sludge reuse are widely adopted internationally, based on extensive scientific research and adapted to local conditions. The standards adopted by different countries generally reflect the actual and perceived risks, and the level of precaution deemed necessary to protect health and the environment. The issue of effluent compliance needs to addressed, to ensure that the quality standards currently adopted are appropriate, and where they are, to ensure that finance is available to enhance WWTPs to achieve the standards for safe reuse. Regulations on the use of sludge need to be adopted.

The steps considered necessary for Yemen to approach the required levels of safety, control and operational security for effluent and sludge reuse, include:

- Clearly defined reuse strategies, in particular how effluent reuse can be integrated into the emerging water resource management strategy (NWSSIP). One of the innovative concepts being considered is to develop a mechanism for farmers to exchange groundwater for effluent but in practice this will be difficult to achieve for all WWTPs.
- Clearly defined institutional responsibilities for effluent and sludge management at central government and local levels. A mechanism for coordination between the relevant ministries is required at the national level, and at the local level, forums need to be created at which all of the stakeholders are represented, with farmer representation through water user associations.
- Specific regulations stipulating the required effluent and sludge qualities and associated monitoring requirements for different reuse conditions. International quality standards must be adapted to the local conditions so that compliance is feasible, and hence encourage monitoring and control. The process should also be transparent and auditable to provide confidence of all of the stakeholders involved.
- Provision of appropriately equipped laboratories. Most WWTPs have basic laboratories that can determine the most critical quality parameters (e.g. faecal coliforms, salinity) but a central high quality analytical facility to provide a service to all water utilities is necessary for the expensive and infrequently required parameters, such as heavy metals.
- Technical guidelines on the management of effluent and sludge reuse programmes, and the provision of appropriate agricultural advice for users.
- Promotion of beneficial reuse of effluent and sludge, and the safe practices that should be observed. This is best achieved by a programme of demonstration trials and a community-based approach through water user associations.