Soil and Groundwater Protection in the South-East Asia Region

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1. Soil Quality and Soil Protection

1.1 BACKGROUND

Soils are an integral part of the natural environment and central to agriculture as well as to the sustainability of natural habitats. The natural fertility of soils varies widely and is often substantially enhanced by modern agricultural practices such as fertilization and irrigation. ‘Soil quality’ reflects the ability of soils to maintain such production on a sustainable basis and without permanent damage to the essential functioning of the soil. These functions include, for example, the breakdown of soil organic matter, microbiological processes such as nitrification and the maintenance of soil structure. The physical characteristics of the soil are important as the loss of soil structure and the cultivation of ever steeper slopes can result in significant soil erosion. This is already of concern in the region. Soil chemical contamination is also of concern and it is this aspect that is of concern in this programme.

‘Heavy metals’[2], such as zinc, cadmium, copper, lead, nickel and chromium are present in all soils but are usually found at low concentrations. ‘Baseline’ concentrations vary depending on soil type, soil parent material and type of heavy metal but are usually in the range 0.1–200 mg/kg. Enhanced concentrations are found in soils from naturally mineralised areas but more commonly arise where heavy metals have become dispersed as a result of human activity since heavy metals are used in a wide variety of industrial processes. These include mining, manufacturing and waste disposal as well as some agricultural activities such as the use of phosphate fertilisers and metal-containing pesticides. As a result of their use in many industries, heavy metals are concentrated in many waste streams. Furthermore as a result of their dispersion into the environment, topsoils tend to be most heavily contaminated. Heavy metal contamination of soils and sediments is often used as an indicator of the beginnings of industrial activity.

The pathways by which heavy metals contaminate the soil vary from direct pathways via mining, waste disposal and agricultural activity as well as more indirect pathways such as atmospheric deposition. Their impacts depend on the use of the affected land. Heavy metal contamination of agricultural land can have serious impacts on crop growth and crop quality and in urban areas is often of concern in terms of pollution of underlying aquifers. If the contamination is confined to industrial areas, then the concern is less than if widely dispersed. Therefore the reduction of the dispersion of heavy metals in the environment is a major concern in most industrial societies. Once contaminated, it is extremely difficult and expensive to decontaminate soils.

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[2] The term ‘heavy metal’ is used loosely here to include both the strictly ‘heavy’ metals such as lead and cadmium as well as the transition metals such as copper and zinc.

The relationship between soil contamination and crop contamination is complicated and depends on many soil and plant factors. Critical factors are the ability of the soil to adsorb the heavy metals and thereby maintain a low concentration in the soil solution and the interactions between the various heavy metals, e.g. Cd uptake can be affected by competition from other metals such as Zn and Cu. Soil pH strongly affects the amount of adsorption – adsorption of most trace metals is much lower under acid conditions potentially resulting in greater plant uptake and greater toxicity. Therefore one of the key ways in which the effects of heavy metal contamination of soils can be mitigated is through control of soil pH, specifically the application of lime.

Most heavy metals are very strongly bound by natural organic matter and so tend to be found at high concentrations where organic matter contents are high. This includes the biosolids found in wastewater and sewage sludge. The nature and extent of contamination strongly depends on the upstream sources. Therefore the use of either untreated wastewater or biosolids in agriculture poses a potential long-term threat.

Heavy metal availability in soils will change with flooding as in rice production. There will be an increase in pH of up to 2 pH units which will tend to decrease availability but an increase in iron and manganese oxide dissolution which could increase availability. It is likely that the former effect will dominate. Aeration of sulphide-rich soils will lead to a decrease in pH and potential release of heavy metals.

Soils contaminated by heavy metals pose a threat in two ways: (i) directly through their toxic effect on the growth of crops thereby reducing crop yields, and (ii) indirectly by entering the animal and human food chain could adversely impact on human health. Even a reduction of crop yield by just a few percent could lead to a significant long-term loss in production. Heavy metals may also have deleterious effects on the microbial functioning of soils, again with important long-term consequences. Zinc, for example, can reduce grain yields as well as reducing microbial activity especially of nitrifying organisms (those organisms that convert ammonium to nitrate). Zinc is usually not present in toxic amounts in the food crop – indeed it is an essential element at low concentrations – but the crop may suffer at high zinc concentrations. Cadmium on the other hand can be taken up by crops in sufficient quantities to be of concern for human health before it impacts on crop growth. In humans, excessive cadmium can lead to renal failure.

Some food importers are now specifying maximum heavy metal contents for imported food and so any deterioration of food quality could have an impact on the export security of food crops.

Therefore the protection of soils from heavy metal pollution is an essential aspect of maintaining soil and food quality. Many countries now have legislation to control the contamination of heavy metals to soils and the wider environment.

1.2 SITUATION IN SOUTH-EAST ASIA

It is clear that the rapid industrialisation of much of South-East Asia has led to the potential for heavy metal contamination of soils in a variety of ways and on a variety of scales. The principal ways are:

- **Mining activity:** Spread of mine spoil and tailings and, in some cases, by the use of heavy metals in ore processing, e.g. the use of mercury in gold mining. Examples can be found throughout the SE Asia region with well-documented examples especially from Thailand. Much mining activity in the region is artisanal and unregulated resulting in pollution over quite a large area. For example, it is estimated that some 5,000–10,000 ha in Thailand are contaminated with cadmium. New mining legislation in Vietnam with an enhancement of its enforcement will hopefully reduce future contamination but there is still a legacy of largely unknown extent to contend with.

- **Industrial activity:** The processing and reclamation of metals by industry has led to the widespread contamination of soils in urban and peri-urban areas. It can even happen in more rural areas where cottage industries are processing metals. An example is the contamination of soils in Dai Dong village, Lam district as a result of the reprocessing of copper waste. Soil contamination extended to more than 300 m away from the recycling operation.

- **Wastewater reuse:** Wastewater is potentially a valuable source of both water and nutrients and there is a long history of the use of untreated wastewater for irrigation in much of SE Asia including Vietnam. In Vietnam, some 30 cities use wastewater and about 5000 ha of land are believed to be irrigated directly with wastewater. Some of the remaining wastewater is inadvertently used because it is mixed with surface water in canals carrying irrigation water. This can result in contamination travelling large distances largely through the transport of contaminated sediments.

  While the use of treated wastewater would be much better both for human health and for the environment, this seems unlikely to be adopted on a large scale in the near future. Because of the lack of treatment and the mixing of industrial and domestic wastewaters, often with storm water, the heavy metal content of wastewaters can be expected to be variable but high. The low and often declining pH of many SE Asian soils under cultivation could lead to an increasing plant availability of heavy metals. This declining pH will be exacerbated by the heavy fertiliser nitrogen applications now common in much of the region. Liming is sometimes practiced largely to increase the calcium concentration of crops rather than controlling the soil pH *per se* or the heavy metal content of crops. In some cases, the pH of soils in the Red River delta has declined from about pH 6.5 to pH 5.5, an order of magnitude increase in acidity, in a matter of years. This could have a significant impact on heavy metal uptake by crops including rice.

- **Fertilisers** – Aside from the indirect effect of nitrogen fertilisers on soil acidification, phosphate fertilisers can increase the soil load of various trace metals, most notably cadmium and uranium. The extent of this contamination very much depends on the geological source of the phosphate rocks used in making the fertilisers. The available evidence in Vietnam appears to indicate that the phosphate fertilisers are quite low in cadmium (about 2.5 mg kg^{-1}) and so should not pose a serious threat. The uranium content is unknown but is quite likely to be similarly low.

The overall situation therefore appears to be one of rapid change with the potential for the serious, long-term pollution of soils. However, the documented cases of pollution in Vietnam and elsewhere in the region refer to quite small areas of land, and in situations where pollution might reasonably be expected to have taken place. The lack of more widespread systematic data and an understanding of the scale of potentially-polluting processes such as wastewater use make it difficult to assess the situation in the larger, unsampled areas. Establishing this should therefore be an early focus of the project.

There appears to be most concern about the cadmium concentrations in rice in the region. In Japan, there are examples of areas such as the Jinzu River basin where cadmium contamination of the environment has led to excessive cadmium concentrations in the rice with probable adverse health outcomes.

A recent survey showed that the mean concentration of cadmium in polished raw (uncooked) rice is about 50 µg kg^{-1}. Cadmium in food is usually the major pathway (c.f. water and air) and a study in Japan showed that rice contributed about 30% of the daily dietary intake of cadmium.

2. Groundwater Quality and Aquifer Protection

2.1 CONTEXT

Hanoi, Ho Chi Minh City and other cities and towns in Vietnam do not have conventional piped sewerage collection and treatment systems, even in the oldest-established central parts. It appears that domestic wastewater and effluents from small-scale industrial premises have instead been discharged into open street drains, and thence to the existing rivers which have become canalised wastewater collectors where they pass through the city. Over the course of time, the open drains have gradually become enclosed channels to improve the sanitary condition of the streets, and the canals were observed to be have been at least partly lined. For Hanoi, therefore, several hundred thousand cubic metres per day of untreated wastewater are conveyed out of the city by this means.

The city has grown up close to the Red River over a complex sequence of alluvial material which is at least several hundred metres thick and contains two important and extensively exploited aquifers, the uppermost mainly by shallow private wells and the lower by the municipal supply wellfields. Recharge comes from the Red River, from storm drainage, leaking water mains, rainfall and leakage from the wastewater canals.

A groundwater quality study undertaken by BGS and GSV in 1994 and 1995, together with data presented at the seminar indicate that some impacts on groundwater are already significant. Thus, ammonia concentrations in groundwater beneath and to the south of Hanoi were in the range 5–20 mg l^{-1} in 1994–95 in both the Upper and Lower Aquifers, and appear from data presented at the seminar to be somewhat higher now. This is a cause for concern in its own right as a serious groundwater pollutant, and also for the change that it brings to the hydrochemical environment, leading to greater mobility of contaminants such as arsenic. There also appears to be some evidence of mercury contamination in the groundwater from beneath Hanoi. Bicarbonate concentrations are also somewhat elevated beneath the city, reflecting the organic loading from wastewater.

The organic loading also increases the trihalomethane (THM) potential from chlorination of public water supplies. This risk needs to be assessed, although preliminary work by the Vietnam/Swiss collaborating team found that existing guidelines for THM formation were not currently being breached. This needs to be regularly monitored for the wellfields within and to the south of the city especially if the extent of pollution is increasing.

A further impact of the rapidly increasing urbanization and associated growing water demand is the accelerating drawdown of groundwater levels. Hanoi's abstraction of groundwater for municipal supply has reached 600,000 to 700,000 $m^3 d^{-1}$, and an elliptical cone of depression beneath the city and surrounding areas covers about 200 km^2 with water level declines of 0.3 to 0.4 m yr^{-1} beneath some wellfields. A relatively newly observed impact is that of land subsidence, which was reported as being 20–44 mm yr^{-1}, and 30 mm yr^{-1} in a 2 km^2 area around the Phap Van wellfield south of the city. This is a high rate of subsidence. The situation is considered to be so severe that plans are being made to supplement the supply by taking and treating surface water from the Red River. This is expected to start with a scheme for 150,000 $m^3 d^{-1}$ in 2005, rising to 500,000 $m^3 d^{-1}$ by 2020.

2.2 IMPACTS ON GROUNDWATER QUALITY

2.2.1 Artisan Handicrafts and Recyling

Reference was made at the seminar to the possible impact of small-scale artisanal handicraft industries and village level businesses recycling metals from waste.

The two relevant presentations were detailed case studies of two individual villages recycling lead and copper respectively, from which it was not possible to get an overall view of the distribution and scale of such activities, although it is assumed to be quite widespread. As mentioned above, significant contamination was demonstrated in soils and local paddy field irrigation waters and ponds in both cases. In the former, elevated lead and zinc concentrations in groundwater were not observed, in the latter no sampling of groundwater was undertaken.

Localised but high levels of pollution of groundwater from the leaching of surface deposited wastes has been observed for chromium from tanneries in Mexico, India and Pakistan. In this case, however, the threat to groundwater is unlikely to be great from disposal at the ground surface of solid and liquid wastes, unless very large amounts of waste are leached, or disposed into pits, ponds or soakaways, by-passing the soil.

2.2.2 Mining

The potential impact of small-scale mining in Vietnam was referred to but not covered in the seminar presentations. In general, mining is likely to occur in the hilly and mountainous regions and to be associated with hard rock areas of the country rather than the alluvial plains. Thus, although these areas will have some rice cultivation, they are not likely to be areas of significant groundwater usage. The distribution, scale and character of such mining, methods of extraction, waste generation and waste disposal should be briefly covered in the initial collection of relevant data in activity 2 of the project using DGMV as the primary source.

2.2.3 Irrigated agriculture

The widespread practice of irrigated agriculture in the region could have a significant long-term impact on water quality in underlying aquifers. For example, the puddling of soil and the flooding of fields during the cultivation of paddy rice will inhibit the diffusion of oxygen to the subsurface. In the long term – and the timescales are unknown – this could affect the redox status of an underlying aquifer and thereby indirectly affect the solubility and mobility of redox-sensitive metals and metalloids such as iron, manganese and arsenic as well as other redox-sensitive species such as nitrate, nitrite and sulphate. This would be especially important in the alluvial aquifers of the delta areas with their shallow water tables. Such effects could be exacerbated if groundwater pumping enhanced the downward migration of organic-rich, oxygen-demanding soil water (potentially contaminated with animal and human waste) to the subsurface. The generation of increasingly reducing groundwaters has recently been said by one group to be responsible for at least part of the Bangladesh groundwater arsenic problem. This is analogous but less extreme to the situation found near landfills and beneath urban areas such as Hanoi.

Unlike in temperate regions where the concentration of soil organic matter in agricultural soils is gradually declining due to enhanced oxidation as a result of agricultural activities, the reverse could arise in densely populated, lowland areas with a shallow unsaturated zone and paddy cultivation. The oxidation of organic wastes from animals and humans in such environments is difficult. The implications of this are potentially broad, long-term and poorly understood.

Elevated chloride concentrations of groundwater beneath cities are also generally an indication of the impact of infiltrating wastewater, and might also be expected beneath the irrigated area. The 1994 and 1995 sampling of groundwater showed elevated but still not very high (100 mg l^{-1}) concentrations of chloride. The modest concentrations may be the result of mixed influences of the high-chloride wastewater and large volumes of low-chloride water recharging from the bed of the Red River.

3. Project structure

The present project as proposed is divided into several activities and groups of tasks. However it is our view that the project needs to have clearly defined Phase 1 in which the likely extent, scale and severity of problems associated with mining and wastewater use and impacts on soils, crops and groundwater is assessed. While individual studies were described in the seminar, the extent of some of the activities and their actual or potential impacts was not clear. For example, the total land area irrigated by wastewater from Hanoi and Ho Chi Minh City combined was estimated by one participant at 6000 to 8000 ha, a tiny fraction of the total land area irrigated for rice.

Phase 2 could then focus on the areas of greatest concern identified in Phase 1. Where important information gaps are found, then new studies should be undertaken to collect the required data.

3.1 INFORMATION REQUIREMENTS

3.1.1 Soils and crops

The scale and nature of any heavy metal pollution is unclear. One-off studies of particular sites give little indication of the extent of any problems and so some kind of stratified random survey is required. Since the joint Australia/Vietnam/Thailand project is looking mainly at vegetable crops, it is recommended that this study only look at the rice crop. It is recommended that the stratification should be on the basis of the likely extent of contamination, for example, that it should be stratified into:

- Cultivated areas close to known metal mines
- Peri-urban areas where crops are grown
- Areas receiving wastewater irrigation
- Background cultivated areas (none of the above).

Such areas should be identified across the whole of Vietnam. Within each such area, one or more sites should be randomly selected for sampling of both soil and crop when the crop is mature. Detailed sample location should be noted using GPS.

The scale of the survey in terms of numbers of samples depends on the resources available. We recommend that at least 30 sites be chosen within each of the above strata.

The rice samples should be analysed for Cd, Zn, Pb, Cu, Ni and Cr and preferably Ca and Mg. The soil samples should be analysed for acid-extractable and phyto-available metals. Before any such analyses are undertaken, the laboratory carrying out the analyses should have an adequate QA procedure in place, i.e. it should be able to demonstrate that it has carried out analyses with acceptable accuracy (based on the analysis of recognised standard materials) and that it has regular QA procedures in place to ensure that this standard continues to be met during the survey analyses.

Such a survey would: (i) identify any contaminated soils and rice along with their spatial distribution; (ii) enable the relationship between soil contamination and crop uptake to be established, and (iii) highlight whether further action was necessary.

3.1.2 Groundwater

As a component of Phase 1 of the project, and to provide the necessary background on groundwater for Activity 2 of the proposed project as written, the following information will be required:

- Types, sizes and distribution of industries and their effluents;
- Characteristics of the urban wastewater – volumes, variability, chemical (inorganic and organic) and bacteriological quality;
- Physical infrastructure – canals and canalised rivers, lined or unlined;
- Irrigation methods, pumping from canals, distribution, field application;
- Cropping regimes, fertiliser and pesticide usage;
- Existing groundwater quality data.

If the groundwater quality were a key focus of the project eventually developed, then a somewhat different stratified random sampling approach to provide an overall distribution of quality would be required.

If the project is largely soils and crop oriented, then tracing the food chain links and health impacts, one question always asked is the relative importance of the intake in food and water. For activity 2c, therefore, in developing sampling programmes, the source of drinking water will need to be identified and regularly sampled to allow this distinction to be made, even if groundwater pollution by heavy metals is unlikely to occur. Rural or peri-urban domestic water supplies from groundwater are likely to be much shallower than the large-scale, urban public supply boreholes in the municipal wellfields, and therefore more vulnerable to the impact of wastewater irrigation at the land surface. The extent to which such sampling would be extended to other parameters remains to be decided, but it would certainly need to include the parameters which define the major hydrochemical environment – pH, DO/Eh, EC, major ions, trace metals of interest and ammonium.

3.2 MANAGEMENT OF THE PROJECT

The project envisages a multi-disciplinary team to develop management approaches that are suitable and can be adopted. The current emphasis in the proposal as written is on management at the farm level, which is clearly required, and options from the field study in Thailand were presented. However, it is a wider issue of waste management in the environment and the feasibility of selective collection and treatment of industrial wastewaters may need to be investigated. Experience from elsewhere (Mexico, India, Pakistan and others) suggests that collection and treatment of small volumes of wastewater from large numbers of dispersed, small informal industrial premises is, while technically feasible, difficult to impose by regulation as the industries do not separately have the financial capacity to install suitable treatment.

The project needs a partner or partners to cover this – to be able to characterize the industrial wastewaters, their trends of growth, the present environmental legislation and any proposed new legislation and the management options for improving wastewater quality. The same considerations apply to the mining and artisanal industrial sources referred to earlier. National partners/collaborators to cover the wastewater generation, environmental legislation and management options are needed.