Mine spoil restoration: a strategy combining rainwater harvesting and adaptation to random recurrence of droughts in Rajasthan

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SUMMARY

Rajasthan presents evidence for the existence of one of the most advanced examples of ancient mining and accompanied deforestation to be found anywhere in the world. Mining continues to be an important economic activity contributing to 2% of the State Domestic Product and providing at least a 1.76 % share to the regular employment pool in Rajasthan. However, economic benefits of mineral extraction also accompany environmental, economic and social costs. Mine waste dumps and mined out areas viewed simply as the legacies of past may appear overwhelming environmental hazards presenting ugly picture of cultural landscape. However, mine wastes can be transformed into an opportunity for learning, adaptation and productivity enhancement for sustainable livelihoods through ecological restoration. Here we propose a strategy for mine spoil restoration aimed at creating a multifunctional ecosystem in mine waste dumps. We suggest that dredging and sediment removal from traditional tanks and ponds can potentially be used to prepare the substratum over the mine wastes for direct seeding. It will also create enhanced decentralized water storage capacity for wildlife and people. Our strategy combines the concomitant revival of traditional water harvesting systems, ground water recharge, enhanced biomass production and an adaptation to random recurrence of droughts in Rajasthan.

Keywords: decentralisation, Community Forestry, user groups, local government, Nepal

INTRODUCTION

Rajasthan, the western state of India, faces a severe challenge of random and persistent occurrence of droughts, water crisis, increasing mine-waste dumps, land use change and degradation of natural resources. In addition, climate change is now a real threat to human society and ecosystems (Pandey 2002a, Ravindranath and Sukumar 1996). A holistic restoration is expected to mitigate the impact of climate change by sequestering large amount of atmospheric CO_2 and qualify for the carbon credits and thus livelihoods improvement for participating communities under the Kyoto Protocol (Smith and Scherr 2002, Sayer and Campbell 2004, Auckland 2002, Boyd 2002). A strategy that combines options to resolving these issues is a priority. Ecological restoration and integrated natural resource management can reduce environmental degradation, augment the productivity of degraded ecosystems and potentially minimize the long-term livelihood insecurity of people dependent on natural resources.

Ranging from gold mining in the Brazilian Amazon to marble mining in India, environmental impacts of mining activities around the world are evident in the form of deforestation, biodiversity loss, gaseous emissions, metal-contamination of soils and pollution of water. Consequent processing of ores and minerals also results into widespread environmental pollution (Sinha et al. 2000). These impacts have wide ranging economic, social and ecological ramifications (Hester and Harrison 1994, Hilson 2003).

Over thousands of years, societies have developed a diversity of local water harvesting and management regimes as an adaptation to climate change that continue to survive in South Asia, Africa, and other parts of the world (Pandey et al. 2003). Such systems are often integrated with agroforestry and local forest management practices. Indeed, there are 1.5 million village tanks in use and sustaining everyday life in the 660,000 villages in India (Pandey 2001).

In this article, we briefly describe traditions of rainwater harvesting as an adaptation to climate change in Rajasthan, provide a brief account of ancient and contemporary mining, and propose a novel strategy for mine spoil restoration.

TRADITIONAL WATER HARVESTING SYSTEMS IN RAJASTHAN

Rajasthan has 10% of India's geographical area and 5% of the country's population and is also the driest state. The total surface water resources in the state are only about 1% of that of country. The average rainfall is approximately 550 mm, with per capita water availability of about 700 m^3 which is low compared to India's average of about 1200 m^3 per person. Large parts of Rajasthan face recurrent drought forcing governments periodically to initiate famine relief works. Food and water shortages during these droughts impact men, women and children destroying their assets such as livestock and putting livelihoods at risk (Sivakumar and Kerbart 2004).

Villages in Rajasthan are notable for traditional water harvesting systems (Pandey 2001, Prasad *et al.* 2004). Small tanks and ponds called *johads, talabs, talai or paals* have water spread areas of a few acres, and larger minor irrigation tanks often have command areas of 1000 ha or more. Although Rajasthan is officially reported to have 4600 such minor irrigation tanks with an estimated potential command area of 0.63 million ha (Shah and Raju 2002), the number of traditional water harvesting systems may be up to 48,000. The inconsistency in numbers is due to the fact that official records take into account only those tanks that are used for irrigation, and do not note the small village tanks. These tanks are essential elements in the livelihood adaptations of local communities as aquatic and terrestrial components of tanks provide numerous ecological, social and economic benefits to society. For example, a traditional runoff harvesting system known as *khadin* in western Rajasthan is practiced where rocky catchments and valley plains occur in proximity. Runoff from the catchments is stored in the lower valley floor enclosed by an earthen bund. Standing water, if any, is discharged through the sluice before crop sowing. Crops adapted to dry environments are cultivated in *khadin* without any irrigation because soils in *khadins* are extremely fertile and retain residual moisture (Kolarkar *et al.* 1983). Indeed, there is clear evidence from around the world that rainwater harvesting promotes household income, reduces poverty and enhances livelihood security of poor people (Jose 2003, Qiang 2003, Fooladmand and Sepaskhah 2004).

However, these ponds and tanks are now being neglected and they even do not appear in official records. As we discuss later, there is an urgent need for de-silting and revival of these multifunctional structures constructed by human societies as an adaptation to climate change over the last 5000 years (Pandey *et al.* 2003).

ANCIENT AND CONTEMPORARY MINING IN RAJASTHAN

Rajasthan provides evidence for one of the world's most ancient mining and mineral extraction activities. Archaeological evidence of ancient mining sites in Rajasthan suggests that the zinc, lead, silver and copper ores were worked extensively in ancient India (Craddock *et al.* 1983, Willies 1984, Tewari and Kavida 1984). People of Rajasthan were smelting zinc by the sophisticated distillation process at Zawar in Rajasthan by the 12th century AD. A tentative but conservative estimate suggests that 0.25 million tonnes of zinc concentrates were extracted from some 2.5 million tonnes of ore in the total mined area before modern mining commenced (Agrawal and Tiwari 2003). Thus, mines in Rajasthan were important to local people as well as neighbouring Indus-Saraswati civilization, and perhaps other contemporary economies globally.

Mining continues to be an important economic activity in India. While acknowledging that reliable estimates of mining area and production are not available, TERI (2001) notes that India produces as many as 84 minerals comprising 4 fuel, 11 metallic, 49 nonmetallic industrial and 20 minor minerals. Interestingly, more than 80 per cent of the mineral production comes from open cast mines resulting into large quantities of overburden. The mining leases numbering 9,244 are spread over 21 States and about 13,000 mineral deposits occupying about 0.7 million hectares which is 0.21 per cent of the total land mass of the country. But these estimates do not include the mine waste dumps, area of which is not known. The aggregate value of the mineral production in 1999-2000 was approximately $10 billion. However, these estimates are difficult to reconcile to take into account the artisanal and small-scale mining in India which has seen large increase with respect to area and the production of minerals (Chakravorty 2001).

Not surprising, at least 90 wildlife sanctuaries and national parks in India with unique biodiversity and wildlife are threatened with mining (Vagholikar and Moghe 2003). Precise estimates of the extent of damage is not known but it is considered that 0.25 million ha of land has been subjected to varying degree of mining including dumping grounds or abandoned mining sites.

Mining is an important economic activity contributing to 2% of the State Domestic Product and providing 1.76 % share to the regular employment pool in Rajasthan. There has been more than 50 percent increase in workers in mining sector (RHDR 2002). More recent estimates are not available but in 1993-94 commodities worth US$ 1.52 billion were mined and the Government of Rajasthan earned revenue of US$ 38 million (Sinha *et al.* 2000). Reliable estimates of area affected by mining are yet to become available but may be substantial as there are about 9000 mining units for minerals and more than 16,070 quarry licenses employing a total of about 0.5 million persons per day in the sector (GOR 1993). Mining leases are spread over an area of 0.9 million ha, of which 0.1 million ha is said to be in forestland (Sinha *et al.* 2000); although these estimates are uncertain and contested.

Although all of the lands may not be owned by government, it would be potentially useful to initiate the restoration strategy in mines and waste dumps that are situated in officially notified forest lands under the ownership of the government.

THE RESTORATION STRATEGY

Mine spoils left to nature may take decades to centuries to develop any vegetation cover. However, carefully planned artificial interventions that mimic natural processes can reduce this time span (Dobson *et al.* 1997).

An innovative strategy capable of accomplishing restoration goal has at least 6 key elements. It should:

1. create vegetation cover that may develop into a functional ecosystem in due course of time;
2. provide strong livelihoods improvement incentives to local stakeholders in the form of augmented supply of goods and services;
3. provide an effective framework for cooperation among the stakeholders;
4. address both local challenges and the connected global issues;
5. include innovative institutional and financial mechanisms to make it self - enforcing and self - sustaining; and
6. maintain options and flexibility for adaptation.

In other words, an holistic science and policy is necessary to construct a self-sustaining multifunctional ecosystem capable of supporting biodiversity, performing ecosystem functioning and providing ecosystem services to strengthen livelihoods. A good strategy for mine spoil should also be coherent with the prevailing policies and actions on water, mineral, wildlife and forest. It should also essentially provide benefits in terms of climate change mitigation and adaptation.

In accordance with these key elements, we propose a strategy for mine spoil restoration aimed at creating a multifunctional ecosystem in mine waste dumps. As we describe in the following sections, our strategy combines the simultaneous revival of traditional water harvesting systems, ground water recharge, enhanced biomass production and an adaptation to random recurrence of droughts in Rajasthan.

To our knowledge, the holistic strategy we suggest here has neither been proposed nor been implemented in its present from. However, our proposal incorporates lessons from different strategies attempted in large number of places within Rajasthan and elsewhere (for example, Soni 2003, Singh *et al.* 2002, Soni and Vasistha 1986, Soni *et al.* 1989, 1992, Sharma *et al.* 1998, 2004, Pandey 2002b). We suggest that this restoration strategy may be implemented as an experiment in adaptive restoration.

In the following sub-sections we provide the details of the strategy proposed.

Site leveling

To the extent possible, mine spoils need to be leveled or terraced in order to provide suitable substratum. Leveling will vary according to the type of mine, methods of mining and the way in which a particular area has been worked. For instance, in the case of surface and opencast mines the procedures will be leveling and fencing of the area. In the case of shaft and underground mines although overburden can be treated in similar fashion mined-out areas and abandoned mines will have to have different strategy depending upon the context. For example, mined-out areas in hillside slopes may require contour dikes. Leveling will provide a base of coarse material over which to spread sediment. Some of the large mining pits that have developed into reservoirs can be developed as water-bodies aesthetically appealing for ecotourism and simultaneous fish culture to support local livelihoods.

Sediment removal from traditional water harvesting systems, transport and spreading over the mine spoil

The main physical problems with mine spoils are shallow substrate of soil (or often lack of it), large cavities in the very coarse-grained substrate, very high stone content, extremely coarse texture, compaction, and the limited availability of moisture. The main chemical problems are the lack of nitrogen and phosphorus due to the lack of organic-matter content, low cation exchange capacity, and base saturation (Jim 2001).

To overcome these challenges, addition of organic wastes is useful which will ultimately increase N fertility and stimulate microbial action (Singh *et al.* 2000, Wong 2003). Excavated sediment of ponds and tanks is an effective indigenous soil amendment practice in India. Pond silt is not only productive but also a seed bank for a variety of grasses, herbs, shrubs, and trees (Pandey 1996). This silt, rich in organic material, can be used for preparation of a topsoil layer of about 30-50 cm over the mine waste and leveled pits. The silt layer increases the productivity of the land and also helps in ground water recharge. Transporting the silt away from ponds and using it for organic enrichment of mine spoil serves other purposes as well including the safe disposal of excavated sediment and solid waste, ecological restoration of mine-waste, and increased rainwater storage capacity for people and wildlife in village tanks.

In addition to the above activity, *in situ* moisture conservation to encourage growth of vegetation over mine spoils could be useful. For example, rehabilitation success to revegetate mine spoils in arid regions in India was achieved using a combination of *in situ* rainwater harvesting, soil amendments, and establishment of trees, shrubs and grasses (Kumar *et al.* 1998, Sharma *et al.* 2000, 2001).

In many cases toxicity of mine spoils due to presence of metals affects the restoration plan. In such cases, one of the methods that can also be applied along with sediment use is microbial enrichment of the ore whereever feasible. Some arbuscular mycorrhizal fungi (AM fungi) native to limestone mine spoils may play a critical role in rehabilitation of mine spoils in arid Rajasthan. AM-fungi have positive role in improving the water and nutrient uptake and enabling the plants to withstand high temperatures (Rao and Tak 2002).

It should be noted here that the best practice should have been the safe storage of topsoil for reuse in restoration before mining commenced (Rate *et al.* 2004). This is a mandatory requirement. However, as that has not happened the strategy we propose is a practical one.

How feasible is the proposal to remove sediment from the water harvesting systems? Only a small number of the 48 000 ponds and tanks in Rajasthan have been periodically de-silted by villagers in the past. This neglect has resulted in large quantities of silt accumulation which can be removed from the water impounding area. For instance, de-silting of lake Man Sagar in Jaipur yielded approximately 0.5 million cubic metres of silt which has been used for strengthening of embankment and construction of islands for migratory birds in their wintering grounds. Preliminary results of direct seeding in the islands have been very encouraging (Harsh Vardhan, unpublished data). Assuming that this silt was used to spread a 30-50 cm thick layer over the mine waste, it would have been enough to cover 166.66 ha to 100 ha. Thus, even if we consider only the 4 600 reported minor irrigation tanks - nearly all of which have more area than Man Sagar - for de-silting once, it would yield enough silt to spread 50 cm thick layer over the 0.46 million ha mine waste out of the total 0.9 million ha leased area under mining (Sinha *et al.* 2000). Additionally, we must note that even this is a very conservative calculation for the simple reason that we have not taken into consideration the smaller tanks and village ponds numbering 48 000, and nearly all of the 4 600 minor irrigation tanks are 3 to 5 times larger than the Man Sagar lake.

Furthermore, another approximate estimation of potential availability of sediment for restoration is possible based on the annual rate of lake sedimentation in India. For instance, the sediment accumulation rates for Udai Sagar, Fateh Sagar and Pichola lakes in Rajasthan is estimated to be 8.9, 3.42, and 2.80 mm/yr, respectively (Das and Singh 1994). But the rate may have actually increased due to increased degradation of watersheds. Indeed, a recent estimation of sedimentation rate and expected life of lakes in India suggests that the average rate of sedimentation in upper Bhopal lake is 20.7 mm/yr. For Sagar lake the sedimentation rate was found between 14 to 16.8 mm/y (Kumar *et al.* 2005). Taking a conservative rate of sedimentation to be 5 mm/yr, theoretically a tank with 1 ha area would yield 50 cm thick sediment in just about 100 years, which is enough to cover 1 ha of mine waste. We must, however, add here, that almost all the village tanks have suffered from thick silt build-up in the bed, ranging from approximately 100 cm to 350 cm, as these have not been de-silted for a long time. Thus, it is expected that village tanks can provide enough sediment for mine spoil restoration.

Another evidence of feasibility of the proposed strategy comes from China. Lan *et al.* (1998) which provides an interesting example of use of river-bed sediment and domestic waste as soil amender in China. The Fankou Pb/Zn tailings pond abandoned in 1978, resulted in a 20 ha tailings pile with heavy metal (Pb, Zn, Cu and Cd) toxicity and poor nutrient conditions. The greenhouse study conducted by Lan *et al.* (1978) to evaluate the ameliorating role of river sediment, domestic refuse and inorganic fertilizers in the revegetation of the tailings showed that the growth of *Stylosanthes guianensis* were enhanced due to amendments. River sediment and refuse amendments significantly increased dry matter yields but inorganic fertilizer had no effect.

Direct seeding

Mine spoil treated with sediment can subsequently be fenced as protection againt grazing by free-ranging livestock and directly seeded with suitable species.

Direct seeding of native species has been found to be is a useful and cost-effective restoration method globally (Camargo *et al.* 2002, Parrotta *et al.* 1997, Parrotta and Knowles 1999, Pandey 1996, Singh *et al.* 2004). Direct sowing provides a large base for choice of species. Seed mixture for direct seeding must be carefully selected based on physical and chemical properties of mine spoil as well as ecological, economic and social criteria. A useful approach is to include a set of selected indigenous herbs, grasses, shrubs and trees known as framework species because they help re-establish a basic forest structure that catalyses the recovery of biodiversity (Elliott *et al.* 2003). Identification of a candidate set of framework tree species for direct sowing is guided by six main criteria:

1. multiple use local species that yield forest products to support livelihoods of the communities;
2. reasonably fast growth with dense spreading canopies which rapidly shade out weeds;
3. ease of collection and storage of seeds;
4. a reasonable success in direct seeding;
5. attraction to wildlife (such as fruit and nectar or perching and nesting sites), because birds attracted by such species disperse seeds of other species into the restoration sites;
6. leguminous species, because they enhance soil microbial biomass and N mineralization and promote growth of other saplings growing in their vicinity.

As several keystone species are also socio-culturally valued, their inclusion in ecological restoration programme is helpful. Examples of such species are *Ficus religiosa* and *Ficus bengalensis, Bombax malabaricum, Prosopis cineraria*, and *Acacia* species. Fruit-eating animals and birds prefer to eat figs even when other food is abundant, as high calcium levels contribute to the desirability of figs as food for many animal species (O'Brien *et al.* 1998). Direct sowing of such ecological and cultural keystone species may therefore enhance natural seed dispersal and accelerate succession in mine spoils.

Some of the species may grow better in mine spoils. A study by Rao and Tarafdar (1998) found that *Prosopis juliflora, Salvadora oleoides, Cenchrus ciliaris* can grow well in mine spoils. *Salvadora oleoides, Colophospermum mopane* and *Pithecellobium* dulce have been noted to be calcium-loving plants. These species can be useful for rehabilitation of gypsum mine spoil in Thar desert.

Production of seedlings in the forest nursery requires large inputs in terms of time and money. The expenditure can be minimized, by opting for the direct sowing. Direct sowing is also comparatively easier in term of maintaining the proper proportion of species. It can be combined with planting and natural regeneration. Direct sowing helps in enhancing biodiversity per unit area, perhaps because it accelerates natural plant succession processes, as the ground cover created by newly germinated seeds acts as a nurse crop and can trap air-borne seeds from the vicinity (Jha *et al.* 2000; Jha and Singh 1993). Direct sowing requires simple technique for *in situ* collection of rainwater with the help of suitable soil work such as trenches and saucers. Thus, multi-tier vegetation (i.e. vegetation assemblage layers of herbs, shrubs and trees with differential height profiles) can be effectively developed (Pandey 1996).

INSTITUTIONAL INNOVATIONS FOR RESTORATION AND LIVELIHOODS IMPROVEMENT

The restoration strategy we suggest can work only in a conducive environment by providing 'spaces' for local people to participate and take decisions on different aspects of restoration. It is essential to involve local communities and help them develop regimes for livelihoods improvement. Although there are administrative departments within the government addressing water, forests, mining and drought policies there remains a lack of coherence amongst them. But, we can find 'spaces' in existing legal and policy frameworks such as joint forest management. We suggest that village forest management and protection committees created for joint forest management (JFM) can be employed for restoration of mine spoils and revival of rainwater harvesting systems provided that the government departments facilitate them and provide an opportunity to take their context-specific decisions.

A large network of forest protection committees is already functioning in India. An estimated 84 632 JFM groups involving 8.38 million families are managing 17.33 million hectares (mha) of forests (or 22.2% of the 76.5 mha of total recorded forest land) in 27 States of India. The total number of people covered under the community forestry programme is 62.39 million (Bahuguna *et al.* 2004). Likewise, there are 3 667 village forest protection and management committees managing 3 760 766 ha of plantations and forests in Rajasthan. These village institutions should be viewed as starting points for implementation. We recognize, however, that all may not be well with JFM institutions and we need identification of challenges to craft workable local regimes that address restoration and livelihoods simultaneously (Sekhar 2000, 2004; Kaushal and Kala 2004; Rishi 2003). The real challenge lies in providing flexibility within the JFM policy to adapt and innovate for achievement of mine spoil restoration and revival of water harvesting systems.

FINANCIAL RESOURCES FOR RESTORATION

We must note here that dredging and transport of sediment and subsequent use for restoration is a costly affair. But society has limited options: either keeping mine lands derelict and ponds ruined, or enhancing productivity through restoration and revival.

The model proposed here may need resources ranging between US$5 000 and US$10 000 per ha depending upon the degree of mining and dereliction of lands. These are tentative estimates and a more robust idea of costs would become known after the pilot implementation of our strategy. In 1986 an economic analysis showed that costs for reclaiming mining overburden were INR 66000/ha (Soni and Vasistha 1986). The high costs, however, should not be surprising as a recent global analysis notes that annual cost in some cases can be as high as US$ 1 million per km^2 in programmes that require restoration to recover conservation value (Balmford *et al.* 2003). The resources can be mobilized by three stakeholder-departments: Mines, Water/Irrigation and Forest. Finances for silt removal can be mobilized from the ongoing efforts of the government for promotion of rainwater harvesting. Transport and spreading of sediment and protective fencing of the restoration areas can be financed by Department of Mines in collaboration with mine owners. The Forest Department may provide technical guidance and genetic resource (seeds, vegetative cuttings, plants).

It would be useful to consider mobilizing financial resources for restoration through a clear legal framework that forces mine owners to finance restoration of mine spoils. Along with command and control measures, it is also important to make use of financial tools such as performance bonds. Government policies need to develop mechanisms for mine owners to ensure that they are compensating for the environmental damage.

Although design and enforcement of mine spoil restoration policy must accept the role of incentives to retrieve and store topsoil before starting the mining operations, we note that such operations are possible only before the start of mining. It would be useful to clarify to mine owners that they need to finance the full cost related to: (i) pre-mining vegetation and soil removal, (ii) protection to adjacent vegetation and trees as seed source, (iii) post-mining restoration of overburden, (iv) treatment to adjacent farmlands and streams affected by mining operations, and (v) cost of the preventive measures to mine-induced groundwater pollution. These are essential measures that will provide robust incentives for minimizing damage to the environment.

PILOT IMPLEMENTATION AT SARISKA TIGER RESERVE

The strategy we propose is conceptually robust as well as coherent with natural resource policies and can be implemented as such. Nonetheless, we realize the limitation of resource availability for large scale implementation. Thus, the strategy could be implemented in a phased manner as a learning experiment initially in 215 closed mines around Sariska Tiger Reserve. There have been mining problems primarily for dolomite in the reserve. A survey in 1989 found that over 200 mines fell in the protected forest area and over 40 in the partly protected area (GOI 1993). Our suggestions for implementing the restoration around Sariska Tiger Reserve are guided by three core considerations:

(1) The reserve provides home to the world's western-most population of *Panthera tigris tigris*. But even though the park is critical from a wildlife perspective there are severe conflicts over the use of natural resources. In early 1990s the Supreme Court of India ordered closure of 215 mines in and around Sariska Tiger Reserve (TERI 2001). Restoration of these mines is expected to help eco-development and provide learning and adaptation for large-scale implementation elsewhere. The adjoining district of Jaipur has another potential wildlife habitat in the Jamwa Ramgarh wildlife sanctuary. This protected area is a critical watershed forest for local communities. It may also be a spillover area for young tigers of the Sariska reserve. Anecdotal evidence suggests that mining for talc and marble may have degraded a large area in the Jamwa Ramgarh sanctuary (Banks *et al*. 2003).

(2) There are numerous traditional water harvesting systems surrounding Sariska Tiger Reserve. Although many of these have been revived, and new ones are being constructed, there is a critical need to address the availability of water for wildlife and people. Sediment removal from the traditional *johads* (ponds) shall be useful as an adaptation to random recurrence of drought in the area.

(3) In spite of conflicts over the use of natural resources and damage to crops and livestock by wild animals, local people still have a positive attitude towards the Sariska Tiger Reserve, because of tangible benefits derived from the Reserve in terms of fodder and fuelwood, wildlife tourism, and cultural and religious attitudes towards wild animals (Sekhar 1998, 2000, 2001, 2003). Implementation of the strategy shall provide insights and help learn the operational aspects of integrated natural resource management, which is recognised in principle but seldom implemented.

CONCLUSION

Interdisciplinary approaches that accord respect to alternative knowledge systems are needed to address the effects as well as responses of human activities on tropical ecosystems (Bawa *et al.* 2004). Restoration should thus focus on scientific understanding as well as strategic inclusion of local people, and their values and knowledge into the restoration process (Janzen 1998, Pandey 2003, Sayer *et al*. 2004). In accordance, we have argued a strong case, and designed a commensurate strategy, for simultaneous revival of traditional water harvesting systems and restoration of mine spoils in Rajasthan. In order to convert mine wastes, and ruined traditional ponds and tanks from environmental hazards to a learning opportunity, we need to implement a strategy for restoration, adaptation and productivity enhancement in such a manner that it also promises better prospects for sustainable livelihoods improvement to people dependent on natural resources.

Ancillary benefits of the proposed strategy include revival of traditional rainwater harvesting, enhancement of groundwater replenishment, safe disposal and use of solid waste, enhancement of the rainwater storage capacity in traditional village ponds and lakes, and drought-proofing in Rajasthan. Restoration also promises to enhance the aesthetic appeal of blighted hills in a state noted for tourism.

Although enough is known to initiate a pilot implementation, we recognize two issues for further research. First, collection of data regarding the precise area under various mining leases, active mining, waste dumps and abandoned mines is urgently required. Second, as the implementation progresses, there should be increased research undertaken on the impacts of mine spoil restoration and concurrent revival of traditional water harvesting systems on livelihoods improvement.

Finally, we note that although our analysis has focused locally, lessons learnt through implementation may hold promise for other regions in India, and other countries in Asia, Africa and South America where similar traditions of rainwater harvesting exist.

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