PREVENTION AND CONTROL OF GULLYING PROCESSES IN DIVERSE CLIMATIC SETTINGS: LESSONS FOR THE AGE OF GLOBAL CLIMATE CHANGE

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Abstract International-development initiatives with widely differing goals involved closely comparable activities to control the movement of surface runoff in rural areas and yielded the prevention and control of gullying processes among their results: 1) the conjunctive use of water resources in the Deccan Trap, Maharashtra State, India; 2) the prevention and control of gully erosion in Abia, Anambra, Enugu and Imo States, southeastern Nigeria; 3) the stabilization of part of the left bank of the Dnipro River, near the north end of the Kremenchuk Reservoir, Kaniv Raion, Cherkassy Oblast, Ukraine; and 4) the protection and management of the environment for water sources in the South-to-North Water Diversion Project, Henan Province, China. Common activities involved combining well known technologies, many of them millennia-old with modern science and human resource development in the integration of water-resource management, soil conservation and revegetation of degraded lands. Slope modifications and the controlled flow of runoff on artificial catchments were combined with restoration of a vegetation cover and yielded important, possible contributions to research and governance policy in times of global climate change: 1) The technologies of water harvesting and spreading both contribute to the sustainability of water supply and reduce soil erosion, but can also set the scene for increased agricultural production. 2) An expanded role of the public in environmental decision-making – including gender equality – is essential to the widespread adoption of these technologies. 3) Rural people will need to make significant lifestyle changes, including reduced access and controlled movement of foot (human and livestock) and wheeled traffic off-road in sensitive ecosystems.

INTRODUCTION

The Science Council of Canada (1986) drew attention to the nature of soil degradation and its widespread occurrence in many parts of the nation, where agriculture and horticulture are practiced. The main types of soil degradation, prevalent in Canada, are erosion by wind and water, soil salinization, acidification, compaction and loss of organic matter (Science Council of Canada, op.cit.). The uncontrolled movement of surface runoff, attendant upon rainfall events of high intensity, localized occurrence and frequently short duration, is of particular concern, in that its erosive power commonly finds focus, related to the differential erodibility of surface materials. This focus sets the scene for the processes of gully erosion and, if unchecked, the early stages of badland formation, which radically change topography, affect the relationships between the surface and subsurface circuits of the hydrologic cycle, and promote other types of soil degradation. The insidious nature of these processes ensures that they are seldom seen right away as disasters in the making, which merit management in the form of corrective measures.

The main objective of this paper is to summarize some of the findings of a series of successful projects in international development, as a contribution to risk reduction planning, applied to soil degradation and in particular to the processes of localized erosion by surface runoff. The projects spanned the years from 1991 to 2006 and took place in different climatic settings of Africa, Asia

and Eastern Europe. They addressed problems, which differed greatly in nature and magnitude. However, the solutions were closely comparable, requiring the integration of water-resource management, soil conservation and the return of a vegetation cover to degraded lands. In the account, which follows, the projects are outlined in the terminology of logical framework analysis and results-based management, constructs that are widely applied in international development. Logical framework analysis employs a "narrative summary", a hierarchy of objectives, early project results and the resources, making them possible. Results-based management uses a parallel hierarchy of results, following the same general time sequence.

IMPACTS OF GLOBAL CLIMATE CHANGE

High-profile conferences to set limits on emissions of greenhouse gases at a national level at best can hope to establish policies, which will find applications and benefits, to be realized only decades in the future. In the meantime, there are indications that the impacts of global climate change are increasingly widespread. For example, the main impacts in Canada include: 1) a general decline in summertime extent and thickness of Arctic sea ice with increasingly poor wintertime recovery, during 1979-2008 (Perovich et al., 2009); 2) recent reduction in the areas of the Arctic ice shelves and detachment of the 50-sq.-km, 4,500-year-old Markham Ice Shelf from Ellesmere Island in 2008 (Scott, 2008); 3) shrinkage of the Baffin Island ice caps by 50 percent since the 1950s (Anderson et al., 2007) and the areas of glaciers in the southern Canadian Cordillera declined by up to 15 percent from 1951-2001 (DeBeer and Sharp, 2007); 4) the northward migration of the southern limit of the permafrost in northern Canada, triggering thermokarst processes, such as subsidence and solifluction (Payette and Thibault, 2009); 5) the northward migration of the treeline, with possible, future replacement of tundra lichens and mosses by trees and shrubs and related changes in biodiversity (Serreze et al., 2000); 6) a yearly average increase in air temperature by 1.2^{o} C in the Prairie Provinces, with projections of an increased frequency of drought in southern Saskatchewan (Hengeveld, 2000).

The onshore changes, listed above, are to varying degrees related to each other and to the year-round continuity between the surface and subsurface circuits of the hydrologic cycle, a new phenomenon in northern locations, now increasingly exposed to elevated temperatures. The combination of extreme, climatic events and the increased vulnerability of soils to erosion and other forms of degradation poses a serious threat to water supply and food security. Indeed, parts of North America may be destined to face challenges of this type, which have been traditionally associated with the less developed countries. The viewpoint, presented in this account, is that the more developed nations can benefit greatly from the lessons learned in international-development initiatives with a focus on water and soil. This is particularly true, where there is a basis for comparison with the gullying processes, occurring at accelerated rates under tropical conditions.

CONJUNCTIVE USE OF WATER RESOURCES IN DECCAN TRAP, INDIA

The research partners were the University of Windsor and the Pune NGO, Bharatiya Agro Industries Foundation (BAIF), working with the tribal and rural people of Akole *Taluka*, Maharashtra State, India. The aim was to design a strategy for a year-round, domestic water supply in three villages and outlying areas and to explain the shortage of water in the region (Sohani et al., 1998). The project utilized demonstration sites for technologies of water

harvesting and spreading, which solved the water-supply problem. Other results of the project in the dryland area included: reduced soil erosion, expanded vegetation cover, increases in agricultural production, improvements to public health, advances in gender equality, and expansion of biodiversity (Simpson, 2006). The project contributed to research policy in BAIF through a joint training programme over a five-year period and to governance policy in the villages. The funding agency was the International Development Research Centre, Ottawa.

Project Outline "Conjunctive use" of water means the integrated use of water from multiple sources. The project **goal** was to improve the management of water resources in Akole *Taluka*. The **purpose** was to explain the scarcity of water in the area and design a strategy for access to a year-round water supply, with an emphasis on domestic supply. Three villages were selected as partners. The project ran from 1992 to 1996. The frugal use of funds permitted an assessment of project sustainability with some of the remaining money in May-June, 1997. The technical and financial reports were processed by IDRC in early 1998. From 1996 to 2001, BAIF and University of Windsor Earth Sciences mounted a series of project-related workshops and other training initiatives for the NGO's personnel in Maharashtra, Karnataka, Gujarat and Rajasthan.

The project **output**s were a strategy for improved management of water resources, demonstration sites for water and soil conservation, research results, trained BAIF personnel, villagers with vocational skills, and an enhanced sense of community in the partner villages. The **activities** that produced the outputs were compilation of a database on water- and soil-conservation technologies, laboratory analysis of field samples (rock, soil and water), fieldwork in hydrology and hydrogeology, compilation of indigenous knowledge (IK) on water and soil, and expansion of the RRA database. The project **inputs** were "on-the-job" training of BAIF personnel and the people, computing equipment and software for BAIF, logistical support in the field from BAIF, and the funding from IDRC.

Research Imagery from Earth satellites in orbit was analyzed at the Space Applications Centre, Ahmedabad, and the Maharashtra Remote Sensing Application Centre, Nagpur, to provide base maps, including a land classification and the trends of straight-line ground features, termed lineaments. Next, the aquifer properties of the soil cover, weathered bedrock and shallow, volcanic bedrock were investigated by integrating field and laboratory studies. The research partners used Geographic Information Systems (GIS) software to integrate these data, as well as indigenous knowledge and local, religious beliefs, related to water and soil. For example, the people revere the tree *Ficus glomerata*, known locally as *umbar*, which shows an affinity to shallow, underground water. They also contributed knowledge of the terrain, a typology of land and crop patterns, and a set of cultivation practices. Use was made of ancient, Indian hydrology, according to the *Brahat Samhita* of Varaha Mihira (Sixth Century).

A thin, impermeable layer of clay was found to occur at and near the surface of soils with improved aquifer quality, in the wider valleys. The weathered bedrock, occurring at variable depths below the soil, forms shallow, discontinuous aquifers. The bedrock consists of basalt lavas, in a thick pile of extensive flows. Many of the lineaments were found to coincide with fractures in the otherwise impermeable lavas. These commonly form conduits for ground water, up to several kilometers in length. Some lineaments are the sites of valley erosion by ephemeral streams; others mark the locations, at which springs issue from the hillsides. The isotopic content

(oxygen-18 and deuterium) of water samples from surface and underground locations for the most part showed only minor variation, indicating that most ground water originated during the previous monsoon (Sohani et al., 1998).

Results Research results and indigenous knowledge were used in selection and citing of **appropriate technologies** for water and soil conservation, from late 1992 onwards. These included adaptations of millennia-old techniques from other dryland regions, in India and around the world (Sohani et al., 1998). The appropriateness of particular technologies for local use was determined in consultation with village watershed committees, which reported to their communities at public meetings (Simpson and Sohani, 2003). The concept of a watershed committee came from the transfer into the area of the indigenous concept of *ayojan*, which allows a group of villagers to make recommendations, affecting the community, as a whole. Another indigenous concept, introduced from outside of the area, was *wavli*, which allows rural women to generate income from small-scale, commercial activities, such as the sale of vegetables. This took the form of a number of women's self-help groups in the partner villages.

The three villages and outlying areas were made up of 494 families, altogether 3,239 individuals, who gained year-round access to water from **demonstration sites**, implemented over an area of about 1,000 ha. About 73,000 cu. m. of water were stored behind 14 masonry check dams and three ferrocement gabions. Up to 20 percent of the households took water for domestic use from six developed springs. Roof water harvesting was adopted in all three villages, in 26 households initially. Water availability increased by about 750 litres per day per capita during the driest part of the year, at the end of the pre-monsoon season (May-June). Domestic wastewater was used to maintain kitchen gardens, close to village dwellings. Water spreading diverted up to 19 million cu. m. of water annually into shallow aquifers. Contour trenches averted an annual soil loss of about 150,000 tonnes. A further 6,500 gully plugs, 75 dry-stone bunds, and 75 gabions trapped about 32,000 tonnes of soil. The soil conservation technologies were augmented with vegetative techniques, which employed multipurpose plants, such as bamboo, agave and vetiver grass. About 300 ha of wasteland were brought under cultivation during the rainy season. A second crop was obtained from 75 ha of land, as a result of increases in soil moisture.

The project **outcomes** were successful demonstration sites for the technologies, sustainable access to water year-round, empowered village partners, pluralism in environmental awareness in the project area, and an enabling environment for water-supply projects of a similar nature. Artificial recharge had the effect of elevating the soil moisture over an extended period. This caused increases in agricultural production during both growing seasons. Increased amounts of wasteland were put into agricultural use. The people reduced the numbers of their livestock and replaced them with animals of better quality. The check on project sustainability in May-June 1997 and also each year up to the end of 2000, attested to the continued availability of water. BAIF employed the same technologies over a wider area of Akole *Taluka*, with funding from the National Bank for Agricultural Research and Development (NABARD), as part of the Indo-German Watershed Development Programme. The project **impact** is year-round access to water in the highland regions of the *taluka*.

GULLY EROSION, NIGERIA

The research partners were the University of Windsor and the University of Port Harcourt, Port Harcourt, Rivers State, and the Nnamdi Azikiwe University, Awka, Anambra State, working with the people of twelve villages, in Abia, Anambra, Enugu and Imo States, South-East Nigeria. The aim was to design a strategy for the control and prevention of catastrophic gullies, which destroyed homes, isolated villages, devastated infrastructure and rendered land useless for agriculture and forestry, and also to account for the high incidence of gullies in the region (Hudec et al., 2005, 2006). The project also contributed on an emergency basis to the termination of gully growth at several villages under threat. It made contributions to research policy at the partner institutions and to governance policy and increased public awareness of the environment in South-East Nigeria. The funding agency was the International Development Research Centre, Ottawa.

Project Outline In Southeastern Nigeria, catastrophic gullies are formed by surface runoff in the fine- to medium-grained Coastal Plain Sands (Pliocene to Recent) and Nanka Sands (Eocene) and the medium- to coarse-grained Nsukka Sandstone and Ajali Sandstone (Cretaceous) of the Anambra-Imo basin region. Gully processes ultimately yield a degraded "badlands" terrain, comprising knife-edged ridges, separated by deep ravines, and no longer amenable to agricultural use. The pronounced erosion of the land surface causes an overall lowering of the water table. The resulting scarcity of water supply for rural people is compounded by the reduced quality of the water in down-slope locations, where it is laden with the suspended sediment, eroded from the adjacent uplands.

The project **goa**l was to reduce gully erosion in Southeastern Nigeria. The **purpose** was to explain the localization of gullies in the area and to design a strategy for the prevention and control of gully processes. The villages, selected as partners, were: Umennekwu and Uturu (Abia State), Ekwulobia, Oraukwu and Umuchu (Anambra State), Ngwo and Obfinia/ Ndiono (Enugu State) and Amucha, Umuaka/ Okwudor and Umuchima (Imo State). The project ran from 1992 to 2000. The work was interrupted in 1996 by a hiatus in democratic rule in Nigeria and was resumed, during the summer of 1999.

The project **outputs** were a strategy for the prevention and control of gully erosion, demonstration sites for both soil and water conservation, research results, trained research personnel at the two Nigerian universities, villagers with improved technical skills and informed policy makers in different levels of government. The **activities** that produced the outputs were engineering-geology fieldwork in the areas most affected by gully processes, laboratory analyses of the soils and sediments and a rapid rural appraisal (RRA) with a focus on gully erosion. The **inputs** were "on-the-job" training of the Nigerian university researchers and the villagers, computing equipment and vehicles for the university researchers, logistical support in the field from the Nigerian university partners and the funding from IDRC.

Research The project research included detailed mapping of the gully systems at selected locations, over a period of eight years. As well, revisions were made to existing maps of the surface deposits and the solid geology at and around the main sites of gully erosion. These

systematic observations yielded information on the principal mechanisms of gully formation and data on the rate and configuration of gully advance. The soils, sediments and rock units were sampled for examination in the laboratory and engineering-geology analyses were performed on them. These analyses included gradation (size) analysis and determinations of Atterberg limits (the liquid limit and the plastic limit), dry bulk density, dispersion rates (rates of disaggregation of wetted samples), proportions of mineral cement and moisture content in the soils, sediments and rock units, affected by gully processes.

Close to the beginning of the project term, the people of several villages and outlying areas began **emergency measures** to arrest the advance of gullies that were threatening parts of their settlements, as well as nearby highways and communication systems. Discussions with the villagers, based on project research and observations in other tropical locations at risk from soil erosion, led to beneficial changes in their approaches to remediation. These locations provided observation sites that were monitored carefully throughout the project term. Such interactions with the village partners greatly facilitated the compilation of RRA data on how gully processes affected the daily lives of rural people. They provided insights into indigenous knowledge, as applied to the control of surface runoff. Some observation sites demonstrated the natural termination of gully processes by vegetation.

Results The research teams encouraged the people to elect erosion committees in each village. Modifications to the design of the emergency remediation measures, implemented by the people, were proposed, on the basis of project research results and considerations of indigenous knowledge. Local methods for the diversion of surface runoff away from settlements and roads include the use of adobe and brush barriers, diversion ditches and catchment basins. As well, the people initiated terracing of the hillsides, about fifty years ago. All of these indigenous technologies for the control and prevention of gully erosion fell into disrepair, as a result of major increases in the rural population, with related increases in foot traffic over the hillsides.

Laboratory analyses indicate that the textural properties of the soils and the horizontal to gently inclined sediments and sedimentary rocks make them inherently susceptible to erosion. They are among the defining elements of a sensitive ecosystem, which undergoes rapid degradation, in response to surface runoff and human disruption. Gully initiation is the result of localized erosion by surface runoff, associated with rainfall events of high intensity. Erosion occurs, where the forest cover has been removed for agricultural purposes and at sites of uneven compaction of soils by foot (human and livestock) and wheeled traffic. It also takes place, where soils and sediments abut against artificial materials, notably at poorly designed road culverts and roadside gutters. Gully propagation is by caving and sliding of materials at the gully head and sliding along the sides, accompanied by the overall, down-slope transportation of gully-floor debris by storm runoff. Gully growth tends to occur in directions of increasing proportions of coarse sand.

The project **outcomes** were controlled runoff at the observation sites, sustainable control of gully erosion at the sites of emergency, empowered village partners and pluralism of environmental awareness in and around the partner villages. The termination of gully processes requires the integration of water-resource management, soil conservation and revegetation on the scale of a drainage basin. The technologies of water harvesting and spreading are necessary on hillsides, cleared for agricultural production. Some water-harvesting technologies, such as roof-water

harvesting, contribute to water supply, but also assist in the control of runoff in settlements directly under threat. Spillways, diversion channels, culverts and gutters must be designed to accommodate runoff amounts at particular locations, with design elements of indigenous technologies as their starting points. The project **impact** is reduction and local control of gully formation in Abia, Anambra, Enugu and Imo States.

RIVER BANK STABILIZATION, UKRAINE (SHORELINE DEMONSTRATION PROJECT, GREEN TECHNOLOGIES, UKRAINE)

The University of Windsor and Ecologistics International Limited, Waterloo, advised the Dnipro Basin Water Management Association, Vyshgorod, about appropriate measures to reduce erosion and improve water quality, along part of the left bank of the Dnipro River, between the villages of Keleberda and Prokhorivka, Cherkassy Oblast, Kaniv Raion, Ukraine; the Association worked with the rural people of the villages and outlying areas. The evaluation by the Canadian International Development Agency (CIDA Performance Review Branch, 1999) states: "A river bank stabilization project not only controlled erosion, but helped establish a responsive approach to public works by involving local residents in [the] decision making process." "They [the Dnipro Basin Water Management Association] began at [the] local council in the next stabilization zone project…." The work was funded by the International Development Research Centre, Ottawa, as part of its project Environmental Management Development Ukraine, Phase 1.

A demonstration site for river bank stabilization measures was located along the 2.5 km of the left bank of the Dnipro River between Keleberda and Prochorivka, south of the city of Kaniv and to the immediate north of the Kremenchuck Reservoir (Dnipro Basin Water Masnagement Association, 1998). The river channel and banks had undergone modifications in process and form after the filling of the Kremenchuk Reservoir in 1960 and following the start of operations at the Kaniv hydroelectric dam in 1972. Operation of the dam involves discharges of water twice daily, during the morning and the evening. This has resulted in river bank erosion and flooding. Groynes were later constructed near Keleberda and close to the resort centre of Prokhorivka to eliminate erosion of the river bank. Sand was introduced in the inter-groyne parts of the bank near Keleberda to form a series of bars, sloping down to the river channel. A line of willows was planted at the base of the sandy bluffs, also for the purpose of reducing river erosion.

The DBWMA recognized three zones within the demonstration site: 1) a northwesterly, upriver zone near Keleberda, with low relief, minor bank degradation with incipient gullying, groynes in the river channel and sedimentation at the bank close to them, and use of the adjacent land by the villagers as pasture for cattle; 2) a central zone, with a flat sand-bar surface, giving way to sandy bluffs, wind and gravity-controlled modification of the slopes overlooking the river, pine forest at higher elevations, relative stability in relation to river processes, and touristic use of the land at and close to the bank; and 3) a southeasterly zone near Prokhorivka, with intermediate relief, sporadic bank recession from physical and biological weathering, groynes in the river channel, associated pools and only minor sedimentation near the bank, and recreational use of the land.

The Canadian team was briefed by the DBWMA about the location of the demonstration site, within the Dnipro Cascade, a system of interconnected reservoirs, constructed along the Dinpro River and linked by parts of the river channel that are relatively unmodified. The team visited the

demonstration site twice between August and December 1996 and advised the DBWMA about additional measures to mitigate erosion, employed in North America, and related socio-economic issues. These included considerations of a protection zone and the possible introduction of low-cost bioengineering measures. The recommendations of the Canadian team also included the introduction of participatory management and evaluation by the local people (Cressman, 1996; Simpson, 1996a, 1996b). A question set for assessment of the socio-economic impact of land degradation was prepared and presented to DBWMA researchers for possible use by them (Simpson, 1996a) and provided a basis for discussion. The question set was also put to use in the brainstorming sessions of workshops, held during the training activities, carried out in India.

Measures for the mitigation of erosion in the demonstration site (Dnipro Basin Water Management Association, 1998) included the creation of a protection zone along the river to eliminate the weakening of bank materials by the foot traffic of livestock herds and to safeguard the quality of river water against degradation by animal feces. Human foot traffic was restricted and access by off-road vehicles eliminated in the area of sandy bluffs and the adjacent, recreational area with forest cover. A buffer zone of willows and other trees was put in place, where pastures formerly bordered on the river bank, and grasses were planted to protect the vulnerable sands against wind erosion. The acceptance of rural people as full partners in the project by the Ukrainian researchers was a significant innovation, which was adopted in the subsequent projects of the DBWMA. The demonstration site provided a basis for a course on the protection of water resources at the T. Shevchenko Kyiv State University.

CONSULTATION FOR PROTECTION AND MANAGEMENT OF ECO-ENVIRONMENT FOR WATER SOURCE OF SOUTH-TO-NORTH WATER DIVERSION PROJECT, HENAN PROVINCE, CHINA

The author worked with the Nanyang Local Agenda 21 Administrative Office, Nanyang, Henan Province, China, in an initiative of the Office, by visiting and commenting on field demonstration sites for water-resource management, soil conservation and revegetation of degraded lands. The sites are located in the source area for waters, entering the Danjiangkou Reservoir and the Hanjiang River, an important part of the Middle Route Project of China's South-to-North Water Diversion, which will transfer water from the southern regions to the northern cities of China. The author incorporated these observations into a public lecture in Nanyang, which dealt with the experience of the University of Windsor in the field of integrated water resource management in India, Nigeria and Ukraine. The work contributed to research and governance policy in Henan Province. The work was funded by the Nanyang Local Agenda 21 Administrative Office.

The first official event was a briefing by staff of the Nanyang Local Agenda 21 Office and the Science and Technique Bureau in Nanyang City about the Middle Route Project of the South-to-North Water Transfer. The South-to-North Water Diversion Project comprises three separate projects, the West Route Project, the Middle Route Project and the East Route Project, which will divert water from different parts of the Chiangjiang (Yangtze) River to northern and northwestern regions of China. The Middle Route Project will divert water from the Danjiangkou Reservoir on the Hanjiang River, a tributary of the Chiangjiang River, to Beijing and Tianjin (ACCA21, 2004). It is anticipated that this water will be supplemented by flow from the Three Gorges Reservoir, on the Chiangjiang River to the south. The Nanyang Local Agenda 21 Administrative Office and

the Nanyang Bureau for the Introduction of Foreign Experts were responsible for the protection and management of water sources for the Danjiangkou Reservoir and the Hanjiang River.

There was a day-long field trip to the Taocha Sluice, which marks the start of the main trunk canal of the Middle Route Project at an existing 8-km. canal, running along the south side of Funiu Mountain and through Nanyang City. The route also included stops along the Mancheng Section, where various soil conservation technologies have been implemented. The terracing of hill slopes and the introduction of "living fences", composed of vetiver grass and bahia grass, were the main measures introduced for protection against soil erosion in the river basin regions of Henan Province, bordering on the Danjiangkou Reservoir. Vetiver and bahia grasses were grown in special nurseries for use in the project (Nanyang Local Agenda 21 Office, 2006).

Another one-day field trip was to the Danjiangkou Reservoir, which was undergoing enlargement as part of the Middle Route Project. The height of the dam was being increased from a crest elevation of 162 m. to 176.6 m. and the normal water storage level from 157 m. to 170 m. The projected total storage capacity is to be 29.05 billion cu. m., which will be an increase of 11.6 billion cu. m. An additional 370 sq. km. of land will be inundated by the end of the Danjiangkou Dam Extension Project. The field party visited some of the locations that will be flooded.

The author gave a public lecture on the projects in India, Nigeria and Ukraine, outlined above, and afterwards visited the Nanyang Normal University. Comments on the demonstration sites and surrounding areas, visited during the two previous days, mainly dealt with additional slope modifications to augment the highly effective vegetative measures. The author also met officials from parastatal organizations, government agencies and educational institutions.

CONCLUDING REMARKS

Combinations of slope reduction measures and vegetative techniques for the stabilization of slope materials reduced erosion at demonstration sites in projects, with very different objectives, but sharing the common aims of controlling the movement of surface waters and minimizing soil erosion by runoff in the diverse, climatic settings: 1) collaborative research on the design of a strategy for the provision of a year-round water supply for domestic use in a dryland region of the State of Maharashtra, India; 2) collaborative research on the prevention and control of erosion, leading to the formation of the catastrophic gullies that disrupt infrastructure in southeastern Nigeria; 3) recommendations to Ukrainian researchers on the stabilization of part of the left bank of the Dnipro River, within the Dnipro Cascade of linked reservoirs; and 4) recommendations to Chinese collaborators on the protection of the water sources for the Middle Route Project of the South-to-North Water Diversion

Research on the conjunctive use of water resources in part of the Deccan Trap region in Maharashtra State, India, combined cutting-edge science with the indigenous knowledge of the rural poor and the millennia-old technologies of water harvesting and spreading. Lineament analysis from the study of satellite imagery permitted the effective siting of check dams and associated reservoirs, as well as slope modifications, including the excavation of hillside terraces. The terracing of hill slopes and management of water movement between consecutive terrace levels greatly reduced soil erosion. Masonry gully plugs at sites of incipient gully formation and

gabion structures, constructed across narrow valleys, also contributed directly to the reduction of more localized soil erosion.

The study of gully erosion in SE Nigeria demonstrated that the poor design of roadside drainage was responsible for the localized erosion of hillsides and most of the occurrences of gullies in the region. Specifically, roadside gutters, too small to contain the highway runoff, are the sites of undercutting by overflowing water, followed by the collapse of the gutters and localized erosion, leading to gully formation and initial expansion in a down-slope direction. Other causes of gullying processes include faulty farming practices and the uncontrolled movement of humans and herds of livestock in off-road locations. It is noteworthy that the terracing of slopes under agricultural production and the harvesting of water from the roofs of dwellings greatly reduced the incidence of localized erosion by runoff.

The work on rural water supply in India placed emphasis on slope modifications that slow the down-slope movement of surface runoff and reduce its erosive power. As well, the Indian study put to beneficial use both artificial and natural catchments in the harvesting of water for consumptive use and for irrigation. The Nigerian project on gully erosion showed that control of the movement of surface runoff on both natural and artificial surfaces is essential to eliminate localized erosion of catastrophic dimensions. In different ways, each of the four projects demonstrated the benefits to be gained from integrating water-resource management, soil conservation and re-establishment of a vegetation cover on degraded lands.

The Indian study drew attention to the fact that many of the technologies of water spreading and harvesting are of considerable antiquity and also have a place in the knowledge systems of rural people. All of the projects benefitted from the integration of knowledge of this kind with the techniques of modern science and engineering. A common thread throughout the projects was the need for research partnerships with rural people. The practical advantages, as well as the ethical imperative, of gender equality were shown most clearly in the work with Indian villagers.

The potential harm to water and soil from the uncontrolled movement of foot and wheeled traffic off-road in sensitive ecosystems provides another link between studies, carried out in very different climatic settings. This connection carries particular significance among the burgeoning populations of less developed countries, where beneficial change will require significant adjustments to deeply ingrained practices and to lifestyles in general. It points to an expanded role for environmental education, targeting the rural people, who are project partners. The lessons learned in these projects, involving collaborators and beneficiaries with very different, cultural backgrounds, are likely to gain wider application as global climate change affects increasing areas of the more developed countries.

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