EMBANKMENT EROSION CONTROL:
TOWARDS CHEAP AND SIMPLE PRACTICAL SOLUTIONS FOR BANGLADESH

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Abstract

Costly rehabilitation to combat erosion of earth embankments has been going on in Bangladesh since time immemorial. Institutional steps started during the 1960s and nearly 13 000 km of embankments have been constructed to safeguard against inundation, intrusion of saline water and devastation. A system of routine maintenance could not be established, mainly due to institutional shortcomings and the lack of an appropriate system of erosion control. Maintenance has been restricted to major repairs only when embankments were close to failure or had completely failed and caused serious losses. Soil thus eroded, including from other constructions, terraces and slopes and accumulated in water bodies (more than 2 700 million m^3/year) disrupting the transportation system, affecting productivity and deteriorating the environment. To combat this disaster, erosion control is necessary and must be technically suitable, cost-effective, people-oriented, sustainable and environmentally safe.

The Coastal Embankment Rehabilitation Project (CERP) has adopted the land-use approach for biological means of protection against erosion. To control runoff erosion of embankments, models have been developed with vetiver and other associates combined with low-cost mechanical methods.

Introduction

Bangladesh is one of the least developed and most densely populated countries of the world. The great majority of the people directly or indirectly depend on agriculture for earning a living. The annual growth rate of GDP is greatly dependent on agricultural produce. With the aim of increasing agricultural production, construction of earth embankments and dykes, their repairing and rebuilding for irrigation, flood control and drainage have been the history of Bangladesh since time immemorial. The zamindar (landlord) system came into existence long ago to organize agricultural production.

Institutional steps for constructing embankments started with the creation of the East Pakistan Water and Power Development Authority (EPWAPDA) in 1959. After the independence of Bangladesh, EPWAPDA was split in 1972 into two organizations, namely the Bangladesh Water Development Board (BWDB) and the Bangladesh Power Development Board (BPDB). Embankment, dykes and other allied structure fall under BWDB to save life and properties from natural disasters and to increase agricultural production. Over the last few decades, nearly 13 000 km of embankments have been constructed[1]:

- Over 4 000 km of coastal embankments along the coastline surrounding the Bay of Bengal and offshore islands[2]
- Nearly 4 600 km of embankments along the bank of big rivers flowing across the country[3]
- Nearly 4 500 km of low-lying embankments along the small rivers, *haors* and canals[4]

To develop an effective system of irrigation, flood control and drainage, a few thousand allied structures also form the integral part of embankments. 1 488 regulators/sluices, 108 bridges and 923

[1] *The Bangladesh Observer, p.6, 20 August 1999*
[2] *BWDB statistics of 30/6/1998*
[3] *Ditto*
[4] *Adjusted from total length of 13 000 km*

other structures have been constructed in 135 polders over 472 km of embankment to protect 1.09 million ha of land.[5]

River embankments protect lives and property from inundation during the monsoon. Sea embankments of the offshore islands and coastal zones provide safeguard against the intrusion of saline water and devastation associated with repeated attacks of tidal surges and cyclonic storms.

To minimize the impact of natural disasters as well as to achieve the aim of agricultural production, sustainable and cost-effective maintenance of those embankments and allied structures is a sine qua non for Bangladesh.

Causes of Erosion and Their Effects

Earth embankments in Bangladesh are beset with multi-facetted problems. The design and construction methods used to build the embankments, the nature and extent of erosive forces to destabilize them and above all the attitude of the local people for whom they are built altogether determine the magnitude and degree of instability.

Most earthen embankments face light to moderate erosion problems arising out of rainfall splash, animal actions and the nature of human uses. Some of the critically positioned submerged types of embankment in *haor* areas of the eastern part and river embankments of the main land are subjected to turbulent water currents and changes in river courses. The problem is acute in offshore islands and coastal belts where the embankments are in addition exposed to erosion by sea waves and tidal fluctuation of water levels.

The estimate prepared by BWDB in 1984 shows that about 1 200 km of bank length of rivers were subjected to erosion, 565 km of which faced severe erosion problems. The instability in river regime coupled with huge discharge and sediment load cause erosion, scouring and also deposition, and thus a chain action proceeds. This is almost a recurring phenomenon. As per the latest information available from BWDB, it is found that 441 projects/sub-projects are either fully or partially damaged due to the severe floods of 1998. The total estimated cost of the rehabilitation works listed below is about US$143.17 million.

- Embankment – 2 987 km
- Irrigation/Drainage canal – 373 km
- Water control structures – 1 031
- Protection works – 187

In the coastal belt and offshore islands also, severe bank erosion problems occur frequently. New accretion and shifting of the bank line due to erosion happen almost in the same way as those observed in the inland rivers. However, the nature and extent of erosive forces damaging the seashore and successively the dykes differ in certain aspects from those of the inland riverbanks.

The process of erosion gradually destroys the shore lands/riverbanks, foreshore areas/berms and successively the earthen embankments engulfing the plain agricultural lands, habitats and many important installations. In the affected reaches, the embankments built with adequate setback are found to disappear within a year or two of the start of erosion. Generally new embankments are constructed along separate alignments (further back in the countryside), simultaneously adopting sufficient measures to check the bank erosion. Whenever the situation compels to protect the high-value assets and important installations as the losses are really irreparable or would have a great impact on the national economy, sophisticated structural means of proven engineering solutions involving huge costs are often adopted to combat the erosive forces.

Other constructions vulnerable to rain and flood damage include about 7 000 km of national highways, 90 000 km of feeder roads and millions of homestead flat forms. In addition, agricultural and forest land on terraces and hill slopes are subjected to sheet and gully erosion during the monsoon. Soil thus eroded each year becomes accumulated in rivers, reservoirs, harbors, estuaries and other water bodies,

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[5] *Annex 1, Inception Report of 2nd CERP (September 1999), JPC*

disrupting the water transportation system, shrinking fish habitat and affecting surface water storage capacity and groundwater recharge. All this affects the productivity of agriculture, fishery and livestock. Frequent dredging or re-excavation of silted-up water bodies is costly. These consequently deteriorate the overall environment of the country.

The volume of silt deposited in Bangladesh each year including the silt received from across the border amounts to more than 2.70 million m^3. Dredging the volume of silt deposited each year by deploying all the dredge power of Bangladesh 24 hours a day and 365 days a year would require a hundred years[6].

Thus erosion creates a double disaster – erosion of resources from where it is mostly wanted and simultaneous accumulation where it is unwanted.

The most common causes are natural forces and human interference.

Natural Forces

The natural forces cause erosion of the embankments in the following way:

Rainfall impact (from both the regular monsoon rains and torrential rains): Mean annual rainfall varies from about 1500 mm in the northwest (Khulna district) to over 3750 mm in the south (Cox's Bazar). The heaviest rainfall occurs in July and ranges from 350 mm to over 875 mm accordingly[7]. The slope erosion caused by rain runoff is enormous and its speed/force grows exponentially towards the toe. Toe erosion is the combined effect of runoff and wave action. The main features of rainfall impact are:

- The embankment crest is mainly affected with the formation of *ghoghs* and initiation of piping action leading to collapses in combination with either.
- Surface runoff caused by rainfall results in sheet erosion and the formation of gullies and rills on poorly protected embankment shoulders, slopes and toes.
- Flooding (monsoon/periodic floods and those created by storms/cyclones).
- The high head of water on the river side induces piping across the embankment, which may lead to breaching and collapse of the polder system.
- Monsoon flooding often gives rise to serious erosion of embankments by undermining due to current, vortex and wave forces; the entire embankment gets affected, beginning with the damage of shoulders and crest due to undermining, and gradually the overtopping causes a complete wash down.

Wave action (daily/periodic and created by constant wind)

- Tidal waves cause damage to the embankments located too near to the sea (the earthen embankments in the coastal zones should have adequate setback not allowing its exposure to wave actions). A severe hydraulic load is steadily exerted on the toes and slopes and causes erosion.
- Cyclonic storms in the coastal zone (occurring repeatedly) act upon the water surface, causing it to advance towards the shore with enormous hydraulic loads. The waves thus formed eventually hit the embankment toe and slopes. The high hydraulic loads exerted on the embankment cause erosion and if there is overtopping, the physical structure of the embankment is destroyed.

Turbulent water currents (mainly in rivers and at coastlines)

- The high velocity flow of water associated with vortex motion in rivers and estuaries often causes erosion of the banks by undermining, and the eventual collapse of the embankment threatens unless protective measures are taken.

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[6] *Professor Ainon Nishat, BUET/Dr. M. M. Hassan, The Bangladesh Observer, 20.08.99, p.6*
[7] *Source: Bangladesh Meteorological Department*

- At the mouth of a branch river or canal, especially in the surroundings of sluice gates, the turbulent water current erodes the banks and subsequently the embankments.
- The presence of continuous borrow-pits on a river or seaside induces undercutting of the embankment toes and slopes due to complete inundation of the riverbank or seashore during the monsoon. The borrow-pits and adjoining lowlands thus inundated induce a parallel water current to flow along very near the embankment toes and slopes, thereby eroding the surfaces rapidly.

Wind action: the slow and steady action of wind in the relatively sparse fields and coastlines blows away the topsoil of the embankments where it is sandy or a mixture of silt and sand. The embankment crest and bare surfaces are gradually eroded to leave patch holes and undulated surfaces for further decaying by rainfall splash, runoff or wave action.

Human Interference

The human interference responsible for major embankment erosion is quite diverse in nature and often varies according to the lifestyle and manner of using the embankments of the inhabitants of different areas. The most commonly observed erosion problems out of the varied human uses are noted below:

Travel paths for men and cattle: The people living around use the embankments as the main travel paths. The crests thus serve as a rural communication road between villages. Besides plying rickshaws, vans, bicycles and bullock carts, in many areas motorized vehicles also move regularly on these earthen embankments in the dry season. Movement of bullock carts in the rainy season inscribes deep path marks along the track which induce further decaying of the embankment crest by trapping of the rainwater inside.

The people and their cattle, while moving along the damaged crest, often tend to take a better alternative route along the shoulders, slopes and even toes. Gradually the shoulders and slopes are also affected.

Villagers frequently have to cross over the embankment to have direct access to the river or the sea to meet their various daily needs. The slopes of both the sides near such passages and boat-landing ghats erode continually. Also the bank and foreshore areas are destroyed due to frequent crossing of the embankment, thus inducing funnel action of the river or sea to advance towards the embankment, eroding toes and slopes. The movement of people on the embankment becomes more intense if the concentration of economic activities around and on the embankments is higher.

During field trips, various kinds of uses including boat building, cattle rearing, post-harvest processing, cultivation and trade activities have been observed. Exceeding the population-supporting capacity of the embankment results in the weakening or disappearance of the plant cover and eventually in the complete collapse of the embankment.

Homesteads and agricultural practices: Embankments often become the privileged sites for the construction of villages and isolated homesteads. This is mainly due to the fact that the embankments give the people a sentiment of security from flooding. Those who have lost their lands and properties due to river erosion or acquisition of land for development activities and practically have no shelter find no other way than to become squatters to live on the embankments. Also the poor and landless people who are marginal day labourers without any house to live in build their huts on the embankment slopes. The presence of homesteads on the embankment gives rise to various other associated uses, including raising agricultural produce for subsistence and intensive cattle grazing.

Very often, steep or very steep embankment slopes are cultivated with annual or biennial crops imposing regular soil tillage. By loosening the soil and denuding it, repeated soil tillage results in severe erosion. To obtain a gentler slope and to facilitate agricultural practices, the upper part of the embankment slope is cut and the earth is spread over the lower portion. Farmers usually plant banana and papaya on the shoulders and slopes. After their eviction or if these trees are cut down by them to harvest the crops, the roots are subjected to rapid decay, leaving root holes. The unmanaged cultivation of these species destabilizes the embankments.

Agricultural practices on embankments are encouraged by:

- a high demographic pressure on the available land and accordingly a shortage of land for the rural population;
- minimal land acquisition by the government brought about by high appropriation costs; as such, there is often no or insufficient provision to resettle people displaced by the construction of embankments; and
- a poor performance of routine maintenance activities for the embankments.

Cattle grazing: Cattle, mainly belonging to people living on the embankment, cause erosion by uncontrolled browsing of natural grasses. When the embankment is overgrazed, plant species and the vegetative cover, especially the grasses, show retarded growth, weaken and cannot continue to ensure adequate protection of the embankment. The squatters, most of whom are poor and landless, prefer to keep goats as pet animals with their limited scope at the embankment homesteads. The grazing of goats is particularly harmful to the vegetative cover.

Slopes grazed by heavy cattle, mainly cows and buffaloes, often show a typical pattern of browsing tracks running more or less along the contours. These paths form unstable micro-terraces, where the upslope soil material is deposited at the lower side of the track and finally reaches the embankment toe in successive down-slope movements. The uncontrolled grazing of heavy cattle destroys the foreshore gardens and shrubs or bushes growing on the riverbanks, resulting in direct exposure of the embankment surfaces to wave action and water currents. The community people rarely feel it necessary to prevent their grazing animals from destroying the embankment slope vegetation because of their lack of knowledge on the importance of stable embankment as well as unscrupulous attitude of profiteering through grazing.

Public cuts: Public cuts and tubes linking a river or seaside with the country side of its embankment are frequently observed. These cuts weaken the embankments, exposing them to slow but continual erosive forces. During flood or cyclonic storm, breaching or major erosion occurs at those points. The people mainly cut the embankments to fulfil their purposes:

- To get rid of the poor and inadequate drainage conditions of the existing structures, they arrange quick removal of excess floodwater from the polder area to the river or the sea. This is a failure of the planning and design end not to take care of this problem appropriately.
- They create temporary irrigation inlets for applying sweet river water to the cropping fields when there are prolonged droughts in the polder area. These problems arise due to a need of adequate people participation during planning and design of the embankment.
- For short-term economic purposes yielding individual-level benefits, sometimes people allow river or seawater to penetrate inside the polder for shrimp cultivation or any other fishing requirement or salt panning.

Unplanned afforestation of embankment slopes: Afforestation without appropriate planning and management techniques destroys the undergrowth grass cover and becomes ineffective for erosion protection. In such cases, afforestation results in the weakening of the embankment without any substantial contribution to its stability.

However, a differing opinion on afforestation of embankment slopes stresses the need for plantation, provided grass cover is ensured and there is successive management in a most scientific way involving the local people so that appropriate routine maintenance is performed and healthy embankments are ensured.

Uncontrolled animal activity: Other animals than grazing cattle also cause erosion of embankments. Burrowing animals such as rats often seek shelter on the embankment during floods. Rat burrows and holes, cavities, tunnels, etc, dug by other animals like earthworms often cause substantial weakening of the embankment. Some rodents, for instance muskrats, are able to remove 0.5 to 1.0 m^3 soil per year to build cavities and chambers.

Improper design and construction technique: In many cases the embankments are designed with insufficient setback, resulting in increased exposure to waves and current action. This may be due to the high costs involved in land acquisition. Sometimes the setback area is also eroded.

Furthermore, insufficient supervision during construction results in poor-quality earthworks with the use of inappropriate soil materials, insufficient or no clod breaking, inadequate compaction and no or insufficient laying of topsoil layers. Scouring holes and rills appear in no time after completion of the construction.

Measures Taken for Erosion Control

Efforts have been made at times to protect the embankments from erosion. In fact the embankments are regarded as very dynamic living microcosms. The multi-facetted problems facing the embankments in Bangladesh are fascinating and challenging. These embankments are continually exposed to conditions of erosion, breaching or retirements. Light to moderate erosion of the reaches of embankments is common but only those with severe erosion (like turbulent water current, wave action, fluctuating water levels, etc) tending to near failure and destabilization are deemed worthy of protection. A 1984 BWDB report listed 305 such places (565 km) along riverbanks and 85 towns or villages experiencing severe erosion problems (Table 1). In addition to those referred to above, erosion in small reaches occurs at innumerable places along the river and coastal embankments of the country.

Table 1. Main areas of erosion in Bangladesh[8]

River	No. of location of bank/embankment erosion	Length of erosion (km)
Brahmaputra-Jamuna	41	162.60
Ganges-Padma	26	94.50
Meghna	8	72.00
Teesta	11	34.90
Minor river	112	92.30
Flashy river	75	23.00
Tidal river	32	85.80
Total	305	565.10

Number of cities affected = 85

The project embankments of the Pabna Irrigation and Rural Development Project, the Meghna-Dhonagoda Irrigation Project, the Bhola Irrigation Project, the Coastal Embankment Project, the Chandpur Irrigation Project and the Brahmaputra Right Embankment executed by the Bangladesh Water Development Board (BWDB) are under erosion at different places.[9] Conventional engineering practice recommends layers of granular filters protected by stone armour or concrete blocks to prevent erosion of base materials. Cohesion-less filters prevent the underlying natural soil from being piped through the riprap, restrain the riprap from sinking into the natural soil and permit natural seepage to occur from the protected soil, which prevents a potential build-up of excess hydrostatic pressure.

BWDB executed most of these protection works with either brick mattresses or natural boulders or brick/sand-cement/cement-concrete blocks as cover layer over granular filters. The granular filters used are either brick chips or stone chips or stone shingles over natural. These are sand of specified size ranges, predominantly the structural means of hard-cover protection for eroded surfaces.

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[8] *Source: Alam S.M. Zakiul & Faruque H.S. Mozadded, "Bank protection methods used in Bangladesh"*
[9] *Source: M. Zaman, Desk Study 1998*

In fact the causes of erosion and the problems encountered in each of the protective works so far executed by BWDB are not identical; hence the methods adopted to solve the problems are all location-specific and not necessarily the same. The protective measures of bank/embankment erosion at different locations fall under any of the following methods:

- Mattressing along the bank line
- Revetments either by boulders or by concrete/brick boulders
- Permeable spurs
- Groynes
- Guide bundle
- Artificial loop cut
- Porcupines
- Retards (palisade fences)
- Gravel drains
- Bandals
- Biological treatment viz. afforestation in the foreshore and embankment

In the bank/embankment protection works geo-textiles are often used to protect the subsoil from being washed away by hydraulic loads such as wave and turbulent currents. The geo-textile replaces the granular filter. The function of a revetment is to protect the slope (usually riverbanks) against hydraulic loading. The use of geo-textile in many cases reduces the thickness of granular filter layer and hence the associated costs, thereby rendering it cost effective.

Geo-textiles have also been used for bank protection works in Bangladesh. Severe erosion of riverbanks adjacent to the Meghna bridge on the Dhaka-Chittagong highway was corrected by using needle-punched, continuous filament, non-woven, mechanically bonded geo-textile placed on the bank slope both above and below the water level and by placing stones as revetment on the geo-textile below the lowest water level[10].

Past Experiments in Biological Protection

Under the project entitled Development Oriented Schemes for the BWDB-FFW program (BGD/87/021) sponsored by the UN Department of Technical Cooperation for Development (UN-DTCD) and WFP, an experimental program was designed to improve the biological protection of embankments and canal slopes. The efforts undertaken to implement the program included formulation of guidelines for biological protection of embankments and canal slopes countrywide. This, in turn, necessitated identification of the problems related to biological protection works and analysis of possible solutions. To this end, embankments were selected in different parts of the country presenting location-specific characteristics and problems about biological protection. Four experimental schemes were planned to implement the biological protection works in the selected embankments. Those schemes were situated in:

- the *haors* of the North, characterised by annual long-lasting inundations,
- the area influenced by brackish tidal rivers in the Centre-South and
- the sea-facing polders of the South-East.

The identification of problems and analysis of possible solutions towards implementing the biological protection works involved developing a framework for the planning, implementation, monitoring and evaluation of activities. In carrying out the experimental program, adequate emphasis was put on the control of animal activity and agricultural practices on the embankment slopes. To achieve and to maintain the desired biological protection, the following conditions were identified as the main prerequisites:

- a proper setback of the embankments
- good-quality earthwork and selection of suited soil material
- improved design of the embankment physical structure
- systematic good turfing/plantation

[10] *Source: Hannan and Daulah 1994*

- an optimal management of riverbanks and shores and
- adequate maintenance

Efforts were directed to realize the intermediary results to produce guidelines for biological protection. The whole experimentation was carried out with the following activities:

- Establishing collaboration with the National Herbarium and the Forest Research Institute;
- Locating experimental plots under the food-for-work program;
- Identifying suited plant species and possible light structural improvements;
- Designing an experimental scheme per plot including a time schedule for implementation and technologies to be used;
- Indicating responsible organizations and persons for implementation, maintenance and monitoring, evaluation and framing guidelines;
- Implementing the experimental schemes;
- Maintaining and monitoring the experiments;
- Evaluating the preliminary results;
- Developing a preliminary methodology for biological and light structural protection of embankments and canal slopes countrywide; and
- Organizing a joint evaluation mission with the collaborating partners (BWDB, UN-DTCD, WFP and EIP).

The experiments were set up in polders 43/2C, 66/1 and 69/1 during the monsoon period of 1992 with a limited amount of technical and financial means. Apart from the scheme developed for the *haor* area (Shangir *haor*), three other schemes on the following experimental plots were realized:

- Polder 43/2C – Patuakhali: embankment of a tidal river
- Polder 66/1 – Cox's Bazar: sandy sea embankment
- Polder 69/1 – Cox's Bazar: acidic sea embankment

The experimental schemes on the biological protection of embankments were implemented jointly by BWDB, FFW, EIP, UN-DTCD and local NGOs. Based on the growing period characteristics of the selected species for the experimental sites, plantation was completed as per schedule specified in the framework for planning, implementation, monitoring and evaluation. Four months only after the implementation of the experimental program, a first evaluation of the preliminary results and methodology was undertaken by a consultation mission during November-December 1992.

Following a detailed assessment of the experimental schemes, the guidelines for diversified biological and environment-friendly protection of embankments and canal slopes was published in January 1993. The guidelines took stock of the various aspects of the experiments set up on each of the polders separately. This included analysis of implementation conditions, selection of plant species, collection of saplings, seedlings, plantation techniques, survival rates, maintenance and costing. The guidelines will act as a valuable document for implementing biological protection works on embankment and canal slopes elsewhere in the country.

Recently Developed Biological Means of Protection

Biological protection of embankments on a massive scale has proved effective in many countries of the world including Bangladesh. A considerable width of foreshore mangrove plantation and turfing of slopes with vetiver and other associate grasses ensures protection of the majority of embankments.

The diversified biological and environment-friendly protection of embankments and canal slopes (development-oriented BWDB-FFW schemes; project BGD/87/021) adopted on an experimental basis under different conditions of erosion exposure at separate locations of the country is the first attempt of this type in Bangladesh. Successively efforts were made to establish dense vegetation cover on embankment slopes and foreland areas under the coastal greenbelt project. The aim was to ensure the protection of embankments for the safeguard of lives and properties against cyclonic storms and surges in the coastal zone. Besides, the preventive maintenance technique of the systems rehabilitation project of BWDB is also considered as a major breakthrough in the protection of earthen embankments from normal wear and tear round the year. Studies on the most suited protection methods for earthen embankments are going on at home and abroad.

In places where the erosion is severe and has almost destroyed the available setback, putting important installations and other valuable assets in danger of loss or collapse, and where flooding would have dire financial and economical consequences, costlier means of protection have been adopted. This involves the use of very scarce materials like rocks, stones, boulders, geo-textiles, steel piles, etc. Furthermore, the construction and maintenance techniques are only available at present to BWDB. The other embankments scattered all over the country, including the sea-facing ones, protect mostly low-value agricultural lands and have been experiencing light to moderate erosion. Sophisticated and expensive engineering solutions for these can hardly be considered.

No biological and environment-friendly protection methods are reported to have been adopted to protect embankments from erosion until recently. Trees are planted along the embankment shoulders and also on the slopes without the specific objective of protecting the embankment. The main theme behind such plantation is to make use of this public land remaining fallow round the year and to alleviate the problem of wood scarcity in the country. In the absence of prior long-term experimentation, there was a simple belief that the roots of the trees helped stabilize the soils of the embankment slopes. On the other hand, afforestation of embankment slopes was found to induce localised erosion problems in many cases. This contradiction retarded the afforestation of embankment slopes as an effective means of erosion protection, provided turfing is ensured with grasses and systematic management is established.

In practice, however, the embankments are not simply engineering structures, but the focus of complex land-use systems. This, combined with institutional shortcomings and funding shortages, has made a system of routine maintenance – in the engineering sense – impossible to establish. As a result maintenance has been restricted to major repairs or rehabilitation, generally carried out only when embankment is close to failure or has completely failed and caused serious losses. For a least-developed country like Bangladesh, the most effective forms of erosion control should be vegetative protection combined with limited hard protection.

Biological means of protection against erosion are the cheap and simple practical solution that must be:

- technically suitable: for different levels of exposure to erosion; for different soil types; for saline and non-saline condition,
- financially suitable: with respect to the cost of both initial construction and maintenance,
- environmentally suitable,
- people-oriented and sustainable: for routine maintenance.

Very recent experiences of the coastal greenbelt project and subsequent development made under the Coastal Embankment Rehabilitation Project (CERP) provide a sound footing for adopting the land-use approach for biological means of protection against erosion while providing various commodities for local communities. For controlling runoff erosion of embankments and for increased fodder production, a model has been developed, including vetiver *(Vetiveria zizanioides)* and associates like Napier grass *(Pennisetum purpureum)*, Para grass *(Brachiaria mutica)*, German grass *(Echinoclora grousgali)*, in addition to other suitable plants like Ipil-Ipil *(Leucaena leucocephala)*, Jhau *(Casuarina equisetifolia)*, Akashmoni *(Acacia auriculiformis)* and the like. A model has also been developed combining mechanical and vegetative toe protection methods as a sufficiently low-cost alternative for sites where the embankment is not directly exposed to wave attacks and the toe erosion is moderate.

CERP has made a breakthrough in organizing the embankment settlers for plantation on embankment slopes and toes in the country and at the seaside. Instead of being evicted from the embankment, the settlers are provided with shelters and other assistance, including leasing out a reach of embankment where they can make homestead gardens for vegetable production and even plant trees for timber, firewood and consumptive uses. This will ensure proper preventive maintenance of the embankments by the settlers on a regular basis, CERP suggests. For a number of engineering reasons, afforestation on embankment slopes was long believed to weaken the embankment without contributing substantially to its stability. After a careful study and review of similar experiences from other countries, CERP has adopted the strategy of systematic afforestation of sea and river embankment slopes.

The experiences likely to be gathered from these experimental efforts of afforestation on the slopes and toes by the settlers will be used for further expansion of the program on all embankments countrywide. If the program becomes successful, the age-old controversy of afforestation of embankment slopes will come to an end, thereby establishing a sustainable system of routine maintenance of embankments in addition.

The community development component of CERP will provide necessary technical assistance to the settlers through NGOs to ensure massive afforestation on embankment slopes and toes. Plantation on the selected polders has already started and is expected to gain momentum very fast. Initially efforts will be made to achieve positive results through a land-use development approach without strict adherence to intensive afforestation.

The envisaged vegetation pattern will have a short-term economic benefit for the settlers; grasses and bushes will provide quick benefits from the production of fodder and thatching material; the trees will start to be productive after four to ten years. Gradually, with settlers' growing interest, efficient techniques for embankment protection may also be evolved. Intensive care and close supervision by NGO workers and BWDB personnel will lead the program towards success, it is expected.

CERP is also organizing foreshore forestry groups to establish forests in the foreshore areas. Since the efficient biological protection of embankments cannot be achieved only by growing cover on the embankment slopes, afforestation of the foreshore areas should also be considered. It has been observed that the reaches of coastal embankments where mangrove forests or even non-mangrove Jhau forests exist in the foreshore area are more stable than those directly exposed to wave and current actions. Glaring examples of relatively efficient protection of embankments due to the presence of foreshore gardens can be had along some of the reaches of polder P-62 Patenga near Chittagong. CERP, therefore, wants to use these proven examples of foreshore afforestation in other coastal embankments too. Its community development component is organizing the poor farmers of the polder areas to create foreshore forests with recommended species of either mangrove or non-mangrove plants. Likewise the foreshore forestry groups will get all necessary assistance, including lease ownership of the plots on which the gardens will be established. The NGOs will act as the catalytic agents to provide services, expertise and capital. Long-term supervision and monitoring by NGO workers and ultimately by the executing agency (BWDB) will make the program a success in so far as the embankment protection and alleviation of wood scarcity are concerned. From the socio-economic point of view also, the program will benefit the local poor people. Improved plantation techniques and management capabilities will allow the foreshore forestry groups to grow bushes and shrubs simultaneously with the trees, so that their harvest can provide short-term benefits from the sale as fodder and thatching materials. The foreshore afforestation through the foreshore forestry groups is envisaged to bring about a change in the maintenance system of the coastal embankments.

Social and Institutional Aspects

The embankment is not a dead structure but a very dynamic living microcosm. Human activities on the embankments are very intense and these physical conditions have a severe impact on them[11]. The embankments in Bangladesh are exposed to a difficult environmental situation where erosion comes from multiple sources. Of these, human uses of various kinds contribute substantially to destabilize the embankments. The erosion protection measures have never been successful without considering the real problems of the people who are directly or indirectly causing the embankments to erode.

In the past, the settlers and squatters on embankment slopes were considered as the root of all evil in the destruction of embankments. There was a general belief that the eviction of all unauthorised occupants from the embankments would guarantee the stability. Accordingly efforts were often made

[11] *Yoon P.K. 1992*

to remove the embankment settlers forcibly. After some days new group of people were found to take shelter again at the same places or in the next suitable reaches. They lived and at the same time cultivated the slopes and toes of the embankment for their subsistence. No attempt has ever been successful to either eradicate these unauthorised occupants from the embankments or restrain them from cutting the slope and toe for additional agricultural land. In fact these people are landless, having lost their lands to erosion or to the government.

In addition, during catastrophic floods, the poor people who take shelter on the embankment along with the affected mass of villagers often tend to settle there permanently even after flood water has receded. They become the new settlers and in this way their numbers increase gradually. They are the direct beneficiaries of the embankments. There is evidence that these people are more sensitised than others in the community to the need to protect the embankments for the sake of their existence and livelihood support. They are now planting vetiver and other grasses and hedges on embankment slopes and toes to save their homesteads from erosion.

The recent move initiated by CERP to involve the embankment settlers, the poor people from among the villagers inside the polder area, is a major breakthrough in this regard. Organizing the settlers, foreshore forestry groups, embankment protection groups, etc, through NGOs to establish foreshore gardens and better manage embankment slopes and berms with technically sound land-use approaches will be an example for inland river embankments too. The social and institutional context of the land-use approach deserves careful consideration to strengthen the broad-based sea-defence management of coastal embankments.

Vegetation Models for Embankment Erosion Control

General Remarks and Importance of Vetiver

Vegetation models are aimed at controlling erosion of embankments by rainfall and waves and to supply subsistence to the community partners. However, the combination of species and their management in different models depend on the silvicultural characters of those species and site conditions. In all combinations vetiver has been accepted in CERP models as the common species due to its unique characteristics[12] such as:

- A thin layer of vetiver plants (2/3 plants) reduces erosion as tested in gullies created by rain runoff at 63/1A Anowara.
- It is able to survive in prevailing adverse conditions of coastal areas such as drought (survival tested at 62 Patenga for the eight-month-long drought of October 1998 to May 1999), flood, windstorm, fire (fishermen make fire frequently on slopes after fishing, especially from November to February), grazing and other human interferences and forces of nature.
- It has a deep penetrating root system (90 cm recorded in one-year rhizome stock).
- It does not appear to compete seriously with neighbouring fruit or timber species.
- It is easy to establish and maintain. However, the propagation material is not in abundance near the project areas. For trial purposes, it was carried from 50-80 km away, which involved transportation costs. The executing agency (BWDB) may collect truckloads of rhizome using the services of NGOs to develop a small-scale nursery at each section by individual community partners for gradual multiplication to the respective embankment slopes. Cuttings were also successfully propagated with proper watering. During the peak raining period (June-August), they may be planted directly on the slopes.
- It does not appear to host pests or pathogens that attack crops.
- It is not difficult to remove when it is no longer wanted.

[12] *National Research Council. 1993. Vetiver grass: a thin green line against erosion. National Academy Press, Washington DC, followed by some field tests by the author in 1998-99*

- It can survive on many soil types, almost regardless of fertility, acidity, alkalinity or salinity (tested in sandy soil at 63/1A Anowara and in clay of 62 Patenga in brackish water submersion).
- It is capable of growing in a wide range of climates (annual rainfall in Bangladesh varies from 1 500 mm to 3 750 mm and temperatures vary from 19^{o} C to 42^{o} C).

Principle of Vegetation Development

The principle of vegetation development is based on land evaluation – a two-stage process: land capability governed by biophysical characteristics like climate, geology, hydrology, soil types, landform, natural succession of vegetation, etc, and land suitability, which is a measure of social acceptability of using land for a particular purpose. The aim of erosion control should also be the focal point of planning that should coincide with land evaluation. So no typical model is suitable in general and dynamic field planning is required to make the typical model site specific and location specific. However, vetiver grass is included as the common species in general. Due to various types and intensity of erosive forces, vetiver and vegetation should not be treated as the solution to all problems.

The biological system of protection will not be effective enough in the case of embankments directly exposed to the loads induced by heavy currents or sea waves. They must have adequate setback and there must be relatively satisfactory stability of the land between the shoreline and the outer side toe. Otherwise, the erosive forces are severe enough to destroy the foreland areas by gradual engulfing of the setback, leading eventually to the total collapse of the embankment. Structural means of protection or retirement along a new alignment should be adopted following appropriate feasibility investigations. The sea dykes should never be constructed with slopes and toes directly exposed to the sea waves. Dense vegetative cover of grass turfs of vetiver and other associates on the slope and afforestation of the embankment toes as well as the foreland areas increase the stability of the earthen embankments in coastal areas and islands. For the biological protection system to become effective, the following conditions have been identified as important prerequisites[13]:

- the embankment should have adequate setback;
- the physical structure of the embankment must conform to the standard design criteria allowing for proper crest, shoulders, width, slope, height and berms;
- the earthwork should be of good quality with appropriate compaction of the soils having no uneven surfaces or clods with the embankment;
- the topsoil layers selected must ensure the growth of plants, trees and bushes conducive to the stability of the embankment itself;
- there must be appropriate travel paths or crossovers at each of the interceptions and boat-landing stations;
- the underpasses to allow for drainage of country-side discharges should be provided adequately so that no public cut destabilizes the embankment;
- the design and construction of the structures like sluice gates, cross regulators, culverts, foot bridges, etc, must be in conformity with the standard practices, to avoid incipient gullies, cracks or settlement around wing walls and abutments;
- there should be no prolonged submergence of the outer toes and lower slopes;
- the height of the waves directly striking the outer toes and lower slopes during the monsoon is below the average level and those waves are weakened due to wide foreland areas;
- there is an optimal management of the riverbanks and seashores;
- there is an appropriate system established to ensure plantation, nursing and routine maintenance of the vegetation cover, including preventive maintenance of the embankments; and
- the community members are aware of the need of embankments and cooperate in related activities, including prevention of overgrazing.

[13] *M. Zaman, desk study 1999*

Land Components and Vegetation Development

Five land units of different capabilities have been recognized[14]:

Newly accreted land: subject to regular tidal inundation and highly saline and suitable for mangrove species. Vegetation communities vary with different ages of surface and variations in hydrology and salinity. The main associates are (vetiver is yet to be tested):

- *Sonneratia* community, characteristic of brackish estuaries; this comprises *Oryza, Imperata* and *Typha* grasses with *Sonneratia* trees in alkaline soil and *Avicenea* trees in acidic soil. The thumb rule is *Sonneratia* is suitable for accretion along the bay and islands situated upward of the Karnaphuli river and *Avicenea* is suitable downwards, below Cox's Bazar. However, location-specific mixed planting of both *Sonneratia* and *Avicenea* is also suggested by the Bangladesh Forest Research Institute.
- *Nypa* communities, also in brackish estuaries.
- *Cynodon-Acanthus-Excoecaria* community, characteristic of secondary succession.

Raised foreshore land: This land outside the embankments is subject to occasional inundation by very high tides and so tends to remain moderately saline and subject to waterlogging. It is no longer suitable for most mangroves but certain terrestrial species could be tested. *Casuarina* is the main species for sandy soil and *Excoecaria* is the main species for clayey to silty clay. *Vetiver* was also tested and found suitable. Other species suggested to mix with the main species are *Pongamia, Sesbania, Leucaena, Acacia, Samanea, Ipomoea, Typha, Pandanus*, etc. The coastal greenbelt project suggests the construction of 'spur dykes' or individual planting "mounds" to provide initial support to the seedlings before they adjust to the harsh situation. CERP suggests filling the planting hole with fertile topsoil mixed with gypsum as the practical solution for sites subjected to waves.

A 50-200 m-wide belt of well-established mangrove or non-mangrove plantation is expected to play a vital role in a system of coastal defence including saving the embankment, except in special cases of storm surges. However, traditional planting in straight lines must be replaced by the staggering method of planting.

Berms and borrowpits*:* Berms that are immediately adjacent to the toes of the embankments are almost similar to the raised foreshore. To face the accumulated erosive force of waves and rain runoff, dense planting of grasses and shrubs suggested on the berms, extended about 1 m on the slope. Vetiver is suggested at 0.3 m x 0.3 m spacing, overlapped with *Ipomoea* at the same spacing. Other hedges are *Typha, Pandanus, Sesbania,* etc. Beyond berms there are borrow pits from which soil was excavated to construct the embankments. Some borrow pits have been filled in as a result of continual tidal flooding, others remain as semi-permanent water bodies suitable only for plants capable of growing in water or on sites with a permanently high water table and moderately saline groundwater. Vetiver may be mixed with *Nypa, Typha, Pandanus,* etc.

Embankments: These are of mixed height and varying slope. They are usually constructed entirely of soil from adjacent borrow pits and represent a raised, salt-free version of the local soil type. Outer and inner embankment slopes provide contrasting sites for vegetation growth. The main factor limiting growth is likely to be moisture deficiency during eight months, October to May, every year. They are suitable for a wide variety of species, subject to the constraint that they must not destabilize the embankment. Three types of embankments were designed under the coastal embankment project as:

- *sea dikes* – built at locations facing the Bay of Bengal where high waves or cyclone wave surges occur.
- *interior dikes* – constructed to protect areas adjacent to main streams where current and wave actions are moderate.
- *marginal dikes* – built to protect areas adjacent to interior canals where current and wave actions are mild.

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[14] *The Coastal Greenbelt Proposal (Main Report), GOB/ADB TA NO. 1816 BAN, 1994, followed by models suggested for the Coastal Embankment Rehabilitation Project (CERP) by the author in 1998-99*

New embankments after the devastating cyclone of 29 April 1991 are generally constructed with an outer slope of 1:7 and an inner slope of 1:3; crest width is 4.3 m. The designed crest level is usually 4.0 m but raised to 6.0 m when particularly valuable sites (e.g. industrial area at Patenga, Chittagong) are at risk.

Considering the embankment plantation models of the Staff Appraisal Report of the World Bank (October 1995) and ADB reports of the coastal greenbelt project, *Interim guidelines for afforestation* was produced in June 1997. The guidelines took into account among other factors professional observations by engineers and foresters on the impact of trees and other vegetation on embankments as well as estimates of settlers' socio-economic needs and expectations regarding land use on the embankments. Tree planting on embankments was not accepted by BWDB for 30 years, because trees were believed to destroy the structure of the earthworks. Very little thought had been given to analysing the soil-stabilizing effect of roots on embankments. The integration of timber trees, fruit trees, grasses, shrubs, other agricultural elements, and animal husbandry has not been tried systematically on sea-facing embankments, and therefore few field data exist.

Reviewing all the views and models and the experience from the pilot plantation of 1998, a CERP forestry team including the author developed a farm model[15] for the 100-m section of sea embankment (about 0.5 ha) with the general aim of establishing a sustainable maintenance system by controlling the erosion of the embankment by rainfall and wave action as well as ensuring the financial survival of the settlers. Settlers' subsistence is the pivotal factor; the whole embankment afforestation concept stands or falls with the settlers. The main features of the model are as follows:

- The design trend is away from the traditional timber tree plantation (5-6 species) towards a combined species selection.
- Grasses are considered as the important and first line of defence against runoff erosion. Grasses are effective soil binders and can minimize the force of runoff when planted in hedges along contour lines. Vetiver *(Vetiveria zizanioides)* is planted at the lower part of the outer slope to face the accumulated force of runoff and moderate waves. Due to high demand of fodder grasses in coastal zones, intensification of cut-and-carry-type grasses on embankments is believed to be a step in the right direction. German *(Echinoclora grousgali)*, Napier *(Pennisetum purpureum)* and Para *(Brachiaria mutica)* grasses are specified for the lower-middle, middle and upper part of the outer slope respectively.
- Hedge species are given at the shoulders of the crest and at the boundary line for fencing purposes, as soil binder and to control the force of raindrops and runoff as well as to provide fuel and protein for the settlers. The species are *Ipomoea fistula* (cuttings), *Cajanus cajan* (seeding), *Acacia nilotica* (seeding), *Erythrina* spp. (cutting) and *Sesbania aculata* (seeding).
- Three lines of coconut (seedlings) at the lower part of the outer slope, at 5-m spacing from plant to plant and 2.5 m from row to row using the staggering method to resist waves in the long run. Date and palmyra are suggested for the inner slope toe line.
- Drought-resistant, fast-growing fuel and timber species selected mainly for the outer slope are *Acacia auriculiformis, Acacia mangium, Casuarina equisetifolia, Leucaena leucocephala, Dalbergia sisso, Eucalyptus camaldulensis, Albizia procera, Samanea saman.* A small number of important slow-growing species mixed include *Swetenia macrophylla* and *Azadiracta indica*.
- Fruit species are selected for inner slopes. The main species are *Psidium guajava, Citrus limon, Punica granatum, Zyziphus jujuba,* etc. One or two other fruit species like *Eleocarpus robusta, Tamarindus indica, Artocarpus heterophyllus, Emblica officinalis* or *Borassus flabellifer* will also be planted in each settler's farm.
- Bamboo *(Bambusa vulgaris)* and cane *(Calamus guruba)* are also included in the inner side toe line mixed with date and betel nut.
- Vegetables, with the pre-condition of minimum soil-working during planting and no soil-working during harvesting, are allowed in the model at the inner slopes for the first three or four years when trees are grown. *Lycopersicon lycopersicum, Dolichos lablab, Abelmoschus esculentus, Solanum melongena,* etc. may be allowed under limitations for settlers' subsistence.

[15] *ES's farm model and its cost-benefit analysis, March 1999, CERP/JPC*

Location-specific field planning will be done taking the model as a guide for planning.

Agricultural hinterland: This is intensely cropped, mainly for rice. Palms, fruit trees and beans are sometimes planted on the bunds separating the paddy fields. Vetiver is used in some areas as the boundary demarcation of paddy fields. Homesteads occupy one fifth to one quarter of the total area. A wide variety of horticultural and vegetable crops are grown on homestead sites, including multi-purpose trees producing fuel wood as well as fruit and timber or poles.

Conclusion

Without a surface cover of vegetation, any earth embankment will be severely eroded within a few years because of the high monsoon rainfall intensities. For this reason alone, there can be no question that embankments must have a full cover of vegetation. This could typically be a continuous mat of well-maintained grasses, especially vetiver and its associates. This will definitely simplify routine maintenance, which was not possible for the last few decades due to institutional shortcomings and the lack of proper techniques.

The need to provide protection against waves introduces another dimension to the problem. A full range of vegetation levels, both in the foreshore and on the embankment, both above ground and in the soil rooting zone is the most important cost-effective method to save the embankment from light to moderate waves. If the vegetation is combined with some cheap semi-mechanical process like jute bags filled with local soil, bamboo splits, etc, the effectiveness to control wave erosion increases.

In summary, the relevant features of a combination of vegetation types for erosion control are as follows:

- a multilevel belt of trees, shrubs and grasses to absorb wave energy outside the embankment;
- on the embankment, a similar multilevel vegetation cover to provide full protection against runoff and wave action;
- in the soil, a full system of roots including a surface mat of small grasses, deeper clump grass or shrub roots and deep, large tree roots; and
- healthy, vigorous plants throughout, constantly managed and with none allowed to become old, over-mature and weak, and regularly pruned to give a high root-shoot ratio.

Costly engineering methods of erosion control must be limited to specific locations, only when biological protection is not possible in terms of intensity of storm surges or due to the time factor of developing the required multilevel greenbelts.