Photo 5: Exposed tree roots: a consequence of wind erosion when cover vegetation is sparse and strong winds blow across sandy or silty soil surfaces

Photo 6: Soil erosion is the most serious and widespread form of land degradation, as exemplified by this gully erosion on the loess hills of central China

lands, particularly where clean tillage and long fallow cultivation methods are employed. They can also occur on grazing land which has been seriously denuded by overgrazing or any land left bare of vegetation by deforestation, clearing or drought conditions.

Further downslope, as rates and volumes of run-off and quantities of transported sediment increase, larger-scale erosion processes begin to occur. Gully erosion is essentially a macro-scale version of rill erosion which results in the form of large, incised erosion channels too big to be filled by normal cultivation practices and too wide and deep to be crossed by farm machinery. The classification of gully erosion is usually applied when the depth of the incised channels exceeds 300 mm, although depths of 10 m and more may be experienced under severe erosion conditions.

Gully erosion involves a number of interacting processes which depend upon climate, soil type, topography and land use. It is initiated in minor drainage lines when normal equilibrium is upset by concentration of water flow or locally decreased resistance of soil to detachment or transport. It develops by two major mechanisms – gully head erosion, which is caused primarily by concentrated flow over the gully head and is the process by which the gully lengthens and moves upslope, and gully side erosion, which can be caused by diffuse over-edge inflow, interflow and groundwater seepage, undercutting, flow along the gully and raindrop erosion, and is the process by which the gully widens and deepens. As a gully extends upslope the catchment area contributing to head erosion reduces, and uphill movement may eventually stabilize. On the other hand, the rate and amount of over-edge inflow and sub-surface inflow may increase concurrently, enhancing the side erosion process and causing deepening or widening of the gully so long as its capacity to transport eroded material downstream is not exceeded.

Gully erosion can result in the loss of considerable areas of productive cropping or grazing land. It causes significant increases in farming costs, because it makes the operation of farm machinery and the management of livestock more difficult. It also produces serious off *site* effects, resulting from the movement and deposition of sediment, as described below.

Because of their size and areal extent, eroded gullies can remove and transport downslope very large quantities of material. If a stream or waterway does not exist downstream to transport this material further down the watershed, a sediment fan will be deposited at its lower end. This can render a substantial area of agricultural land unproductive and may damage farm infrastructure and public facilities such as roads and irrigation or drainage channels. Disturbed flow across the fan deposit may initiate further instability lower down the slope, leading to extended multi-channel or compounded gully development. If the gully discharges into main watershed drainage system, movement of sediment into stream channels will occur, to be eventually deposited further downstream causing river sedimentation or accumulating silt in lakes and artificial reservoirs, with consequential adverse effects on flooding, river and lake productivity and reservoir storage capacity and a general impairment of downstream water quality.

Tunnel erosion is an unusual form of erosion, because it involves the removal of sub-surface soil by water whilst the surface soil layer remains relatively intact. This produces long, tunnel-like cavities below the surface, which enlarge until parts of the surface collapse inwards, leaving holes and depressions which may eventually develop into open gullies

Tunnel erosion may occur under land systems ranging from equatorial rainforest to semi-arid rangeland. The erosion tunnels may vary in diameter from a few centimetres to several metres, and their formation depends upon the availability of a sub-surface water velocity and flow rate sufficient to produce entrainment and transport of soil particles along the tunnel cavities Tunnel formation is initiated by soil cracks, discontinuities between soil horizons, rodent burrowing or accelerated interflow and groundwater seepage into gully walls. The erosion process is aggravated by any processes that increase soil permeability within or between soil layers and is particularly serious in dispersive soils which entrain readily and can be transported at very low velocities.

Tunnel erosion reduces agricultural productivity and increases farming costs. It is particularly serious if it develops into gully erosion extending over a large area, when it can be the cause of significant land degradation

Streambank erosion involves the removal, transport, and deposition of bank material along streams and rivers. It is a episodic process associated with flood events, initiated by bank scouring during high velocity streamflows, perhaps assisted by wind and wave action. Streambank erosion and deposition are part of the normal processes of stream geomorphology, which also include bed scouring, sediment deposition, and sediment re-entrainment and re-deposition. These processes occur naturally without human intervention, although their extent and their effects and consequences may be aggravated and accelerated by a variety of human activities.

Streambank erosion occurs when the stresses applied by streamflow energy exceed the shear resistance of the streambank materials. The mechanism usually involves scouring and removal of the lower sections of the bank face, particularly along its toe, which leads to collapse of the overlying bank material and its subsequent entrainment and transport downstream by the flowing water. Major factors influencing the rate and amount of bank erosion are the velocity, flow rate, flow depth and duration of the flood flow causing the event; the height and slope of the streambank; the properties of the streambank material; the curvature and plan shape of the stream channel, which influences the direction of erosive flow onto the bank; the existence of natural or artificial features which cause localized increases in flow velocity or concentrate flow against the bank; and the nature and extent of vegetative or other protection or armouring of the bank face.

Streambank erosion occurs most extensively on floodplain reaches and its most direct adverse consequence is the total loss of prime agricultural land Bank erosion may also damage or destroy bridges, roads and other infrastructure, which may have much more serious economic consequences than the loss of agricultural land. The eroded material provides a source of sediment for deposition further downstream, where it may reduce stream capacity and increase flooding damage. Eroded sediment will also provide a source of sediment for silt accumulation in reservoirs and behind weirs and other control structures, as well as producing an impairment in downstream water quality.

The occurrence and severity of streambank erosion can be strongly influenced by land use on the watershed and along the stream banks. Poor land-use practices and inadequate land-use planning and management on the watershed above an erosion site can increase the rates and volumes of flood events. It can also bring down an accumulation of debris or sediment which may aggravate erosion at critical locations. The nature of the land use along the river bank above potential erosion sites, and the nature and amount of vegetative protection along the bank alignment, may also determine the extent of erosion damage and its economic consequences.

The land degradation caused by each of the forms of water erosion discussed above is directly or indirectly a consequence of poor or inappropriate land use. The single most important factor is the existence or otherwise of a suitable vegetative cover, which provides protection against raindrop impact and splash erosion and minimizes the effects of other erosive mechanisms. Land-use practices which involve the destruction or clearing of vegetation and the direct exposure of the soil surface to water erosion processes are particularly likely to result in severe erosion and substantial land degradation.

Watershed land-use planning and the application of appropriate land-use management techniques on the watershed therefore provide a range of important and significant ways and means for the control of water erosion induced land degradation *in situ*, as well as the minimization or mitigation of its off site effects. These tools and techniques are discussed in detail later in this document.

3. Wind erosion

Wind erosion is a process involving the removal of soil particles from the land surface by the action of strong winds. It is a form of land degradation which occurs particularly in semi-arid areas having an annual rainfall of less than 300 mm, and also in more humid areas subject to long rainless periods and seasons of hot dry wind. It can be a serious form of environmental damage in districts where extensive cropping and grazing are practised under marginal climatic conditions, particularly where long drought periods which denude the soil of plant cover are occasionally experienced.

In the ESCAP region, wind erosion is not so serious or widespread a problem as water erosion. There are, however, extensive areas meeting the climatic conditions described above for which wind erosion has been a problem in the past and is a potential problem for the future. In particular, there are extensive areas of Australia and North China where this is the case, along with parts of Pakistan and northern India.

Wind erosion commences on a soil surface when the entrainment and transportation forces exerted by the wind exceed the gravitational and cohesive resistance forces tending to keep soil particles in position. Three distinct types of erosive motion occur, depending principally upon the size of the soil particles. *Suspension* is the movement of very fine particles, generally less than 0.1 mm in diameter, which are lifted by turbulence and can remain aloft for long periods. Suspended material is visible as dust and can be carried to considerable heights (6000 m) and over considerable horizontal distances (8000 km): on several occasions in the past, dust storms from eroded croplands in western New South Wales and South Australia have been blow across the Tasman Sea to be deposited on the Southern Alps of New Zealand.

Saltation is a process by which larger particles, too large to remain suspended in the air flow, are moved along the surface by a bouncing motion. It affects particles ranging in diameter from 0.1 mm to 0.5 mm. The particles do not rise more than about 30 cm but may be transported downwind over distances ranging from tens to hundreds of metres, eventually coming to rest and accumulating against fencelines or other impediments to further movement.

Creep involves the movement of larger particles again, which are not lifted but rolled along the surface of the ground, pushed by the force of the wind and the impact of other particles moving with the wind. Particles which move by creep are usually in the range of 0.5 mm to 2 mm in diameter. Transport distances are rarely more than a few metres.

Of these three modes of movement, saltation is the most important, generally accounting for from 50 per cent to 80 per cent of the total sediment transport. Furthermore, the other forms of movement cannot take place unless saltation is also occurring.

An important consequence of the size-dependent entrainment mechanisms and the size-selective transport modes is that the wind erosion processes change significantly the particle-size distribution of the soil. Wind erosion removes the finer particles, along with organic matter and nutrient material, leaving a coarser and much less fertile material and significantly reducing potential agricultural productivity.

The principal factors affecting the rates and amounts of wind erosion are the physical properties of the soil, the wind velocity and the boundary layer aerodynamics, and the amount and extent of vegetative cover.

The soil types which are most susceptible to wind erosion are sandy or silty soils of low cohesion, particularly when they are dry and the surface is relatively smooth. High soil moisture levels and a well-structured, cloddy surface resist entrainment forces effectively. The wind speed above the surface, and the degree and nature of turbulence in the boundary layer, are important factors in the entrainment process. A high degree of roughness on the soil surface, increasing frictional resistance to the wind and creating a turbulent boundary layer with a comparatively flat velocity gradient over the surface, will limit entrainment forces effectively.

A factor of major importance is the vegetative cover. Indeed, the most effective way of preventing soil erosion is to maintain a suitable vegetative cover. This has two effects – it substantially modifies the surface roughness and the wind velocity distribution in the boundary layer, whilst its physical structure assists in reducing entrainment by suspension and saltation. Either standing vegetation or stubble and crop residue provide effective cover for erosion control.

The various measures used to manage wind erosion depend upon the manipulation of one or other of the factors discussed above. Wind velocity and its above-surface gradient can be managed by increasing surface roughness, maintaining vegetative cover or providing windbreaks. Special farming practices can be used to increase soil moisture, reduce cultivation and maintain as much vegetative cover as possible. Strip cropping, minimum-till or low-till cultivation techniques, stubble retention, or the careful control of over-grazing on pasture lands, are some of the techniques available. These techniques are discussed in further detail in Chapter VI.

It will be obvious from the foregoing that land-use planning and management policies and techniques offer major opportunities for wind erosion control. Land-use planning can be used to zone land uses on lands susceptible to wind erosion and to restrict clearing and farming practices to those which provide effective wind erosion control. As has been briefly discussed above, a variety of specialized farming, grazing and other land management techniques has been developed for wind erosion mitigation and these should be required to be used in districts susceptible to land degradation from wind erosion.

4. Other forms of erosion and deposition

Erosion by water and by wind are the most serious and widespread forms of land degradation occurring in the ESCAP region. There are other forms of degradation by processes involving erosion or deposition which can have serious consequences in specific localities. These include siltation and sedimentation, mass movement, and coastal erosion.

Siltation and sedimentation processes refer to the off-site movement and deposition of the products of soil erosion. The soil entrained by the action of water erosion moves downslope under the influence of the various transport mechanisms in operation and eventually becomes deposited as sediment or silt when the transportation forces, for one reason or another, become ineffective.

In the case of raindrop, sheet and rill erosion, the distance moved by sediment may not be very considerable, perhaps of the order of metres or tens of metres, in the course of any particular erosion event. With the occurrence of another event, re-entrainment, further downslope transport and eventual re-deposition may occur. The process of gradual removal and transport of soil thus becomes an episodic one, with large movements occurring only on sporadic occasions.

In the case of gully erosion, and larger-scale mechanisms such as river bank erosion, the entrained particles may move considerably further before re-deposition. Movement however is essentially local, and confined within small watershed areas, except on very large river basins during major flood events.

An important feature of the transportation and deposition processes is that they are highly particle size selective. The largest particles, of gravel and sand sizes, move only comparatively short distances and will be deposited as sediment within the watershed from which they originated. Very fine particles of silt or clay size, on the other hand, may be transported many kilometres and sometimes tens or hundreds of kilometres downstream, to be deposited eventually as silt on floodplains or in reservoirs, lakes or estuaries.

The rate of soil formation under natural conditions is very slow. Formation rates vary considerably depending upon the nature of the parent materials, the climatic conditions and many other factors, but are likely to be only of the order of millimetres per thousand years. The rate of production of sediment and silt from eroded areas, however, is likely to be several orders of magnitude greater.

Assuming, for purposes of illustration, a surface soil bulk density of 1.4 gm/cm^3, then a soil depth of 1 mm corresponds to a mass of 14 tonnes per hectare and a volume of 1000 cubic metres per square kilometre. Extensive studies of soil losses from soil plots, small watersheds and large catchments throughout Australia provides the following data, which probably can be applied in general terms elsewhere throughout the ESCAP region:

(a) Natural rates of soil formation are generally less than 1 t/ha/yr;

(b) Land-use and management practices have a major effect on soil loss, any practices that reduce the amount of protective ground cover being likely to increase the risk of soil loss;

(c) Soil loss per unit area decreases with catchment size, and care must be taken in the extrapolation of loss figures from soil plot studies to watershed scale;

(d) Mean annual losses tend to be strongly skewed in their distribution and are dominated by major losses in a few years;

(e) Losses from individual storm events can be many times the mean annual loss and can reach values of the order of hundreds of t/ha – reports of high losses during such events can give a biased view of overall conditions,

(f) On forested watersheds, losses are likely to be in the range 0-1 t/ha/yr – accelerated rates of the order of 10-50 t/ha/yr can be experienced after forest fires and before regeneration;

(g) Under pasture cover, mean annual losses are likely to be less than 1 t/ha/yr;

(h) Under cropping, losses are in the range 1-50 t/ha/yr, and can be kept to the lower end of this range with good management;

(i) Under bare fallow conditions in temperate climates, losses are likely to be of the order of 50-100 t/ha/yr;

(j) Under crops such as sugar cane growing in tropical and sub-tropical conditions, losses can be expected to be of the order of 100-500 t/ha/yr.

It is obvious from these figures that substantial quantities of sediment can be expected to be produced as a consequence of erosion processes when poor land management is practised. The coarser sediments will be deposited a comparatively short distance downslope of their place of origin, where they may bury productive agricultural or grazing land or damage roads and other infrastructure. Sediments which reach watercourses may block channel sections and so aggravate the effects of flooding or increase the potential for streambank erosion.

The very fine erosion products of silt or colloidal size may be carried considerable distances downstream of their site of origin by floodwaters, eventually being deposited as siltation when the velocity of flow transporting them becomes so small that the particles can drop out of suspension. Where this occurs as a consequence of overbank flow across a floodplain, the effects may be beneficial, building up arable soil depth and providing additional organic and nutrient matter. Where it occurs in large water bodies such as lakes, reservoirs and estuaries, siltation has a number of adverse effects. These may include the reduction of storage capacity, interference with navigation, damage to fish species and other aquatic fauna, and general impairment of aquatic ecosystems.

As has been explained in previous sections, effective control of sedimentation and siltation can be achieved through land-use control and management, particularly where this involves watershed management practices which aim to minimize land clearing, to maintain vegetative cover on land used for agricultural purposes, and to foster agricultural practices which facilitate water and wind erosion control. These practices and techniques are discussed in detail in Chapter VI.

Mass movement encompasses a variety of erosion processes in which gravity is the primary force acting to dislodge and transport land surface materials: for completeness in the classification system used here, it has been categorized under the heading of soil erosion and deposition. The mechanisms by which these processes occur, along with a discussion of their degradation effects and ways and means of controlling them, are discussed in some detail in Section III.D, "Land Instability".

Coastal erosion refers to forms of land degradation which occur along coastlines under the action of wind and wave induced forces which cause the movement or loss of soil, sand and rock material. It occurs in two principal forms – processes involving the loss of coastline material into the sea, as a consequence of severe wave action, and processes involving the loss of vegetation on coastal sand dunes and the movement of sand inland by wind erosion forces.

Both forms of coastal erosion occur along coastlines within the ESCAP region, particularly in localities subject to tropical cyclone action or the likelihood of storm surge or tsunami effects. Coastal erosion can result in the total loss of coastline land, either valuable for intensive agricultural purposes or, in many locations, intensively developed for high-value urban, commercial or resort use. In some locations, resort areas including resort beaches and lagoons, often of high value to local economies, are particularly susceptible. In less developed regions, coastal communities and fishing villages may be similarly at risk. Wind erosion on coastal sand dunes, causing large volumes of sand to be blown inland, can also result in the burial and loss of land valuable for a variety of purposes and damage to, or destruction of, buildings, industrial sites and public infrastructure.

Erosion processes which result in the loss of material to the sea generally occur sporadically under the same conditions as those which cause coastal flooding. These conditions are discussed in some detail in Section III.C.5, "Coastal Flooding". It should be noted that this form of erosion can sometimes be severely aggravated by the inappropriate construction of devices mistakenly planned to control or mitigate coastline or beach erosion or to develop the coastal zone for navigational or other purposes, such as training walls, breakwaters, groynes, offshore loading jetties, or beachfront retaining walls.

This form of coastal erosion offers considerable potential for mitigation through land-use zoning and the strict control or prevention of either adverse or risk-prone forms of land use. In particular, good management requires the zoning of the immediate coastal strip to prevent commercial, housing or infrastructure development in locations susceptible to land damage and strict building controls over structures which offer potential for the aggravation of wave and wind erosion effects.

Coastal sand dunes are constantly under threat from wind erosion, particularly in areas subject to occasional high winds of tropical cyclone or other storm condition origin. Susceptibility to this form of erosion is vastly increased where vegetative cover is sparse or non-existent, when major sand blows may occur causing the movement of sand a considerable distance inland. The key to the management of this form of land degradation is the establishment and maintenance of a dense vegetative cover, which may require substantial vegetation or regeneration programmes and the careful control or prevention of adverse forms of land use, including grazing, building or road construction, mining, or simply uncontrolled access by humans or vehicles.

D. Soil degradation

1. Soil salinity

Saline soils are soils which contain such a quantity of soluble salts that plant growth is significantly reduced Soils which have been saline for many thousands of years, as a result of natural landscape-forming processes, are said to exhibit *primary salinity.* Soils which have recently become saline, as a result of rising water tables consequent upon changes to the local hydrology or poor irrigation practices, are said to exhibit *secondary salinity.* In this document, we are primarily concerned with land degradation resulting from secondary salinity, which is capable of being managed through appropriate land-use practices and policies.

Secondary salinity occurs in two principal forms, depending upon whether or not the degraded land has been irrigated, which are generally referred to as *irrigation salinity* and *dryland salinity.* In point of fact, the essential features of the salinity process are the same for both forms, although one is the result of poor irrigation practice and the other the result of unsound land use on non-irrigated agricultural, pastoral or forested lands.

Primary salinity is a world-wide phenomenon. Within the ESCAP region, it occurs in China, Thailand and Australia, the latter alone having nearly 40 per cent of the world's total area. Irrigation salinity is also widespread, occurring in most of the world's established irrigation areas and having been responsible, in ancient times, for the breakdown and collapse of some early civilizations. Within the ESCAP region, it occurs in Australia, China, India, Pakistan and Thailand, principally where major irrigation schemes have been developed in semi-arid lands on the flood plains of major rivers. Dryland salinity is a more recent phenomenon, generally occurring in upland watersheds on land which has been cleared for cropping, grazing or plantation forestry. Within the ESCAP region, it occurs in Australia, China and Thailand and is becoming an increasingly serious problem in most areas where it has developed.

The cations and anions most commonly occurring in saline soils comprise sodium, calcium, magnesium, chloride, sulphate and bicarbonate, of which the dominant ones are usually sodium and chlorine. The salts go into solution in the plant root zone, producing an increase in osmotic pressure and causing increased water stress in growing plants. This may severely inhibit plant growth, reducing crop yields and the extent of plant cover or in severe cases causing plant death and making it impossible to grow plants having low salt tolerance. On upland watersheds, the reduction in plant cover substantially increases the potential for water erosion, leading to further loss in productivity and progressive land degradation.

Irrigation salinity develops when the salt concentration in the root zone of irrigated soils becomes high enough to inhibit plant growth. This may be due to the presence of salts in the soil, the presence of salts in the applied irrigation water, or a combination of both. In poorly drained irrigated soils, the water table progressively rises, bringing dissolved salts from the underlying soil material into the root zone. The processes of transpiration and evaporation remove water from the zone, leaving salts behind and causing an increasing build-up in salinity levels. If saline water drains to the lower water table, and is eventually discharged into a watercourse, a progressive build-up of salinity in the river system downstream will develop. Thus the adverse effects of irrigation salinity may not only occur within the irrigation area, but also have environmental consequences for the entire river basin system of which the irrigation area forms a part. These consequences are particularly evident in terms of impaired water quality, reducing the suitability of river water for further irrigation use or domestic and industrial supply and affecting the function of the riverine ecosystems.

An associated problem with irrigation salinity occurs when water tables rise so high as to come close to or reach the surface, causing waterlogging and loss of productivity or, in extreme cases, total loss of land to agriculture. This problem is aggravated when irrigation is practised on clay soils or shallow soils underlain by impervious material.

There is a range of solutions available for the management of irrigation salinity, involving either changes in irrigation practices, changes in land-use and cropping practices, or the manipulation of site hydrology through improved drainage and other means.

Changes in irrigation practice are aimed either at the more efficient use of irrigation water, so reducing the build-up of shallow water tables, or the movement of accumulated salts out of the root zone into the drainage system. Changes in practice may include the use of an alternative, lower-salinity water source, the improved levelling or grading of flood-irrigated land, or changing from flood or paddy irrigation methods to sprinkler or drip irrigation application systems. In extreme cases of irrigation salinity, the total cessation of irrigation as a land use may be necessary. Where sufficient quantities of low-salinity water are available, and the irrigation fields are adequately drained, the practice of leaching, involving the application of excess irrigation water to flush salts from the root zone downwards to the water table, is a common technique.

Changes in land use involve changing to different crop or pasture types or different farming methods. Most commonly, this involves the selection and introduction of more salt-tolerant plant species.

Manipulation of site hydrology is aimed at facilitating leaching and drainage to remove excess salt concentration from the root zone and prevent the build-up of high water table or waterlogging problems. It normally involves the construction or improvement of sub-surface drainage systems, which may be achievable with simple drainage channels or dykes but might, particularly in very flat land, require the installation of pumping equipment. Improvement of drainage brings an additional problem, in that means must be found for the disposal of saline drainage water. Where drainage water is discharged into the nearest watercourse, potential problems of water quality impairment further downstream are likely. Where drainage water is highly saline, alternative methods of disposal might be necessary. These include discharge to other catchments, into salt lakes, into saline aquifers or into the ocean. In Australia, discharge into evaporation basins, from which salt is eventually harvested commercially, is an increasingly common practice.

Dryland salinity is also a problem associated with rising watertables, which generally develops on hillslopes and the valley floors beneath them as a consequence of upper slope clearing. Under natural conditions, rainwater falling on upper slopes infiltrates through the soil surface and moves into the groundwater zone, from whence it gradually percolates downwards beneath the surface to the valley floor and discharges into the stream bed. The vegetation on the upper slopes, particularly if it includes deep-rooted trees and shrubs, removes water from the groundwater zone by transpiration, establishing and maintaining an hydrological balance whereby the watertable remains at a safe distance below the soil surface and waterlogging or seepage do not become problems.

If the natural vegetation is removed from the upper slope, the amount of water extracted from the groundwater zone by plant roots is substantially diminished. The water table consequently rises, and may come into the root zone or even to the surface on the lower slope and the valley floor. The flowing groundwater dissolves salts from the rock and soil through which it filters, so that its salinity progressively increases The shallow saline seepage water impairs plant growth, reducing productivity and frequently leading to the replacement of the existing vegetation by more salt-tolerant and generally less productive or less palatable species. Where seepage water comes to the surface, evaporation leaves a characteristic residue of white crystals on the soil and the high concentration of salt may lead to the removal of all vegetation. Under these conditions the surface is particularly susceptible to erosion, and this may be aggravated by the trampling of livestock attracted to the salt. Severe sheet, rill and gully erosion is a likely consequence.

Apart from its localized effects on vegetation and agricultural productivity, dryland salinity has adverse off-site effects which include, apart from the consequences of severe soil erosion, the impairment of both groundwater and surface water quality, which may be evident for a considerable distance downstream.

The development of dryland salinity is a long-term process, which may take several decades to become established. In Australia, for example, extensive areas of dryland salinity are beginning to make their appearance in locations where the clearing of native vegetation was undertaken 70 or 80 years ago.

The solutions available for the management of dryland salinity are similar in principle to those employed for the management of irrigation salinity. They include methods involving changes in land-use and farming practices, as well as methods involving the manipulation of site hydrology.

Methods involving changed farming practices include moving from cropping to grazing, excluding stock or strictly controlling grazing on affected areas, introducing salt-tolerant grasses, shrubs and trees and changing from farming to agro-forestry. Direct manipulation of site hydrology includes the use of mole or pipe drainage to lower the watertable beneath saline areas, pumping groundwater from aquifers below the saline areas, and constructing banks and drainage ditches to divert excess water or improve the drainage of water from saline locations.

A number of interesting and successful methods of treatment combine both these approaches, by using vegetation to manipulate the shallow groundwater hydrology. These are essentially "recharge control" techniques, which seek to lower the watertable by reducing the inflow from the upper slope areas or increasing the rate of water extraction from the same areas. They include the revegetation of the groundwater recharge zone along the upper slope with deep-rooted trees and shrubs; the introduction to the upper slopes of plants or crops which have a much higher water use than the existing vegetation; and improving the management of existing crops and pastures to maximize their water use.

It is evident from the foregoing paragraphs that the adoption and implementation of appropriate land-use practices provides the key to the management and mitigation of those forms of land degradation which result from secondary salinity. Land-use planning, in anticipation of the development of new irrigation areas, will clearly also provide the key to the development of future problems of irrigation salinity, making it possible to avoid the establishment of irrigation schemes on land which is susceptible to this form of degradation for various reasons. In the same way, the development of future problems of dryland salinity on upland watersheds can also be avoided by sound land-use planning and the early introduction of appropriate land-use controls, such as the prevention of vegetation clearing on upper slopes in districts where soils are susceptible to salinization.

2. Degradation of soil structure

Degradation of soil structure relates to a serious reduction in the continuity, distribution and size of the pore spaces in a soil mass. This occurs either as a result of manipulation or trafficking of the soil surface, which may be a consequence of ploughing or other forms of cultivation, the passage of heavy farm machinery, or trampling by livestock, or as a result of the practice of irrigation on susceptible soils.

Degradation caused by trafficking or cultivation has a variety of adverse consequences, which include surface sealing and crusting, sub-surface compaction, and the formation of sub-surface plough pans or hard pans. It results in much reduced infiltration capacity, permeability and aeration, restricted germination, declining plant yield and substantially increased susceptibility to water and wind erosion. It also causes increasing farming costs as more and more energy is required for satisfactory cultivation. This form of degradation is most likely to occur with soils which have a high clay content and high in situ soil moisture levels. Dispersive and sodic soils are particularly likely to be susceptible.

Rehabilitation of soils damaged in this way can be achieved by discontinuing cropping and changing the land use to pasture production. The rehabilitation process is slow and stocking rates have to be carefully managed whilst it is in progress. More rapid but much more expensive improvement of the soil condition can be achieved through mechanical processes such as deep ripping and by the application of a soil ameliorant such as gypsum.

Structural breakdown under irrigation is a consequence of the effects of wetting on clayey soils. It occurs in two principal forms; slaking, which is the mechanical collapse of normally well-structured soil aggregates when wetted, and dispersion, which is a consequence of the chemical behaviour of high-sodium soils when wetted. The type of irrigation and the irrigation techniques employed affect this process, degradation being more severe under flood irrigation. Soil cultivation and crop management techniques, particularly the use of heavy farm machinery when soils are at high moisture levels, may also have an effect on breakdown.

The consequences of this form of degradation are impaired soil structure, reduced soil permeability and deteriorating sub-surface drainage characteristics. Poor germination, severely reduced crop yields and increased farming costs result. A combination of reduced surface infiltration capacity, restricted sub-surface permeability and much poorer drainage capability can lead to severe problems of rising water table, waterlogging and salinization, as well as raising problems with the management of excess tailwater.

Degradation of this kind is most likely to occur when soils are fine-textured and poorly-draining, susceptible to slaking and dispersion, susceptible to sub-surface compaction under farm machinery, underlain by highly saline soils or groundwater, or poorly drained because of flat topography or the presence of underlying soil or rock strata of low permeability.

This form of degradation can be managed, and rehabilitation achieved, through an understanding of the factors which cause it to occur. Modified irrigation practices and improved methods of cultivation and harvesting are necessary and a change in farming practice, involving planned cropping rotations with alternating irrigation and dryland cereal cropping phases, has been shown to be effective in reversing the process. In cases of severe deterioration, and where the high cost warrants it, treatment with an ameliorant such as gypsum may also be necessary.

Within the ESCAP region, degradation of soil structure is an increasing problem in countries where extensive, highly-mechanized cropping is practised. It occurs in India, Pakistan, China, Thailand and is prevalent in Australia, where it is claimed to be a more costly form of land degradation than soil erosion. There is considerable potential for this problem to become increasingly widespread and increasingly serious within the region as populations expand and the demand for greater food production accelerates.

Because this form of degradation is a consequence of the application of unsuitable farming practices and methods on susceptible and readily identifiable soil types and topography, there is very considerable potential for its control, and the limitation of its further spread, through sound land-use policy and the application of appropriate land-use management techniques. Land-use policy must provide for the proper identification and assessment of potential problem areas for future development, through such means as land survey, soil survey and land capability assessment; the zoning of farm lands to restrict development on soils susceptible to this form of degradation; and the control or prohibition of inappropriate forms of land use on farming areas under existing development. Methods of land-use management for the control of this problem have been briefly discussed above and will be further detailed in Chapter VI.

3. Soil fertility decline

Soil fertility decline is a progressive reduction in the productivity of a soil. It is a complex process, evident through a deterioration in organic matter content, nutrient availability and biological activity in agricultural soils. It becomes evident through impaired germination, reduced crop yield and declining crop quality, along with increased farming costs brought about by the need for increasing amounts of chemical fertilizer application.

The extent and severity of this form of degradation is not well documented, largely because its effects may be attributed to a variety of other causes such as climatic variations, changing farming practices, or the consequences of other forms of degradation such as water and wind erosion. It is known to occur in many parts of the ESCAP region. It may occur in tropical areas where rainfall rates are very high and soils are porous, as a result of nutrient leaching It is particularly likely to occur in cropping lands of low natural fertility, in locations where rainfall is generally variable and marginal. Extensive cropping lands in China, India, Pakistan and Australia are likely to become increasingly affected – in Australia, it already appears to be widespread in cereal cropping regions.

Soil fertility decline will become a problem of serious potential significance in the region as the demand for food and fibre production increases and more extensive cropping of low-fertility marginal lands become necessary. To avoid its development, land-use policy needs to emphasize the need for comprehensive resource data collection, particularly topographic survey, soil and vegetation survey, and land capability assessment. Monitoring of soil fertility conditions to provide warning of potential fertility decline, along with the adoption of land-use practices aimed at the better incorporation of organic matter, the good health of the soil biota, and the maintenance of natural nutrient sources, are all necessary for the effective management of this form of degradation.

4. Soil acidification

Soil acidification is a progressive reduction in the pH of a soil, leading to a gradual increase in soil acidity. It appears to develop when certain farming practices cause modification to the carbon and nitrogen cycle processes within the soil mass. It occurs on naturally acid, light-textured soils in regions of comparatively high rainfall where nutrient leaching is more pronounced. It develops principally on lands used for pasture production which have been subject to a long period of artificial fertilizer application, particularly on leguminous pastures with a long history of superphosphate application.

This form of degradation becomes gradually evident through reduced pasture yield, poor plant establishment and increasing susceptibility to plant disease. The health of stock grazing on the pasture may be affected, and where the condition is severe an erosion hazard may develop. Response to chemical fertilizers is progressively diminished, leading farmers unaware of the cause to increase their fertilizer application rates, which has the effect of compounding the problem as well as increasing farming costs.

The most common and effective method of treating soil acidification is to apply agricultural lime, which raises pH, increases calcium content, improves the availability of trace elements and enhances legume nodulation. Lime is applied by surface spreading or, in some cases, by sub-surface injection at the time of pasture sowing.

Knowledge about the extent and severity of this problem within the ESCAP region is not well established. It is widespread on the grazing lands of the slopes and tablelands of Eastern Australia, and is likely to be a potential problem in other districts within the region where soil types, climatic conditions and farming practices are similar.

As with soil fertility decline, the adoption of good land-use policy is necessary to ensure the early detection of this form of degradation and develop appropriate ways and means for its management.

Monitoring of soil acidity and levels of crop and pasture production, along with the development and dissemination of information about detection, treatment and the appropriate land-use practices, are all necessary requirements for the effective management of this problem.

5. Other forms of *in situ* degradation

Soil waterlogging occurs when the water table rises and comes close to the soil surface. If it comes high enough to enter the root zone, air is driven out of the soil pore space and saturation occurs. Under these conditions, plant growth is severely restricted and crop or pasture yields severely reduced. The existing vegetation may be killed and replaced by far less productive or less palatable species. In extreme cases, the water table may rise to the surface or above it, causing surface saturation or flooding and effectively rendering the land useless for crop or pasture production

As has already been explained, this form of degradation results from changes in local hydrology and is usually a consequence either of vegetation clearing on upper slopes or of the application of excess irrigation water. It is compounded by a variety of factors which include soil types, soil drainage characteristics, and climatic conditions.

This form of degradation is usually associated with problems of soil salinity, either of irrigation salinity or of dryland salinity, and has already been discussed in association with those problems in Section II.D.1 above.

Soil pollution occurs when soils become contaminated with toxic pollutants. This may have a number of adverse environmental consequences, including reductions in crop and pasture yield, crop and pasture losses, sickness and poisoning of livestock, surface and groundwater pollution, or the rendering of land unsuitable for human settlement or habitation

This form of degradation is most commonly associated with industrial or mining activity, often being a legacy of abandoned factory or mine workings. In such cases it generally affects a specific and localized area, where it is easily identified and can if necessary be treated, although this may be at considerable cost. Land-use zoning, to prevent or restrict agricultural, urban or village development on or close to such areas, may be an appropriate management technique.

Less severe but more widespread forms of soil toxicity can occur as a result of farming practices. Contamination due to the excessive application of herbicides, pesticides or fumigants is an example. Other forms of soil degradation, such as salinity and soil acidification, may also have secondary toxic effects producing a build-up in concentrations of salts or trace elements. These problems are best controlled through a monitoring of their presence, an understanding of their causes and the application of sound farm management practice to minimize their effects.

E. The regional experience

The majority of the countries within the ESCAP region are now experiencing the adverse effects of land degradation and deforestation. These effects are manifested through such indicators as increased soil erosion, loss of soil fertility, increased sediment discharge and a decline in agricultural productivity. They are also evident through more frequent flash flooding and more active mass movement on upland watersheds.

Bangladesh is a relatively flat country, with less than 5 per cent of its total area classified as hilly. The elevated lands of the Chittagong Hills Tract is well covered by forest and jungle and is not subject to severe erosion or sedimentation problems. Elsewhere, soil erosion due to intense rainfall is not a serious problem. The most serious form of natural disaster affecting Bangladesh is flooding, which predominantly has its origin in the upper catchments of the large rivers beyond the borders of this country. Under flood conditions these rivers carry heavy silt loads, which causes raised river bed levels, creates navigation problems and reduces the hydraulic capacity of the river channels. The high rates of discharge and high velocities associated with flood flows are responsible for land degradation in the form of migration of river channels and the erosion of banks and floodplain surfaces.

Forest cover across Cambodia decreased from 73 per cent of the total land area in 1972 to 63 per cent in 1995. The consequences of this rapid rate of deforestation have included widespread erosion, soil and water degradation, landslides, siltation of watercourses and reservoirs and an increasing frequency of flash floods. The principal reasons for this deforestation have been agricultural expansion, shifting cultivation practices, firewood gathering, commercial logging and forest fires.

Land degradation, in the form of extensive soil erosion, is a serious problem in China, where nearly 40 per cent of the land area is so affected. Of this area, some 48 per cent has been caused by water erosion and the remaining 52 per cent by wind erosion. It has been estimated that the total area of eroded land is increasing at the rate of two per cent per annum. Adverse consequences of this widespread erosion have included the siltation of rivers, lakes and reservoirs and an increased intensity of such disasters as flooding, landslides and mud flows.

The area of degraded land across India represents about 25 per cent of the total land mass. This comprises land which is deteriorating because of inappropriate land-use practices or because of deforestation or a lack of adequate vegetative cover. Degradation is most evident through soil erosion and the loss of agricultural productivity.

As a result of uncontrolled land development and a high demand for agricultural land, forest cover has been progressively removed from the steeper slopes in many parts of Indonesia. This has led to degradation in land and water quality and accelerated soil erosion. Population pressures have compounded the problem by increasing the demand for the utilization of steep slopes for agricultural purposes. Insufficient funding for watershed protection and improvement has not helped to slow the rate of degradation. Over-exploitation of forests, shifting cultivation practices and mining activities have all been instrumental in producing soil erosion and sediment production. High rates of rainfall on unprotected land surfaces have increased the erosion of fertile soils and the incidence of landslips and mud flows. Sedimentation in the lower reaches of major rivers has increased the magnitude and severity of lowland flooding.

The main cause of land degradation in the Lao People's Democratic Republic is deforestation. Removal of vegetation through uncontrolled logging, slash and burn methods of agriculture, and over-utilization of fragile lands have all accelerated the rate of soil loss and increased surface run-off.

In Malaysia, nearly 60 per cent of the land surface has been retained under forest cover. Within the undisturbed forested areas land degradation is not a significant problem. Elsewhere, however, land clearing, shifting cultivation, intensive land use and urbanization have caused land degradation, which is evident in the forms of soil erosion, sedimentation and landslip. This is particularly the case in many of the watersheds of Sabah and Sarawak, and, to a lesser extent, in Peninsular Malaysia.

Deforestation and clearing of natural vegetation have been responsible for significant soil erosion and land degradation in Myanmar. Such activities as commercial logging, shifting cultivation, inappropriate farming practices, uncontrolled grazing, wild fires and poor maintenance of roadways and other earthworks have all contributed to this problem.

In Nepal, the exploitation of forests has resulted in significant deterioration of environmental quality and extensive degradation of watersheds. Massive deforestation has been undertaken over recent decades in order to create more land for cultivation, in an attempt to satisfy the needs of a rapidly-growing population. The removal of vegetation, along with uncontrolled grazing, has severely damaged the fragile slopes of this mountainous country, increasing gully erosion, triggering landslides and mass wasting, accelerating the rate of run-off and causing increased sedimentation in rivers and streams.

Pakistan has developed significant land degradation problems in the forms of soil erosion, landslides and sedimentation. These have been exacerbated by the exploitation and over-development of marginal lands on upland watersheds. Increased cultivation. excessive livestock grazing. deforestation and removal of vegetative cover have all contributed to the process of environmental degradation.

The rate of forest destruction in the Philippines is estimated to have been amongst the highest in the world. In less than ninety years, the area under forest has been reduced by more than 75 per cent. In addition to deliberate clearing, frequent forest fires have been responsible for the destruction of large areas of virgin and plantation forests. The destruction of upland forests has resulted in massive soil erosion, landslips, declining soil productivity, sedimentation of river channels and siltation of reservoirs, and acute water shortages during the dry season. It is estimated that about 75 per cent of the total uplands area of the Philippines is now vulnerable to soil erosion.

Encroachment onto forest reservations by squatters, deforestation from both illegal and commercial logging, clearing for rubber plantations and mining activities have all contributed to the degradation of upland watersheds in Sri Lanka. Poor soil conservation techniques and frequent landslides have resulted in the widespread loss of topsoils, evident in heavy siltation of the lower reaches of the island's rivers.

Significant deforestation over recent decades has denuded much of the landscape of Thailand. Increased soil erosion on unstable slopes, a consequence of the excessive removal of the native vegetative cover, has led to significant land degradation, sedimentation, landslip, and the more frequent occurrence of flash floods on the smaller watersheds.

The practices of shifting cultivation, overlogging and land clearing, along with the effects of forest fires, have reduced Viet Nam's forested area by 16 per cent over the past fifty years. As a consequence, flooding has intensified and the areas of land inundated during major flood events has increased dramatically. In contrast, the altered hydrologic regime has also increased the intensity of droughts. The removal of forest cover has resulted in severe land degradation, which takes the forms of soil erosion, loss of soil fertility and increased downstream sedimentation.