Soil Erosion and Conservation

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With Special Reference to the Sri Lankan Dry Zone

By

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Cambridge Scholars Publishing

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'The philosophy and the techniques of soil conservation, which worked in the United States were extrapolated to the Third World in the 1930s and 40s, and it has taken us nearly fifty years to slowly and painfully realize how much of the expertise is not suitable for developing countries'.

—Professor Norman Hudson (1987)

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PREFACE

Soil erosion is a serious global issue, affecting billions of people and undermining food security, livelihoods, and the climate, with up to 40% of the world's land already degraded. The purpose of the book is to describe the severity of soil erosion and its influencing factors, and strategies to minimize soil erosion. Arresting soil erosion needs the advancement of knowledge and practical implications to provide location-specific recommendations. This book based on a literature review together with the author's field research findings and theoretical development provides adequate information on the subject to enable using in universities and development projects. Field experiments conducted and theoretical developments made by the author have provided key findings such as mathematical relationships, models, and recommendations for soil conservation measures and sustainable land management practices.

The book contains 11 short Chapters. The first chapter provides a brief introduction to the dry zone of Sri Lanka including climate, soil and farming systems. Chapter two compiles a review on soil erosion and conservation with special reference to the dry zone. Then the book describes from chapter three onwards the research studies conducted by the author describing the methodology in Chapter three, theoretical advancement of the subject made by the author in Chapter four, analysis done on erosivity and erodibility in Chapter five, the impacts of soil erosion in Chapter six. Then the conservation strategies are explained in the Chapter 7 on the basis of various field experiments conducted by the author. Chapters eight and nine have been devoted to conservation models developed by the author. Chapter ten discusses the socio-economic aspect of soil conservation. Finally, the Chapter eleven summarizes the whole content of the book with conclusions and recommendations.

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Independent Consultant, 1st May 2025.

CHAPTER ONE

THE DRY ZONE OF SRI LANKA

1.1. Introduction

The "Sri Lankan Dry Zone" refers to the northern and eastern parts of the country, characterized by significantly less rainfall compared to the rest of the island, making it a region with limited water availability for agriculture and often facing drought conditions; this area is primarily located in the North Central and Eastern Provinces, and is considered a major agricultural region despite its dry climate, relying heavily on irrigation systems to support farming practices.

The dry zone accounts for nearly 60 percent of the total land area (6.54 million hectares) of Sri Lanka (Madduma Bandara, 1985; Panabokke, 1988). The land that can be used for agricultural purposes is about 2.71 million hectares in Sri Lanka of which about 48 percent is in the dry zone (Abeyratne, 1956).

For a long time, the dry zone settlers have realized that the pre-requisite to life and culture in any form, in Sri Lanka's dry zone is the water reservoirs and the intricate network of channels, which water the land (Broheier, 1975). Hence, the basic feature of the traditional farming system has become the man-made small reservoirs (village tanks) which are constructed by damming of river tributaries or streams and linking of the large reservoirs, through anicuts and channels, with a perennial source of water in the wet zone (Abeyratne, 1956).

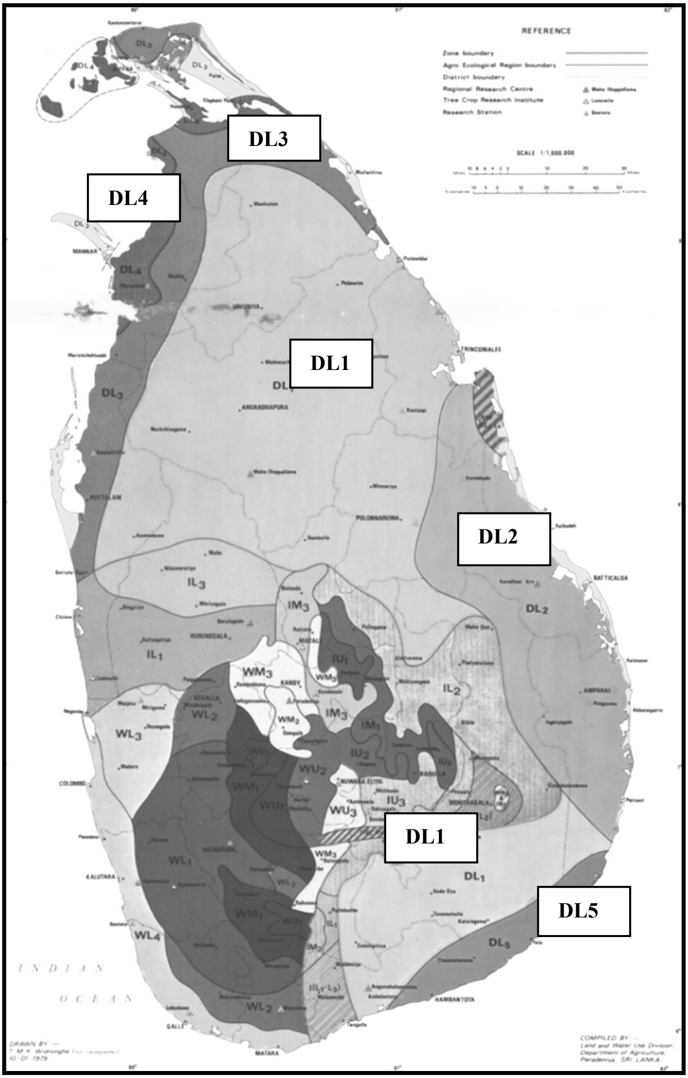
According to the modern international climatic classifications, the Dry Zone could be categorized under different nomenclatures. The classification used in FAO (1991) identifies the Dry Zone as Seasonally Dry Tropics along with its northwest and southeast sectors as Semi-Arid

Tropics. It also qualifies to be designated as a Semi-Arid region according to the definition of the World Meteorological Organization, where any ecosystem having more than 250 mm of annual rainfall but is not highly productive, is named so. It is also in agreement with the classification used by Gregory (1989), who defined Semi-Arid regions as an area of which monthly rainfall exceeds potential evapotranspiration for at least two and at most seven months, and the mean annual temperature exceeds 18 ^{0}C.

Thus, the Dry Zone exhibits both bi-modal and uni-modal distribution of rainfall depending on the geographical location. Out of these four rainfall seasons, two consecutive rainy seasons make up the major growing seasons of Sri Lanka, namely *yala* and *maha* seasons. Generally, *yala* season is the combination of First Inter Monsoon (FIM) and South West Monsoon (SWM) rains. However, since SWM rains are not effective over the dry zone it is only the FIM rains that fall during the *yala* season in the dry zone from mid-March to early May. Being effective only for two months, the *yala* season is considered as the minor growing season of the dry zone. The major growing season of the dry zone, *maha* begins with arrival of Second Inter Monsoon (SIM) rains in Mid-September/October and continues up to late January/February with the North East Monsoon (NEM) rains (Punyawardena, 2010).

1.2. Agroecology

An agro-ecological region represents a particular combination of the natural characteristics of climate, soil and land relief (Panabokke, 1996), which determines the land use and management requirements of a given location. A system of delineation of agro-ecological boundaries for Sri Lanka has been devised (Panabokke and Kannangara, 1975), in which Sri Lanka has 24 distinct agro-ecological regions (AER). Of them, 5 AERs lie in the dry zone (Figure 1.1). In identification of those five AERs of the dry zone, other than the amount and distribution of rainfall, type of great soils found in the region has also played a key role. Panabokke (1996) gives a good account of the characteristics of those regions.



Source: Wijesinghe (1979)

Fig. 1.1. Agroecological Regions of Sri Lanka

In general, a major portion of the dry zone falls under the Low Country Dry Zone 1 (DL1) region, which has a characteristic bi-modal rainfall pattern and Reddish-Brown Earths as the predominant soil group. Meanwhile, areas in the North-eastern part of the DL1 region receives comparatively higher amount of rains from the North East Monsoon over an extended period of time. Therefore, the *maha* season in this region is fairly long compared to other parts of the DL1 region. More than 50% of total irrigated lands of the dry zone and more than 60% of rain-fed upland cultivation are situated in this region (Panabokke, 1996). The Eastern sector of the dry zone falls under the Low Country Dry Zone 2 (DL2) region, where Non-Calcic Brown soil is the predominant soil type.

However, coastal strip of this region is mainly made up of Sandy Regosol. The rainfall pattern is characteristically unimodal being FIM and SWM rains are not effective over this region. Hence, the *yala* season usually does not exist in this region of the dry zone. Northern and North Western parts of the dry zone fall under the Low Country Dry Zone 3 (DL3) agro-ecological region, where the predominant soil type is Latosol except Kalpitiya peninsular, which is mainly made up of Sandy Regosol.

Low Country Dry Zone 4 (DL4) agro-ecological region has a similar kind of rainfall regime as in the case of DL3 region, but different soil groups such as Grumusol, Solodized-Solonetz and Solonchaks. The driest part the dry zone is falling under the Low Country Dry Zone 5 (DL5) agro-ecological region where rainfall is effective only during mid-October to mid-January. Even though, April and first week of May receive appreciable amount of rains in this region, they are insufficient to raise a successful crop during *yala* season (Punyawardena, 2010).

1.3. Major Dry Zone Soils

The dominant soil type in the dry zone of Sri Lanka is Reddish Brown Earth (RBE), often accompanied by "Low Humic Gley (LHG)" poorly drained soils, both characterized by relatively low water retention capacity and susceptibility to erosion due to the dry climate of the region; other soil types present include Non-Calcic Brown soils and Red-Yellow Latosols depending on the specific topography within the dry zone. A brief description of these soils is given below (Panabokke, 1996).

1.3.1. Well-drained Reddish Brown Earths (RBE)

This is the most widespread great soil group in Sri Lanka and it occupies the largest area compared to all other soils. These soils are mainly confined to the dry zone and they occur in a catenary sequence with the other drainage members on the undulating landscape of the dry zone. They occupy the crests and the well-drained upper and mid slopes of the land catena. Closest analogues of these soils are found in similar climates of East and West Africa, especially where the soils are derived from the basement complex of rocks. Their equivalents in Asia have been described as Red Mediterranean soils and Red Brown Earths in Thailand.

RBE is derived from quartz rich parent material which occurs on the crest and upper slope physiographic positions within undulating and rolling landforms. This is a well-drained to excessively well-drained soil with a deep soil profile. However, the depth of soil varies from place to place depending on the physiographic position. As a result of erosion, a thin layer of topsoil could be observed in some locations and therefore, pieces of quartz-rich decomposing parent material could be observed in the subsurface. In some locations, undecomposed pebble or stone size quartz fraction could be observed in the subsurface soil. Colour of the soil varies from reddish brown to red with soil depth. Texture of the soil varies from gravelly sandy loam, gravelly clay to gravelly sandy clay with the increase in soil depth. However, in some locations, quartz veins with variable thickness could be observed within the subsurface soil. Structure of the soil is weakly developed fine to medium sub-angular blocky. Weak development of the structure is mainly due to the presence of quartz gravel. This soil is porous and therefore, subsurface soil has good soil aeration. Under wet condition, the soil is sticky but non-plastic. It was observed that this soil has been extensively utilized as an earth filling material for road construction work due to the presence of higher quartz content. Organic carbon in the surface horizon is less than 0.8%. Phosphorus content in the surface soil is less than 10 ppm and decreases with soil depth.

1.3.2. Imperfectly Drained RBE Soils

These soils are imperfectly drained with a deep soil generally found below the well-drained RBE on the land catena. The occurrence of this soil is confined to mid and lower slopes of the gently undulating topography. Texture of the soil varies from sandy clay loam to gravelly sandy clay loam with the increase of depth of the soil profile. Surface soil is very dark greyish brown in colour. Subsurface soil is dark brown to strong brown in colour with mottles. Structure varies from sub-angular blocky to structureless massive with the increase of soil depth.

Earthworms are active in the surface soil and it is shown by worm casts. During the rainy season, fluctuation of the groundwater table could be observed. Surface soil is slightly sticky and slightly plastic when wet, friable when moist.

Low rainfall with lack of adequate drainage facilities that tend to increase the soluble salt content in the groundwater is the reason for leading to salinity development. When the adjacent soil is poorly drained LHG, no exchangeable sodium could be observed from the soil horizons in the subsurface layer. Organic carbon content of the soil is about 0.7% on the surface. Available phosphorus content varies widely through the soil profile, having 12 ppm on the surface and less than 2 ppm in the subsurface.

1.3.3. Low Humic Gley (LHG) Soils

Next to the RBE soils, the LHG soils are the most extensive great soil group in Sri Lanka. Due to its position on the landscape this soil is essentially hydromorphic. The dominant factor that determines the expression of these soils is that periodically high groundwater level.

The LHG soils are poorly drained and found throughout the lowlands of Sri Lanka, usually in the low-lying ground above alluvial or colluvial parent materials. They occur as the lower members of the drainage catena in association with either the RBE or the Non-Calcic Brown (NCB). They are not found in the hilly terrains or in the regions of mountainous relief. In Sri Lanka, the LHG soils are found mainly in the broader inland valley systems. In contrast, in the rest of Asia they commonly occur in large surfaces on the major stream terraces.

Colour of soil ranges from brown to yellowish brown in the surface and changes from brown to grey in the subsurface. Texture of the soil is sandy clay loam throughout the profile and clay content increases with soil depth. Structure of surface soil is massive due to the mixing of surface soil during land preparation for rice cultivation and the subsurface soil is moderately developed sub-angular blocky. Poor drainage conditions are observed right from the surface horizon with the presence of rounded shape black coloured ferromanganese concretions. Prominent or distinct mottles appear with sharp boundaries in the subsurface soil. Calcium carbonate concretions are observed in the lower subsurface horizons Surface soil is slightly sticky and plastic when wet, friable when moist, and hard when dry. Organic carbon in the surface soil is slightly greater than 1% and phosphorus content remains less than 5 ppm.

1.3.4. Non-Calcic Brown (NCB) Soils

The NCB soils in Sri Lanka are a type of soil primarily found in the eastern part of the country, characterized by their medium texture, brownish to yellowish colour, and well to imperfectly drained nature; they often occur alongside RBEs on undulating landscapes, typically in the intermediate and dry zones of the island. The colour ranges from dark brown to ash brown. Mostly NCB soil contains sand. This is a slightly acidic soil and has much of Calcium and Magnesium. Crops like Cereals, green gram, Cowpea, Peanut, Sugar canes, Chilli, vegetables and onions can be cultivated in NCB soil by applying correct conservation techniques and better irrigation.

Groundwater table can be observed in the subsurface layer during rainy season. Available water of NCBs in general is low and hence these are prone to drought. Soils need irrigation and susceptible to water logging during rainy season. Nutrient content and organic matter are poor and prone to soil erosion. Land use is coconut, rice and mixed cropping.

1.3.5. Red and Yellow Latosols

Red Latosols

These soils occur on the coastal region of North-western, North, and South-east of Sri Lanka. This coastal region is about 20 km wide and it occupies approximately up to 30 m above mean sea level in North-western and Northern regions. The occurrence of this soil in North-western Sri Lanka is confined to the crest and upper slopes of the undulating to rolling topography of the upper terrace of the coastal belt toward North. This is a very deep, excessively well-drained soil without gravel or rock structure throughout the soil profile. Colour of the soil varies from dark reddish brown to red with increasing depth. Surface soil is structureless and the subsurface soil is weakly developed coarse sub-angular blocky. Textural class of the soil ranges from loamy sand to sandy clay loam. Clay content increases with soil depth. Iron oxides in the soil are largely concentrated in the clay fraction. Surface soil is completely disturbed in cultivated areas. Consistency of the surface soil is non-sticky and non-plastic when wet. Ant nests and termite burrows at depths below 100 cm is an indication of good soil aeration of the soil. Surface soil is highly prone to wind and water erosion due to very poor structural stability. Red colour of the soil is mainly due to the presence of iron oxides in crystalline form.

Organic carbon content in the surface soil is very low due to higher organic matter mineralization in the region. In most locations, available P content in the soil is less than 5 ppm. Phosphate fixation may be a reason for the lower availability of P.

Yellow Latosols

This soil is derived from older deposits of the coastal plain which occur in the offshore area. This is an imperfectly drained, deep soil. Surface soil is brown in colour with sandy texture. In most locations, surface soil is disturbed due to human or faunal activities. Structure of the surface soil is weakly developed sub-angular blocky. Consistency of the surface soil is slightly sticky and non-plastic when wet, firm when moist, and slightly hard when dry. During the dry season, vertical cracks of 2–3 mm wide could be observed within surface soil. Organic carbon content in the surface soil is less than 0.5% as the rate of organic matter mineralization is higher under warm climatic conditions in the DL3 agro-ecological region. Available P content in this soil is very low as it could be fixed with iron and aluminium oxides in the soil. Lands with these soils are presently used for teak (*Tectonia Grandis*) forest plantations, coconut, and homesteads. Undeveloped lands remain as dry evergreen deciduous forest with lower storey consisting of scrub jungles.

Abundance of soils in the dry zone is given in Table 1.1.

Table 1.1. Dominant soil groups in the dry zone and their relative abundance in Sri Lanka

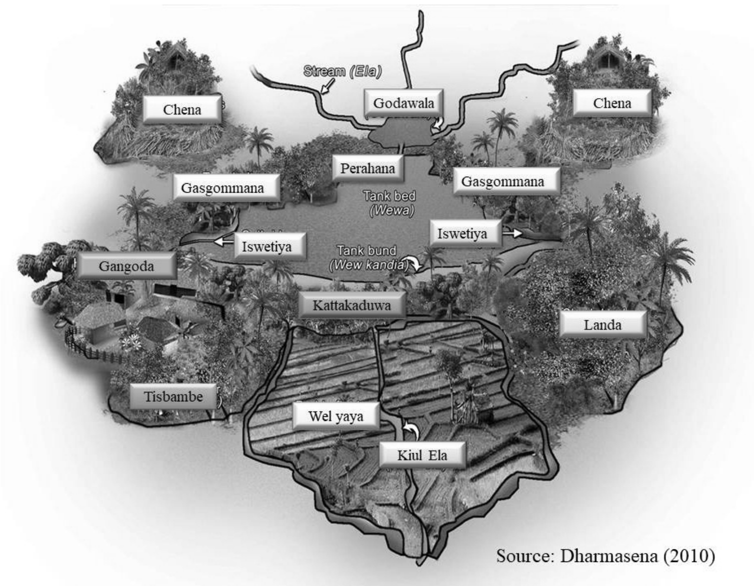
Soil type	Great groups	Extent ('000 ha.)	%
Reddish Brown Earths	*Rhodustalfs*	1610	24.6
Low Humic Gley Soils	*Tropaqualfs*	950	14.5
Non-Calcic Brown Soils	*Haplustalfs*	163	2.5
Red and Yellow Latosols	*Haplustox*	320	4.9
Alluvial Soils	*Troaquents, Ustifluvents, Tropofluvent, Natraqualfs*	450	6.9
Solodized solonetz	*Quartzipsamments,*	210	3.2
Regosols	*Ustipsamments*	190	2.9

Source: Dharmasena, 2001

1.4. Farming Systems

The tank-based irrigated agricultural system in the dry zone of Sri Lanka is one of the oldest historically evolved agricultural systems in the world. The main component of the system consists of a connected series of man-made tanks constructed in shallow valleys to store, convey and utilize water for paddy cultivation. The farming system is characterized by its three-fold pattern of land use.

Rice, the Sri Lankan's staple food crop is grown in the irrigable lowland mainly in *maha* season and perhaps in *yala* season depending upon the water availability of the tank. The village hamlet (*Gan-goda*) is in either side of the rice grown area (*Wel-yaya*) usually below the tank with perennial crops. With influence of tank water and because of lower elevation and imperfectly drained soils, most of the fruit crops such as mango, jak etc., coconut and some vegetables are easily grown in the home garden. `*Chena*' the third component, the most important system of farming, is the oldest farming practice of the dry zone villagers in the upland using direct rainfall. This is presently known as slash and burn or shifting cultivation to most of the scientists. Tank-village farming system in the dry zone is illustrated in Figure 1.2.



Source: Dharmasena (2010)

Fig.1. 2. Tank-village farming system in the dry zone

The traditional type of chena needs at least a fallow period of 15-20 years for a successful cultivation. A small portion of the forest area is still seen within the vicinity of the dry zone villages perhaps they are strictly declared as reserved forest or soil is too much gravelly for cultivation or due to a common decision of the community as to have a village forest for social requirements. Thus, the shifting cultivation phase-I (according to land use classification in Somasiri, 1983) or traditional chena cultivation is no longer in existence.

The next position in the spectrum of evolution of *chena* is the shifting cultivation phase-II which still bears some characteristics of traditional *chena* cultivation. Farmers clear vegetation which is usually less than 10 years old instead of the matured forest. They clear the vegetation, heap and set fire and prepare the land for cultivation.

The ratio between time spans allocated for cultivation and time left fallow is the most important factor determining the degree of success of the *chena* cultivation on the long run. Investigations carried out by Joachim and Kandiah (1948) indicated that the effects of chenaing a land on organic matter, N and mineral nutrients are common to any system of rotational cropping and are not such as would render the land unsuitable for further profitable cultivation. Also, they found no appreciable adverse changes in soil structure as a result of chenaing land. However, they pointed out the factors which limit the continuance of cultivation on *chena* lands as weed growth, insufficiently burnt stumps which begin to shoot up in a year or so, the lack and impracticability of tillage, and in some areas, soil erosion. The above results were based on observations of only two successive cropping seasons and they cannot be extrapolated to the consequences of continuous cultivation.

Continuous cultivation without adding Nitrogen or crop residues results in a reduction of organic matter content in soil (Newbould, 1982). Experimental evidence from Kurundankulama dry farming project indicated that soil fertility was quickly depleted under continuous cultivation on the uplands, and that the addition of fertilizer did not give substantial crop returns in the absence of additions of organic manures such as cattle dung or compost (Abeyratne and Panabokke, 1953).

A series of experiments conducted by Department of Agriculture at Mahailluppallama observed the following four critical problems affecting continuous rain-fed farming (Dept. of Agriculture, 1990).

1. Deterioration of the surface soil structure seriously affecting soil tilth and moisture conservation.

2. Proliferation of obnoxious weeds which make land preparation extremely difficult.
3. Depletion of nutrient reserves in the soil.
4. The need for timely land preparation to establish crops with the on-set of rains, as the rainy season is short.

As the soil erosion process continues surface soil layer changes with respect to its physical composition as well as structural formation. Both these changes lead to form a more compacted soil layer which does neither retain much water nor keep favourable soil tilth for cropping. Most of the nutrients are washed off by erosion and the remaining soil becomes infertile. Such environment favours weed rather than crop causing the weed problem which is the most apparent constraint to the farmer. Thus, a land with more weed and of compacted soil provides a difficult situation for timely cultivation. Four problems diagnosed above therefore, could be easily interpreted as problems arising from soil erosion.

Soil erosion caused by extensive clearing of catchment forest of village tanks and farming without conserving soil has been a major issue for last few decades in the dry zone agriculture of Sri Lanka (Brohier, 1975). The change of process becomes rapid due to population increase and consequent pressure on the arable land. In this process, not only the upper land becomes less productive or perhaps unproductive (Tennekoon, 1980), but also the tanks below are filled with sediment (Kunkle & Dye, 1981) destroying the entire village tank farming system.

The erosion hazard is significant in the Alfisols, which cover the largest part of the dry zone. This is on account of (a) the low water stability of the soil aggregates, (b) easy slaking of the soil macro-aggregates following sudden wetting, (c) rainfall intensities often exceeding the infiltration rates of the soils and (d) the undulating nature of the catenary landscape systems (Panabokke, 1975).

Sedimentation of village tanks could develop several problems such as (a.) reduction of the tank storage capacity, consequently decreasing the extent of irrigable area, (b.) reduction or retardation of subsurface inflow to the tank, (c.) blocking the sluices and channels with sediments, (d.) filling the dead storage entirely with silt so that no more water is available in the tank during the dry season for use of people, cattle and wild animals and (e.) spreading the tank water towards the upstream area which would cause inundation of upper paddy fields and high evaporation losses from the tank. A village tank filled with sediment is shown in Figure 1.3.

Due to lack of knowledge on the magnitude and the rate of soil erosion and tank sedimentation in the dry zone, the causes have not been properly diagnosed and the problem has not been adequately addressed. Thus, the tank village farming system is becoming non-profitable to farmers, resulting in resource degradation and causing irreversible hazards to the environment.

Fig. 1.3. A sedimented village tank

CHAPTER TWO

SOIL EROSION AND CONSERVATION IN THE DRY ZONE: A REVIEW

2.1. Soil Erosion: Its Nature and Definition

Soil erosion is a natural process. It seems reasonable to postulate that the depth of the soil profile is the result of a balance between the rate at which soil is being formed at the base of the profile and the net rate at which soil is being lost from the surface in the process of erosion (Hallsworth, 1987).

Soil erosion is basically a two-phase process consisting of the detachment of individual particles from the soil mass and their transport by erosive agents such as running water and wind. When the available energy is not adequate to transport the particles, a third phase, deposition occurs (Morgan, 2005). The erosion is defined as "detachment and movement of soil or rock by water, wind, ice or gravity" (SSSA, 1984). Most frequently soil erosion is reported in the form of `annual soil loss'. This indicates that most of the workers are in the opinion that the soil erosion is only the removal or loss of the soil from its initial location and not necessarily inclusive of the deposition in another location. Even in small fields, removal and deposition can take place within a distance of few meters. Wolman et al (1986) states "Eroding soil is never lost in the sense of disappearing”. Often it is merely moved from one part of the field to another. Johnson (1988) argues that the terms "soil erosion" and "soil loss" are not interchangeable. However, soil loss data measured in field plots or estimated by using Universal Soil Loss Equation (USLE) or Wind Erosion Equation (WEE) have been accepted as erosion data for soil conservation planning in small fields but not in drainage basins (Morgan, 2005).

The impact of man's activities on formation and erosion of soil is more distinct and dramatic. The soil erosion could be accelerated if man uses the