Editorial

Gender Perspectives in Sustainable Use of Earth Resources

It is well known that good health and well being manifest primarily from the serenity of the living environment, the quality of life and the recreational facilities available, all of which in ancient Sri Lanka stemmed from the cultural backdrop of the village tank, the temple, the paddy fields, and the forest fringe. It is also recognized that the emphasis of the vast storehouse of indigenous knowledge and practices had been largely on natural resource management, agriculture, climate, food security, conservation of genetic resources, and consequently of biodiversity as well as ethno-botany, ethno-forestry etc. But the most significant feature of this traditional way of life was the assurance of the sustainability of the home economy, domestic healthcare, nutrition, spiritual manifestations and the gender contribution to a holistic lifestyle.

Women in ancient times displayed their own capabilities, and played a significant role, not only in bringing up their families, but also in community welfare. It had also been shown that women played a central role in sustainably procuring and producing materials of practical domestic needs for sustenance of family health, nutrition and livelihoods. Their indigenous knowledge related to naturally occurring nutritional foods and medicinal plants in regular use and consequently of ecosystem diversity, as well as its utility value for maintenance of family health, nutrition and general well being for a sustainable lifestyle, were distinctly prominent.

Unfortunately in modern times, this cultural advantage had been overrun, and women are no longer in a position to concentrate on family health due to exigencies of a competitive commercially oriented economic scenario, where they are compelled to supplement family incomes through white collar employment. This sad situation is exemplified by the inability of modern day housewives to utilize advantageously the wealth of indigenous knowledge on maintenance of good health, nutrition, wellbeing and happiness in their families, through not only the sustainable use of floral and faunal species, as well as specific mineral resources, but more importantly maintaining a healthy living environment.

Traditionally, mothers with their generational knowledge could instinctively diagnose simple health problems of children, and treat them with simple home remedies. Take for example the use of the carminative, and anthelmintic decoction prepared with Embelia ribes (Walangasal in Sinh.) for the treatment of intestinal worms in children. Likewise, a decoction made out of Phyllanthus embelica (Nelli in Sinh.) and Tinospora cordifolia (Rasakinda in Sinh.), a medication popularly known in Sinhala as Nelli-rasakinda, was used as a common treatment for rheumatic pains, urinary disorders and for blood purification. These traditional home remedies for which the raw materials were either grown in home gardens, or sustainably extracted from forests, have now been largely replaced with Western pain-killers and antibiotics, which needs no domestic effort for preparation, and are also freely available in pharmacies. Apart from good health and well being, responsible production and consumption were hallmarks of traditional lifestyles. Such an organized community based livelihood and agrarian lifestyle, where the intrinsic value of earth resources, such as floral and faunal biodiversity was also recognized, would have been intuitively conditioned by the Buddhist philosophy of Sabbe Saththa Bhavanthu Sukhithahtā, which literally implies the "Dedication of oneself for the cause of his own well being and that of all living beings".

M. Asoka T. De Silva

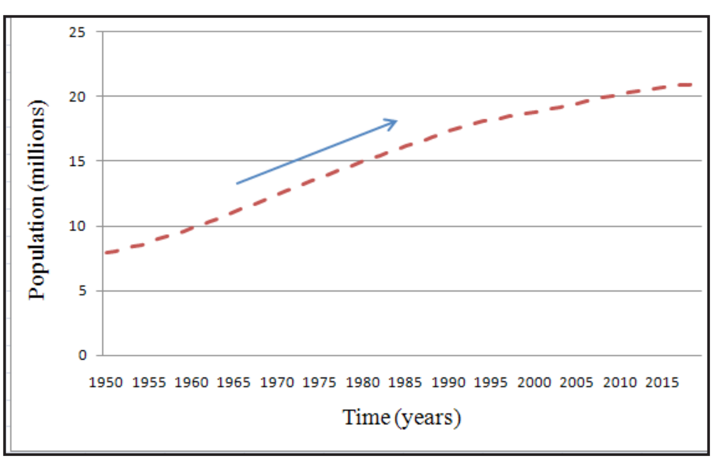
Impact of urbanization on earth resources in suburbs of Colombo, Sri Lanka

Dr Upaka Rathnayake

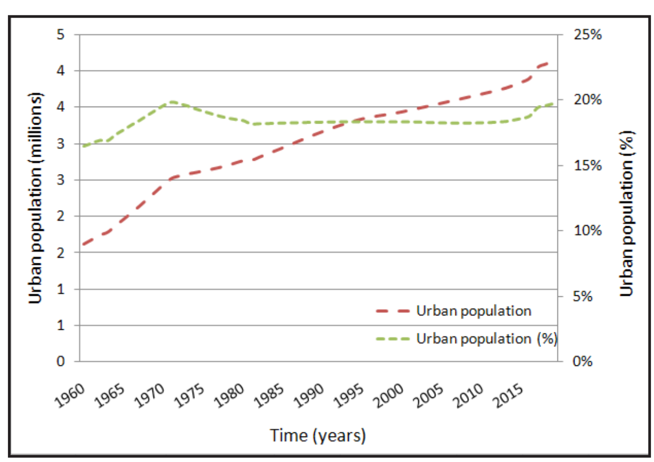
Sri Lanka is a moderately populated island (ranked 57th in the world) located in Indian Ocean. It is ranked 25th in the world in terms of population density. Sri Lanka as a country has faced several social issues since independence. Unplanned urbanization is one of the major issues experienced today. This unplanned urbanization has even indirectly led the society to have many social issues. These social issues include overpopulation, haphazard housing services, health burdens, urban poverty, crime, child labor, erratic education system, mismanagement of waste, deforestation, as well as air, water, sound and soil pollutions, carbon emission, environmental hazards, traffic jam, under employment and unemployment, improper drainage system inadequate entertainment facilities, drug abuse, vulnerable ecosystems, medley lifestyle and culture.

Colombo, the commercial capital of Sri Lanka, is continuously under pressure of urbanization. The land-use pattern in the Colombo District has changed dramatically over the last 50 years. Many migrants from the other districts have settled down in the Colombo city with the introduction of the open economy system in 1977. Many people have been under the belief that they could be economically wealthy, by moving into the capital city of the country. That is the current status of Colombo city, while the suburbs of Colombo began to urbanize during the early 1990s.

Figure 1(a) shows the population growth in Sri Lanka since the 1950's. The variation clearly shows the increasing trend of the total population in Sri Lanka. On the other hand, Figure 1(b) shows the urban population growth, and its percentage to the total population. Both figures show increasing trends as could be expected. However, since the land resources for the urban population are limited, while the growing urban population increases, the population density in urban



(a)Cumulative population



(b)Cumulative urban population

Fig 01 : Population statistics over the years for Sri Lanka

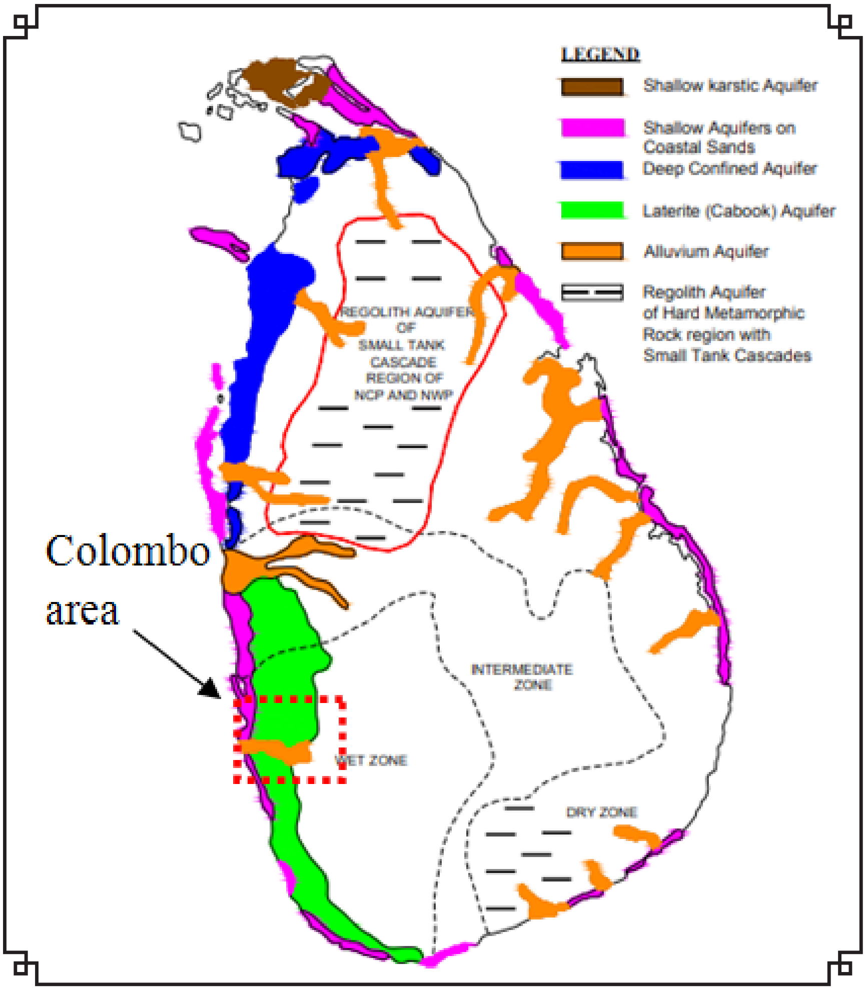
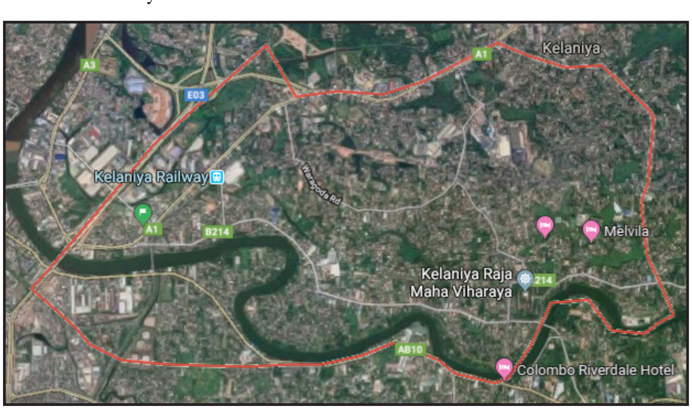


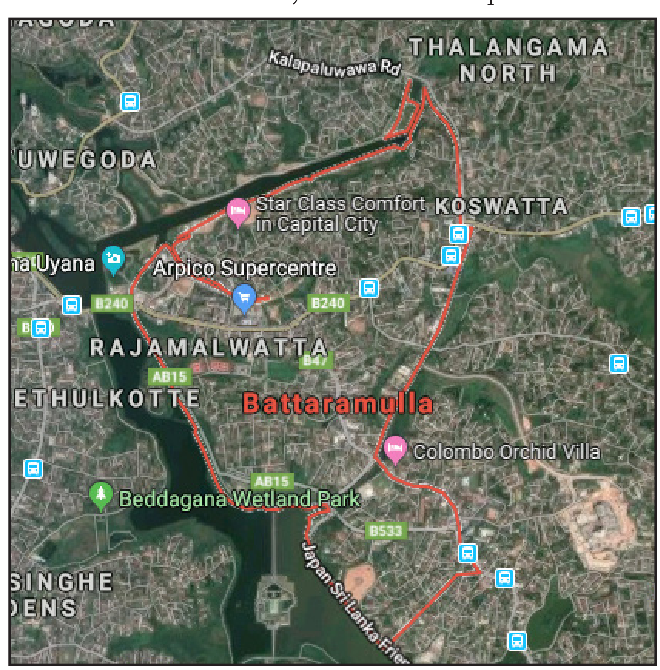
Fig 02 : Types of aquifers in Sri Lanka

areas continues to increase. In addition, new constructions (especially high-rise apartments) are being continuously introduced to the urban areas to cater to the growing population, and therefore the imperviousness of the land areas are at the increasing phase. This not only increases the urban runoff but also reduces the groundwater recharge.

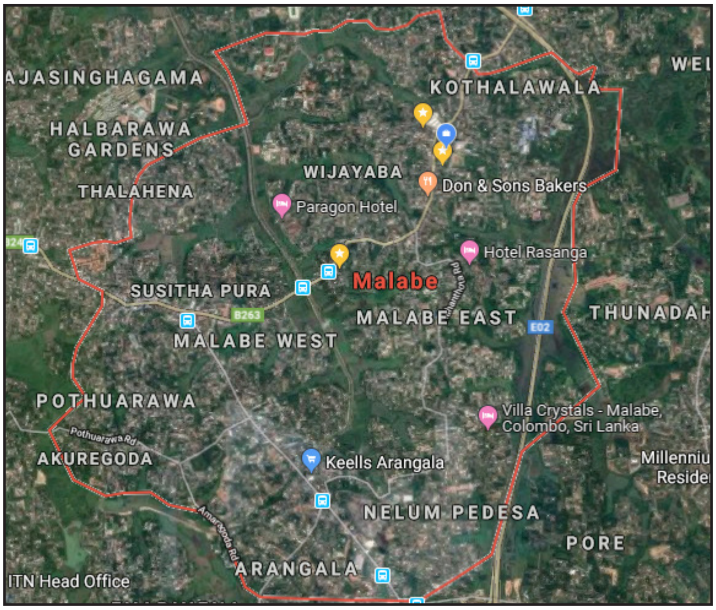
Let us now look at the groundwater resource in Sri Lanka. Groundwater is the largest reservoir of fresh water in the world. Groundwater can be found in aquifers (Wikipedia says; An aquifer is an underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials like, gravel, sand, or silt) and probably treated as the most precious earth resource by many people. In addition, it is one of the highly demanding components of the water cycle. Therefore, the geology (or in other words the soil structure) is very important to keep steady the groundwater aquifers. The geology of Colombo is representative of the entire west coast of the Sri Lanka's geology. The geology can be seen by a borehole test. A borehole can be defined as a narrow shaft drilled (bore) in the ground. This can be either vertical or horizontal though the vertical boreholes are frequent. Borehole analysis showed that the Colombo area had been formed as an estuary of Kelani and Kalu rivers. The flood plains of Kelani River provided thick alluvial (loose and liquidous) profiles for unconfined aquifers (Institute for Global Environmental Strategies, 2007). Unconfined aquifers are



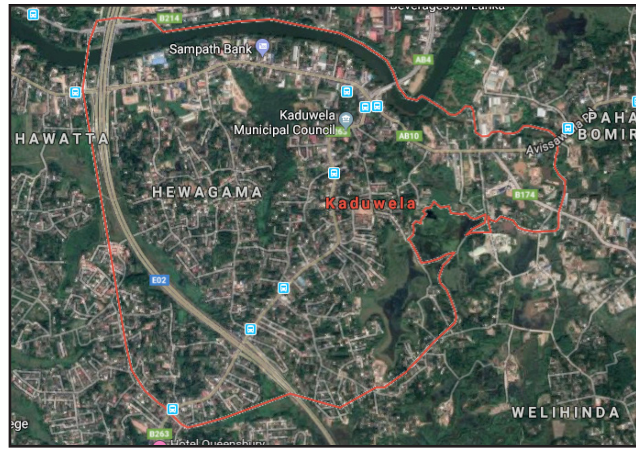
(a)Peliyagoda



(b)Battaramulla



(c) Malabe



(d)Kaduwela

Fig 3 : Google map images

those into which water seeps from the ground surface directly above the aquifer.

Six types of groundwater aquifers can be identified in Sri Lanka (Panabokke and Perera, 2005). They are shallow karstic aquifers, coastal sand aquifers, deep confined aquifers, lateritic aquifers, alluvial aquifers and shallow regolith aquifers. The distribution of aquiters presented by Panabokke and Perera (2005) can be seen in the Figure 2. However, they cited that many small groundwater pockets are distributed all over the country, indicating that Sri Lanka has rich groundwater resources.

As could be seen from Figure 2, Colombo area has three aquifer types including, shallow aquifers in coastal sand aquifers, lateritic aquifers and alluvial aquifers. Therefore, we can justifiably state that the area has a significant amount of groundwater resources. The geological structure also provides very good conditions to store groundwater in the area. Also since Colombo area is in the wet zone of the country, regular recharging of the aquifer through heavy rainfall can be observed.

Now let us look at groundwater usage in Colombo District. Sri Lankans since ancient times, believed that groundwater resources have the better quality compared to other water sources. People never tested the quality of the groundwater. However, they had

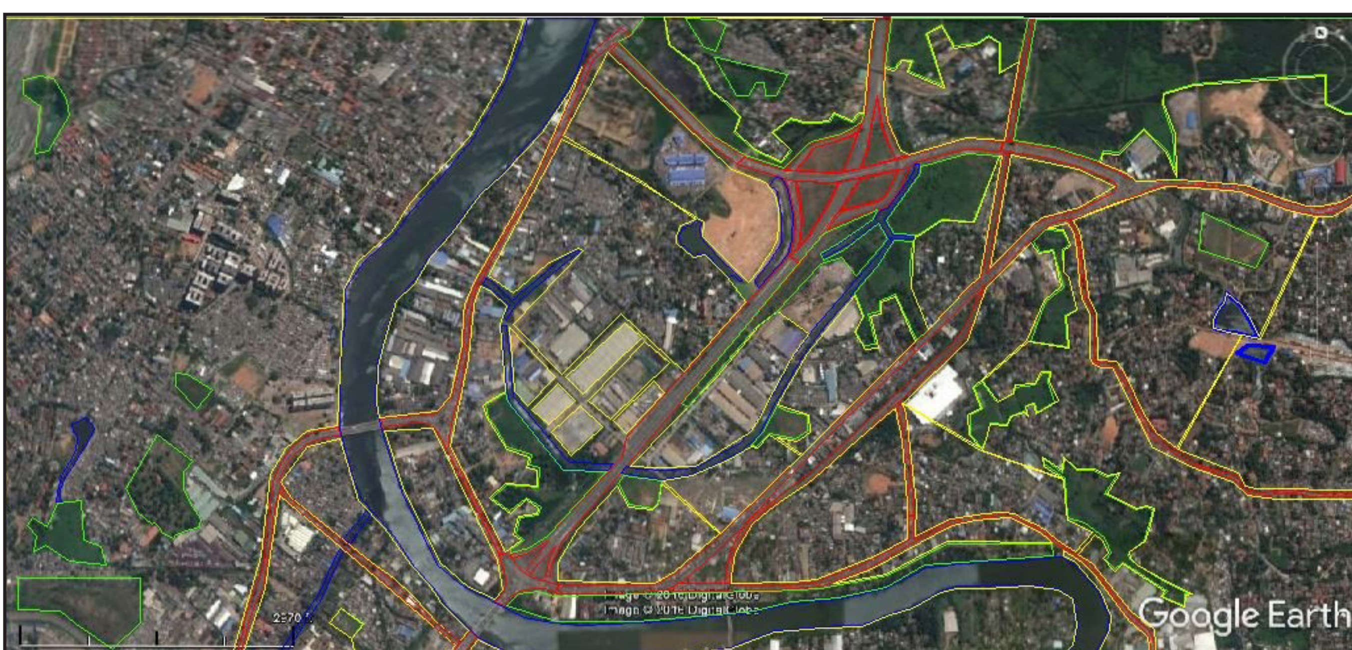


Fig 04 : processing details for Peliyagoda area

Fig 05 : Sample locations on Google Map

that belief. Even without treatment, they believed that the groundwater from wells can be used as drinking water. Many people used a cloth filter to screen small insects and floating particles from the well water, while some others boiled the water before drinking.
Nevertheless, Colombo does not have a groundwater supply system. The water distribution system in Colombo and its suburbs is through the pipe network that originates from surface water. However, a significant amount of residents in the suburbs of Colombo still use groundwater as their primary water supply source. Most of them use a small pump to lift the well water. The population that relies on groundwater in Colombo District is 34.8% (Institute for Global Environmental Strategies, 2007). This is a significant contribution from the earth resources. Malabe, Athurugiriya, Kaduwela, and Homagama are few of the suburbs that use more groundwater for domestic usages.
Now let us look at the impact of urbanization on well water in Colombo. As indicated earlier, Sri Lanka is a moderately dense island by population. However, few of the suburbs of Colombo have been extensively urbanized during the last decade. Peliyagoda, Battaramulla, Kaduwela and Malabe are few examples for such suburbs. The Google map images of these suburbs accessed on 13th of April, 2019 are given in Figures 3(a) to 3(d). These Figures clearly show that the green patches are at a minimum level. These suburbs are several kilometers away from Colombo city. However, they are highly packed. Nevertheless, a significant number of residents in these suburbs use groundwater for their domestic purposes (at least as the secondary water supply system). Several years ago, people used to utilize 10 perch (or more) land extent to build a regular house. However, it is now reduced to 6 perches. Rapid urbanization has reduced the land extent for the households. Within this 6 perch land area, people still use to have their water well and the toilet pit. There are many standard values for the minimum distance from a toilet pit to the water well (Graham and Polizzotto; 2013, Islam et al., 2016). However, as a norm, Sri Lankans use a 50 foot distance. Within the 6 perch land extent it is very unlikely to have such a distance in between the toilet pit and the water well. In addition, radially this 50-feet distance cannot be maintained in relation to the neighboring toilet pits and the wells. This is almost impossible with the on-going rapid urbanization. Therefore, the contamination of well water through toilet waste is not preventable, and thus the quality of well water is in great danger.

The impact of urbanization on groundwater resources can be understood using mathematics. Research (project) work has been done to understand what is happening using simple mathematics. For this purpose the 4 above stated suburbs (Peliyagoda, Battaramulla, Malabe and Kaduwela) were selected. Then, an analysis was done on these suburbs to find the impervious and pervious ratio using image processing techniques. To compare the rate of urbanization, the years 2004 and 2016 were selected. Google Earth was used to locate the land-use maps for the suburbs for an early time period. Therefore, the analysis was used for a comparison of a 12 year period. The Google Earth images Autodesk AutoCAD 2014 software was digitized to find out the pervious and impervious areas. Figure 4 illustrates an example for identification of pervious and impervious land extents in the Peliyagoda area.

Similar studies were carried out for other three suburbs for the years 2004 and 2016. In addition, as an initial step, groundwater quality was measured for a set of wells in Malabe and Kaduwela areas. Several basic water quality parameters (colour, pH, turbidity, conductivity, nitrate concentration, nitrite concentration, sulphate concentration, phosphate concentration, coliform availability and E-coli availability) were measured to understand the quality of the well water in the Malabe and Kaduwela areas. Due to various limitations, it was possible to analyze only few wells in Malabe area for coliform availability and E-coli availability. Figure 5 shows the locations where quality tests in water wells were carried out. The wells were intensively used by the community as the primary sources of their water supply.

Very encouraging results were obtained from this work. The Figures 6(a) to 6(d) show the impervious and pervious ratios of soil layers in 2004 and 2016 for Peliyagoda, Battaramulla, Kaduwela and Malabe suburbs, respectively. These clearly show the temporal variation of the imperviousness and perviousness ratios over the 12 year span. Peliyagoda (5.45%), Battaramulla (4.93%) and Kaduwela (6.41%) areas showed a moderate impervious land ratio increase over the 12 years. Therefore, on an average, 5-7% of pervious lands had been converted to impervious lands. However, Malabe has a much heavier impact. The increased ratio of impervious lands in Malabe area was around 12.8%. It is a significant loss of pervious area for the earth system in that area. Malabe has been treated as an educational hub as well as an information technology hub for some years, and therefore the area has been heavily urbanized.

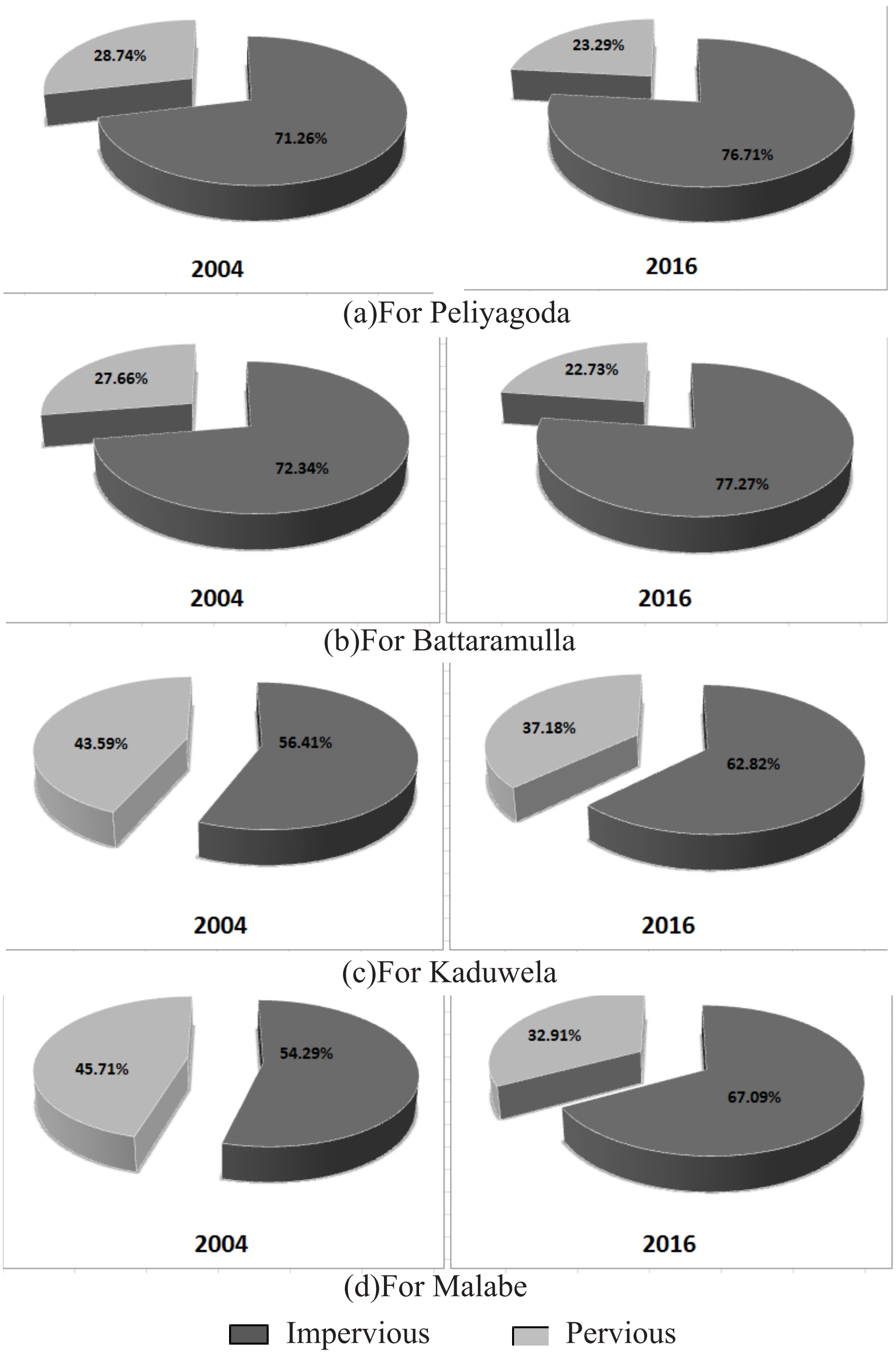
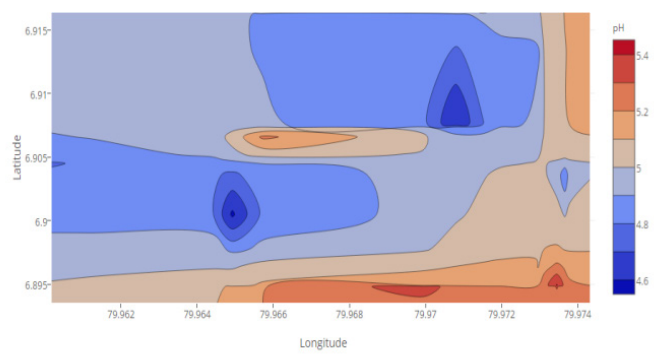
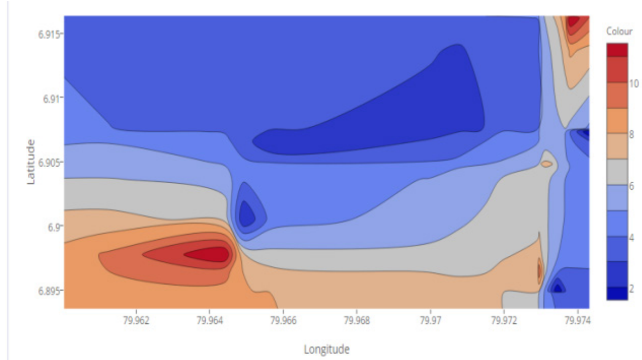


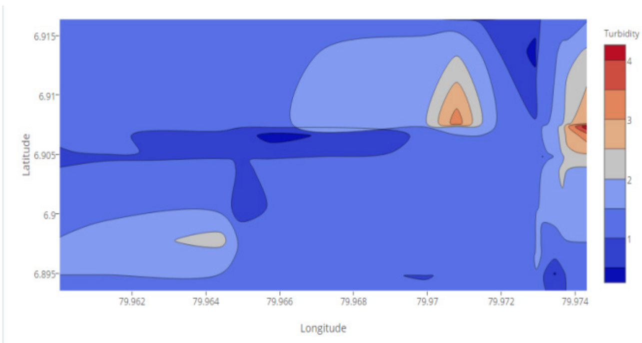
Fig 06 : Impervious and pervious ratios in suburbs of Colombo



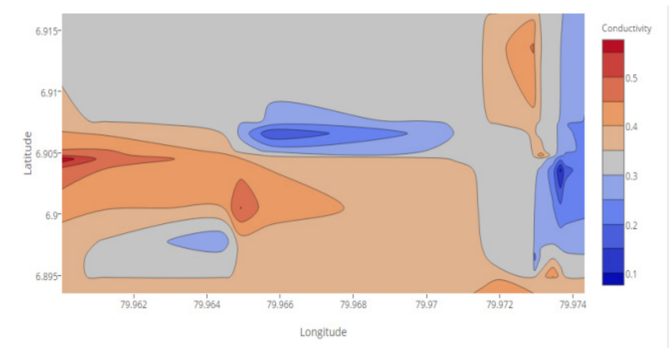
(a)pH



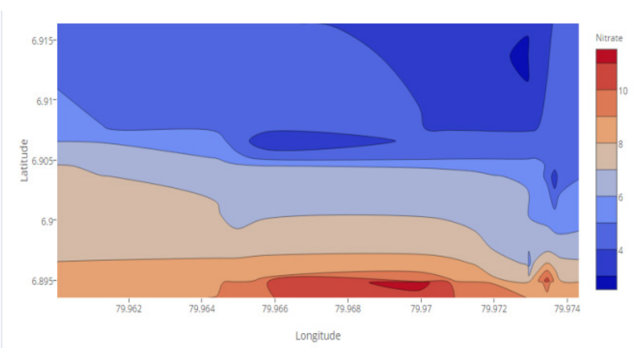
(b)Colour



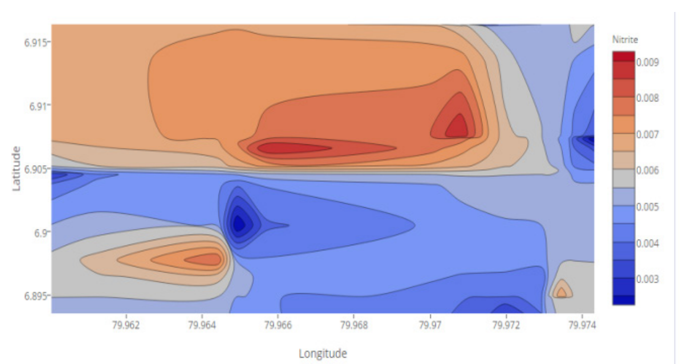
(c)Turbidity



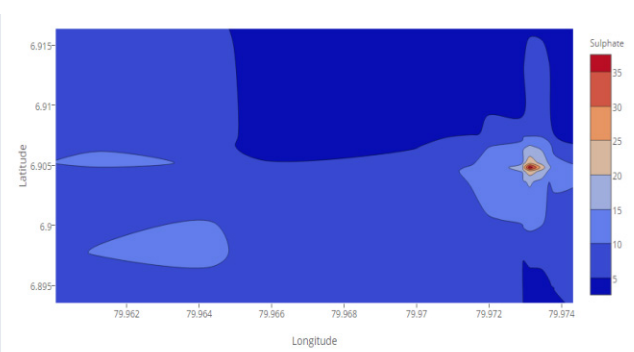
(d)Conductivity



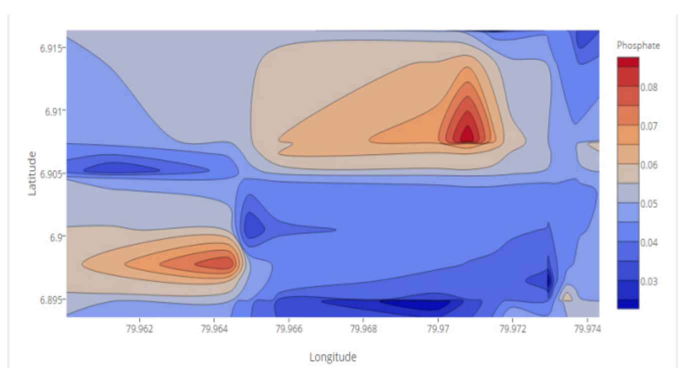
(e)Nitrate



(f)Nitrite



(g)Sulphate



(h)Phosphate

Fig 07 : Developed water quality contours

Table 1 : E-coli and coliform levels

Sample	E-coli (per 100ml)	Presumptive Coliform Count (per 100ml)
MN1	Nil	200
ME1	Nil	200
MW1	33	120
MW2	8	200
Desirable level	**Nil**	**Nil**
Maximum permissible level	**Nil**	**10**

It is well known that Malabe has been highly urbanized during the last decade. Non-state higher education institutes, technological parks, and treating it as one of the best residential areas, have increasingly affected the pervious lands. Since Malabe has an increased level of impervious lands over the years, Malabe and its surroundings were considered for groundwater quality checks.
The water quality tests were carried out at the Environmental and Water Quality Laboratory in SLIIT-Malabe. The required standards and protocols were carried out in measuring water qualities.
The water quality contours were plotted using the measurements taken. Figures 7(a) to 7(h) show the water quality contours for the area. These figures show the pH values of groundwater, colour, electrical conductivity, turbidity, conductivity, nitrates, nitrites, sulphates and phosphates contours in groundwater around the Malabe area.

Figure 7(a) gives the pH variation of the groundwater in the Malabe area. Blue patches in the figure indicates the areas with lowered pH values. Low pH values for drinking water may create some health issues. However, these results can be used to screen-out the areas, and to identify future well water extraction places. Similarly, other contour maps provide various essential water quality details of the groundwater in the area. However, there is concern over some other important test results. These include the coliform and E-Coli levels of groundwater. Initially, four intensively used wells were tested for these parameters and the results are given in the Table 1.

It is important to note that all four well water samples exceeded the safety level of presumptive coliform levels for drinking water (10/100 ml). These test results conclude that the groundwater in these four wells are at a bacteriologically unsatisfactory level for drinking water. More importantly, two wells were found to be contaminated with faecal bacteria. This is clear evidence to conclude the contamination by toilet waste of the groundwater in these wells. These two wells are located in a densely populated area with residential houses. There is thus a clear link between the urbanization and groundwater quality.

However, the water quality tests should be carried out for other wells as well to see the spatial variation of coliforms and E-Coli. In addition, tests should be carried out frequently to see the temporal variation, because the groundwater tables in the concerned areas are at shallow depths.

In summary, based on the studies carried out, it can be concluded that there is a clear link between urbanization and groundwater qualities. This can lead to a new health crisis in the area if timely safety precautions are not taken. Groundwater has to be treated as the most important earth resource. Hence this research is timely, and is necessary to understand the importance of unplanned urbanization on the Earth Resources.

Dr Upaka Rathnayake
Department of Civil Engineering,
Faculty of Engineering,
Sri Lanka Institute of Information Technology,
New Kandy Road,
Malabe,
Sri Lanka
upakasanjeewa@gmail.com /
upaka.r@sliit.lk

Sustainable Land Management in Sri Lanka

Dr P.B. Dharmasena

Introduction

On a global scale, an extent of about 1.5 billion ha is utilized as crop lands. Of these 38 % is affected by land degradation processes. It is also known worldwide that about 55% of the gross value of food is still produced under rain-fed agriculture. Cropland in dry rain-fed areas is used primarily by smallholder farmers to cultivate field and cash crops. Total irrigated cropland worldwide is 252 m ha. This is 17% of the total crop lands. About 20 % of the irrigated crop lands are affected by salinity . It is widely accepted that land degradation is one of the most critical problems affecting the future economic development in Sri Lanka. The demands of a rapidly expanding population has created pressure on the island's natural resources, and these in turn have resulted in a high level of environmental deterioration. The more important manifestations are: heavy soil losses; high sediment yields; soil fertility decline and reduction in crop yields; marginalization of agricultural land; salinization; landslides and deforestation and forest degradation. Severe erosion takes place in the hill country on sloping lands under market gardens (vegetables and potatoes), tobacco, poorly managed seedling tea and chena cultivation.

Conservation of soil resources is now defined as sustainable land management, which includes the processes defined by various organizations such as United Nations, World Bank, WOCAT (World Overview of Conservation Approaches and Technologies) etc. Most widely used definition at present is that of WOCAT, which defines it as 'the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions.

Indigenous Sustainable Land Management Practices in Sri Lanka

In indigenous agriculture, farming was practiced both under rain-fed and irrigated conditions. Soil management involved mainly two activities, namely, tillage and soil conservation. Soil conservation was meant for erosion control and maintenance of soil fertility. Similar to present scenario, the purpose of soil management was to achieve sustainable production, improved soil fertility, weed control and soil moisture retention. However, different strategies were adopted for different farming situations that existed in different regions of Sri

Table 1 : Crops grown in different chena types

Type of Chena	Soil fertility level	Crops
Virgin chena from dense forest	Very fertile	Mustard, legume, vegetable
Chena from secondary vegetation	Fertile	Legume, vegetable, coarse grain
Chena abandoned for few years	Moderately fertile	Coarse grain, sesame
Chena continued for few years	Less fertile	Sesame,
Upland paddy chena	Imperfectly drained soils	Rice, vegetable

Lanka.

Indigenous agriculture was based on more realistic principles. People observed the natural phenomena operating around them, and studied how it could be manipulated for their needs. They observed the state of the natural forests, its anatomy, association of different species for coexistence, regeneration after fire, spatial variations etc. The farming systems which included chena, paddy and home garden cultivation evolved with interaction of man with the environment, and developed in harmony with natural ecosystems . Their experiences and observations on rainfall pattern, wind, temperature, humidity and soil behaviour have been used to adjust their cultivation activities. When they realized that some of the tragedies they faced in farming were due to reasons beyond their control, they sought the devine support of the religion, as well as the spiritual and cosmic influences. The most important fact was that they realized that without primarily giving due respect to the resources being used for farming, they could not expect the sustainability of their food sources.

Tillage was practiced to make the soil surface weed free and smooth for seed germination or for the plant growth. In rice cultivation in lowlands, the land was prepared by a set of operations. It included repairing earth ridges (dykes) meant to store water, irrigate to create stagnant water for about two weeks, facilitate first ploughing in stagnant water as well as second ploughing to convert soil clogs to syrupy mud, draining water from the smoothened and level land, and finally the sowing of sprouted seeds. Tillage was done by a buffalo drawn shallow plough. This tillage operation could lead to the formation of a hard pan at 4-6 inches depth, and thereby prevent rapid percolation of water along with nutrients. The draining water flow did not cause any soil erosion. The plough blades were different from place to place. In areas where soil was soft, a plough made of wood was used, and where soil was hard, a wooden plough fitted with an iron blade at the cutting edge was used. In boggy soils of the wet zone areas, the plough was replaced by turning over the soil with mammoty (hoe) using manual labour. Special mammoties were used for this purpose. In land preparation of low lands for rice, dykes constructed took a special form. The dykes were plastered with mud so that they were kept weed free for some time and thereby seal off the dyke from water leakage.. Robert Knox (1681) , observed that when dykes are plastered with mud, the weed seeds cannot germinate and pierce through the compacted plastered layer of the soil, thereby keeping the dyke weed free for a longer period of time.

Fig 01 : Terraced lands in paddy cultivation

In indigenous farming crops were selected to suit the fertility level of the soil, which gets depleted with chena cultivation. (Table 1).

When chena cultivation is practiced continuously for a few years, the land tends to get infested with weeds, thus necessitating weeding prior to the preparation the of seed beds. Under such circumstances weeding was done traditionally with minimum tillage techniques. The weeds were scraped with mammoties and left for drying and burnt in the field itself. If the weed mass was low, no burning was done, and the dried weeds were left on the soil surface as a mulch, thereby helping to reduce soil erosion, and conserving the soil moisture in the field.

Indigenous Methods of Erosion Control

Indigenous people in Sri Lanka have paid much attention to arrest soil erosion at different levels. The emphasis was on reducing erosion in channels, streams, and tank bunds, and thereby reducing sedimentation

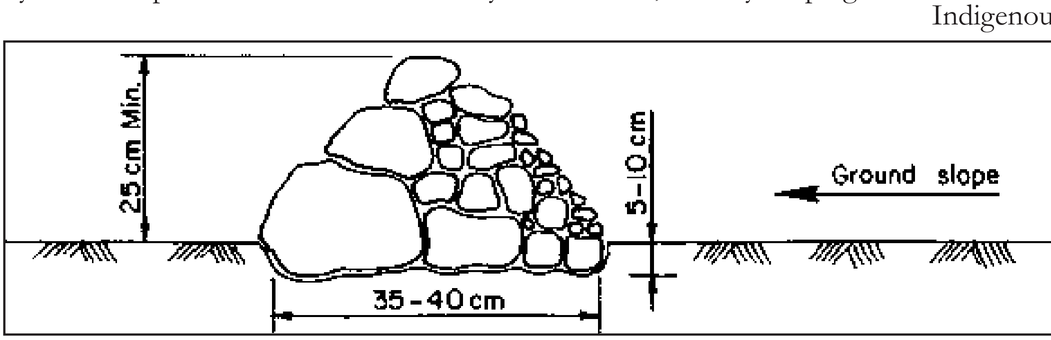


Fig 02 : Cross section of a stone ridge

of reservoirs. Many traditional villages have small tanks, around which the other land uses are organized, such as paddy fields, hamlet, upland cultivation, forest etc. Some of the erosion control and sediment avoiding techniques used in indigenous agriculture are described below .

Bench terrace (liyadda)

Soil erosion control has been achieved by terracing the land, especially in rice cultivation. Both highlands and lowlands have been terraced and leveled. Lowland paddy fields in hill slopes of the upcountry areas are good examples of terracing. The level benches help retaining water on the surface. This type of land development was done only in lands, which were used for continuous cultivation. The main land use in the highland was chena cultivation, where lands had been abandoned for regeneration after about 3-4 years of continuous cultivation. During this period, the land would have been subjected to severe soil erosion because of the rough nature of the surface. Further, on sloping chena lands, the farmers used to stack un-burnt debris across the slope at regular intervals. The soil was minimally disturbed which helped to reduce soil erosion on these lands.

Soil ridge (niyara)

These are ridges made across the slope of uplands to reduce washing off of the soil from the field, where slopes are very mild. Spacing

Table 2 : Land suitability classes and soil and crop management practices

Land class	Land characteristics and limitations for	Risk for crop losses	Control methods
I	Flat to gently sloping (0-10%), very deep soil (>150 cm), no apparent erosion, suitable for many crops	Very low	Normal control methods are sufficient, general fertility management, tillage, erosion control by soil cover and minimum mechanical methods
II	Gently sloping (10-20%), deep soil (100-150 cm), erosion is apparent, suitable for many crops, not suitable for some crops	Low	Soil conservation measures are required. Crops need to be selected.
III	Sloping lands (20-30%), moderately deep (50-100 cm), moderate erosion, moderate crop losses, only selected crops can be cultivated	Moderate	Effective soil conservation measures are required, crops should be selected carefully, essential to select both conservation measures and crops
IV	Moderately steep lands (30-40%), moderately deep (50-100 cm), severe erosion, crops are limited	High	Very effective soil conservation measures are required, not suitable for continuous cultivation, suitable for carefully selected crops
V	Bottomlands, valleys, flat lands, poorly drained marshy lands, only suitable for paddy, some are not suitable even for paddy	No erosion risk	Not suitable for cultivation of crops other than paddy
VI	Steep lands (40-50%), shallow (25-50 cm), very severe erosion, crops are much limited	High, not suitable for normal cultivation	Suitable only for permanent crops, pasture, forestry and wildlife sanctuary. Any selected crop needs continuous cover and very effective conservation measures
VII	Very steep lands (50-60%), very shallow (<25 cm), very severe erosion with gullying, not suitable for cultivation	Very high	Suitable only for permanent crops, pasture, forestry and wildlife sanctuary. Soil conservation is essential for any open phases.
VIII	Precipitous (>60%), very shallow (< 25 cm) with rock outcrops, very severe erosion with land sliding, not suitable for cultivation	Very high	Suitable only for forestry, wildlife sanctuary and protected forest for recreation.

Strategy 1 : Increase soil cover

Strategic factor	Activities	Benefits
Soil and crop management (Ec.)	• Leave all the crop residues in the field • Conservation tillage that leaves the residues on the soil surface • Apply organic materials as manures or mulch • Adopt inter-cropping and relay cropping • Leave the weed residues on the surface	It will reduce soil erosion, increase the infiltration rate, reduce the water loss through evaporation, reduce the soil temperature, improve seed germination, increase organic matter content in surface soil layer, improve the soil stability, stimulate soil biological activity, increase soil aeration, facilitate biological pest control and suppress weed growth

Strategy 2 : Increase soil organic matter content

Strategic factor	Activities	Benefits
Soil and crop management (Ec.)	• Apply compost • Add green manure • Add liquid fertilizer • Apply straw mulch	It will increase in the stability of surface aggregates, increase the moisture retention capacity of the soil, increase the capacity of the soil to retain nutrients, stimulate the soil biological activity

between niyaras had been decided by experience, based on rainfall, type of crops and the soil. The niyara retained the rainwater falling within two niyaras, preventing surface flow and thus reducing soil erosion. Openings (wakkada) have been kept at regular intervals of the niyara to permit flow of excess water in the event of high rainfall (Fig. 1).

Banks of streams and canals are subjected to erosion due to the scoring or scraping action of flowing water. Such erosion has been traditionally controlled and embankments stabilized using techniques presently known as 'bio-engineering techniques'. Trees/ plants, which tolerate wet or flooded conditions have very extensive root systems. Such plants have been grown along stream banks. Plants such as areca nut (Areca catechu) and vetakeya (Pandanus species) were the common examples. Bamboo is also a plant, which is grown to protect river embankments from river bank erosion. The roots of these plants have floating roots, which reduce the velocity of flowing water, thereby reducing erosion of banks and beds. All the plants used for this purpose have economic value too.

Stone ridges (gal weti) and leader drains (neththi kanu)

Inspection of very old homesteads show that stone ridges have been erected across the sloping lands to prevent soil erosion. These ridges have been constructed with rubble available in the land itself. The rubble has been set together with soil. In construction of these stone ridges, the farmers have stacked larger rubble on the downhill side while smaller ones were stacked on

Strategy 4 : Reduce runoff

Strategic factor	Activities	Benefits
Mechanical measures (LSmax)	• Collect the runoff in structures within which the water can infiltrate • Construct structures that collect and lead the runoff away from the field • Establish permeable barriers along the lines of contour to reduce runoff velocity	It will reduce the losses of soil, water, nutrients, fertilizers and pesticides, increase the moisture available to the crop and consequently grain yield and biomass production.

Strategy 3 : Increase water infiltration and moisture retention capacity

Strategic factor	Activities	Benefits
Soil and crop management (Ec.)	• Maintain a protective cover of residues over the soil • Reduce wind velocity by installing wind breaks • Create surface roughness between the crop rows • Keep fallow periods between cropping. • Apply organic fertilizer	It will reduce crop moisture deficit, increase the yield and production of the crop biomass, and reduce runoff.
Mechanical measures (LSmax)	• Adopt contour ridging • Reduce the land slope by terracing	It will reduce runoff and increase the yield and production of the crop biomass.

Strategy 5 : Improve rooting conditions

Strategic factor	Activities	Benefits
Soil and crop management (Ec.)	• Loosen the soil around plants to reduce compaction and increase porosity • Improve drainage by placing drainage channels where soils are poorly or imperfectly drained • Make furrows or raised beds	It will improve root development and growth, and as a result the crop will absorb more moisture and nutrients, reduce probability that the crops will suffer from drought.

In classifying a land for agricultural purposes it is important to identify its suitability and limitations. Land is categorized into eight land classes in Sri Lanka (Table 2).

Table 2. Land suitability classes and soil and crop management practices

Sustainable Land Management Strategies

Universal Soil Loss Equation (USLE) developed in 1978 is still valid and can be used to assess the erosion status and decide the most appropriate soil conservation measures for a given area. The equation was slightly modified to apply for Sri Lanka as follows:
A = RK (LS)max Ec., where,
A = Soil loss (mt/ha), R = Erosivity (mt.m/ha), K = Erodibility
(LS)max = Maximum slope - length factor one can achieve by manipulating land slope and length in a given piece of land, and
Ec = soil and crop management factor termed as Erosion Coefficient.
Mechanical measures can be adopted to reduce LSmax factor, and consequently soil and crop management practices can be adopted to reduce Ec factor.

Dr P.B. Dharmasena
Field crop research and development Institute,
Mahaillupallama
dharmasenapb@ymail.com

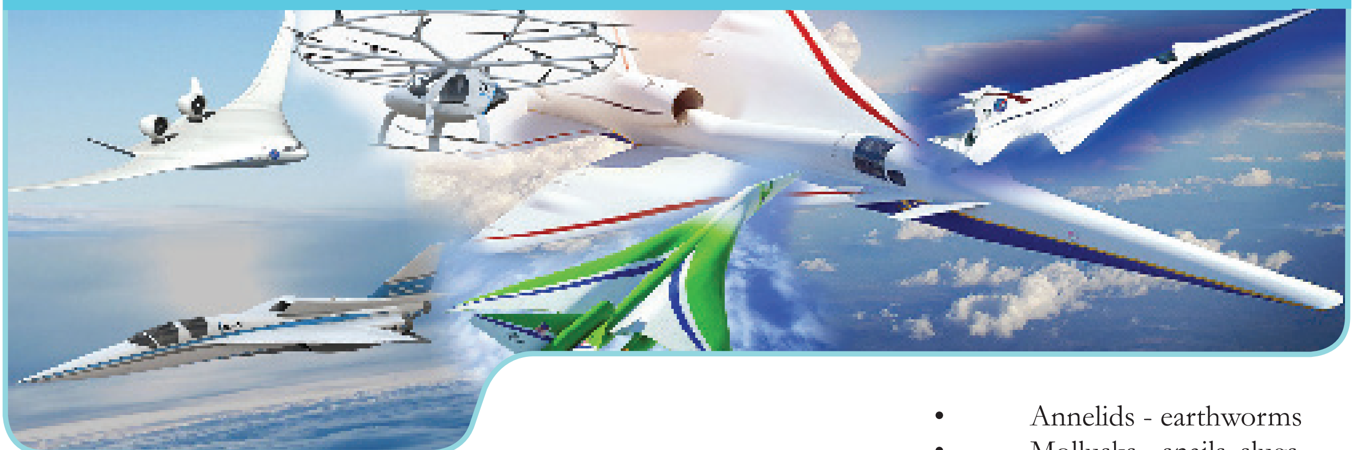
uphill side (Fig. 2).

The soils washed down the hill get collected in the upper depressions. In later years when the plantation crops such as coffee, tea etc. were introduced, these techniques have been used in those plantations. Even today, there are people in the hill country, who have mastered the construction of such stone ridges. In order to carry water down the slope without subjecting the soil to erosion, farmers have constructed neththi kanu. These are drains made of rubble without using any cement.

Present Soil and Crop Management Practices

Human Impacts on Biogeochemical Cycles

Dr D.M.Suratissa



Biogeochemical cycle

Biogeochemical cycle, any of the natural pathways by which essential elements of living matter are circulated. The term biogeochemical is a contraction that refers to the consideration of the biological, geological, and chemical aspects of each cycle. There are biogeochemical cycles for the chemical elements carbon, hydrogen, mercury, nitrogen, oxygen, phosphorus, and sulfur. Biogeochemical cycles depend on the soil organisms, mostly microorganisms.

What is soil fauna?

Soil represents one of the most important reservoirs of biodiversity. Soil fauna is an key of the biodiversity and plays an essential role in several soil ecosystem functions; furthermore, it is often used to provide soil quality indicators. Soil biodiversity indicate several thousand invertebrate species per site, as well as the relatively unknown levels of microbial and protozoan diversity. Soil microorganisms are classified as eukaryotes and prokaryotes. Prokaryotes are single cell organisms while Eukaryotes are either single-celled or multicellular. According to their size they can be classified as,

1. Macro fauna (>2mm, width)

Major specific groups of macro fauna are:

- Vertebrates – gophers (Central American Rodent), moles, mice
- Arthropods - ants, beetles, termites, centipedes
- Annelids - earthworms
- Mollusks - snails, slugs

2. Mesofauna (0.1-2mm, width)

Major specific groups of mesofauna are:

- Arthropods – mites, collembola (springtails), protura (Wingless Insect)
- Annelids – enchytraeid (pot) worms

3. Microfauna (<0.1mm, width)

Major specific groups of microfauna are:

- Nematodes
- Rotiferans
- Protozoans

Soil fauna found at different ecosystems

Tundra soils are formed at high latitudes. It is usually very cold in the tundra. Tundra soils are generally frozen.These regions are too cold for the decomposition of organic matter.In both Tundra and Boreal ecosystems the soil is acidic, waterlogging and has less nutrients. Soil fauna in these ecosystems have short life cycles. Few soil organisms can be found. In temperate

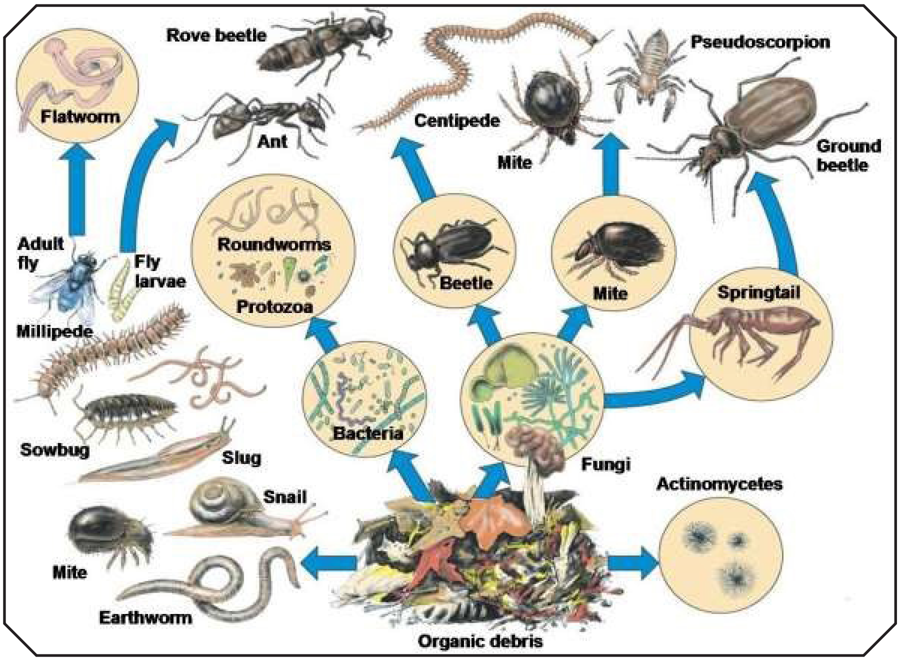


Fig 1 : diversity of soil fauna

ecosystems, the soil pH is variable. Nutrient availability is varying with the changing seasons. More soil organisms can be seen.Tropical soils are found in areas with high annual temperature and rainfall. Soil is rich with nutrients. Soil fauna have long life cycles and consists of high density of soil fauna. Arid ecosystems have a long dry season usually fires occur on arid forests. Temperature of the soil is high and low nutrient available in the soil.

The role of soil fauna.

Soil fauna is abundant with in the soil and it is greatly influenced by the nutrient status and with physical factors including moisture, aeration, pH, temperature, presence of other organisms with in the soil. Soil biota play an essential role in soil functions as they are involved in processes such as the decomposition of organic matter such as dead leaves, stems, dead animals, the formation of humus and the nutrient cycling of many elements.Generally, all the products synthesized by living organisms can be broken down by microorganisms, which is known as biodegradation.They play a major role in the infiltration and distribution of organic matter within soil horizons. Soil fauna also maintain the soil quality by affecting porosity and aeration. The function of soil organisms as organic matter decomposers is very important to maintain the sustainable role for the growth of plants and primary productivity.

The most essential role-taking place with in the soil is the detritus food chains, which are maintained by soil fauna. In detritus food chains, the animal and plant detritus, which are deposited on the soil, are used to consume by organisms such as isopods, certain earthworms, and springtails, many species of mites and the larva and adults of many insects.

The mechanical action performed by soil fauna is very considerable. It is mostly bacteria and fungi, who performed the chemical degradation within the soil system. When consider the whole world, earthworm has identified as the most valuable organism with in soil. They feed on humus compost, dead roots, capable burrowers and they make tunnels that extend horizontally, and vertically that

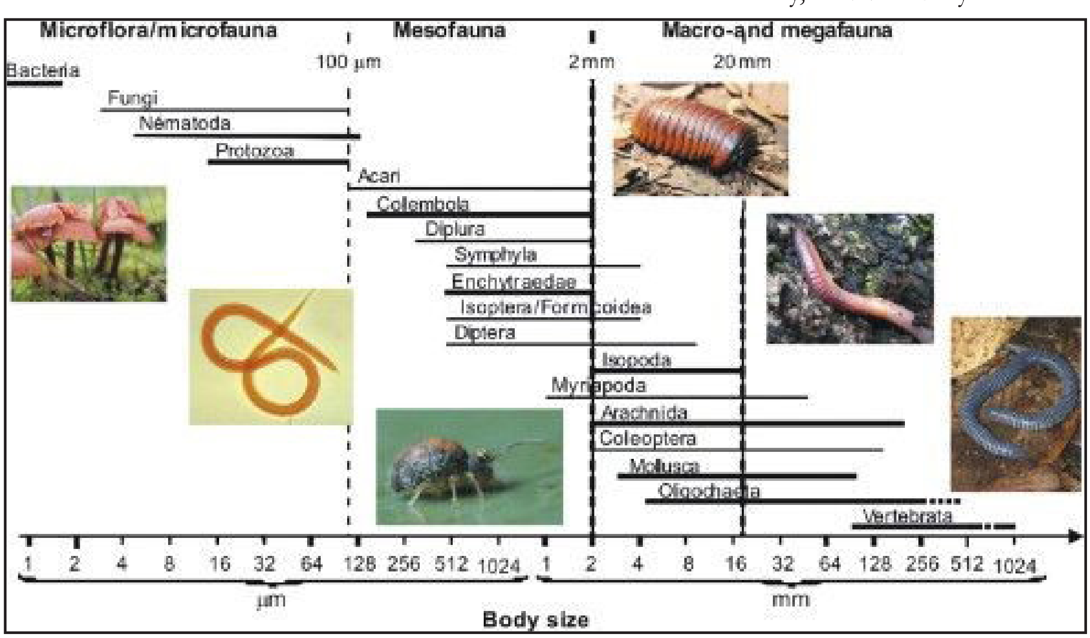


Fig 2 : soil fauna according to their body size

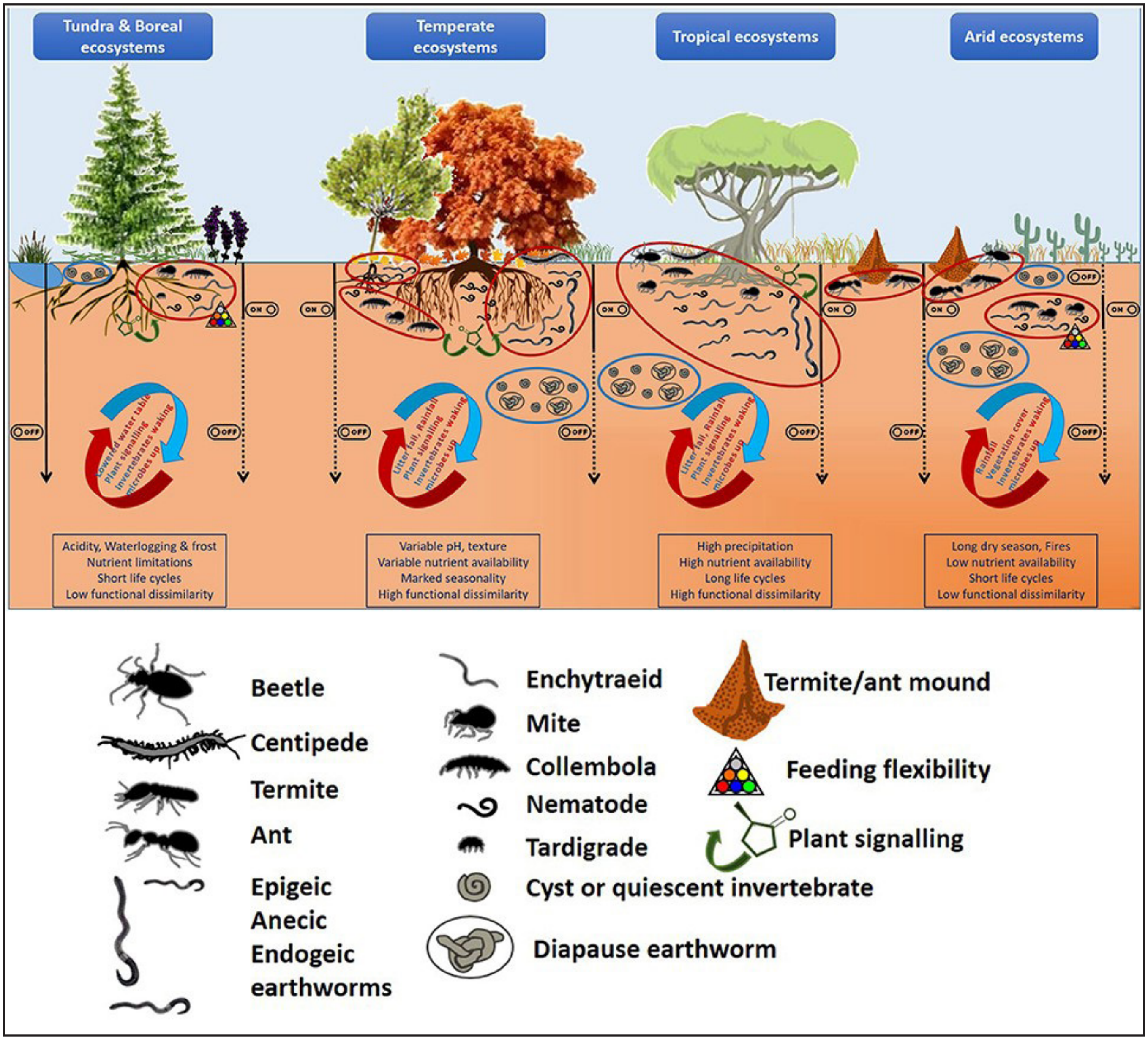


Fig 3 : Soil Fauna found in different ecosystems

can reach several meters in depth. Earthworms perform a significant effect on both structure and chemical composition of soil while living with in it. Earthworms convert most of the organic matter they consumed into a form, which can easily use by plants. Earthworms produce worm cast, from the mineral substances together with organic substances that they ingest after cemented with a little mucus protein. Warm cast contribute to the humifaction and mineralization of organic matter and helps to increase microbial population, enzyme activities and nutrient mineralization that support plant growth and yield. As earthworms released worm

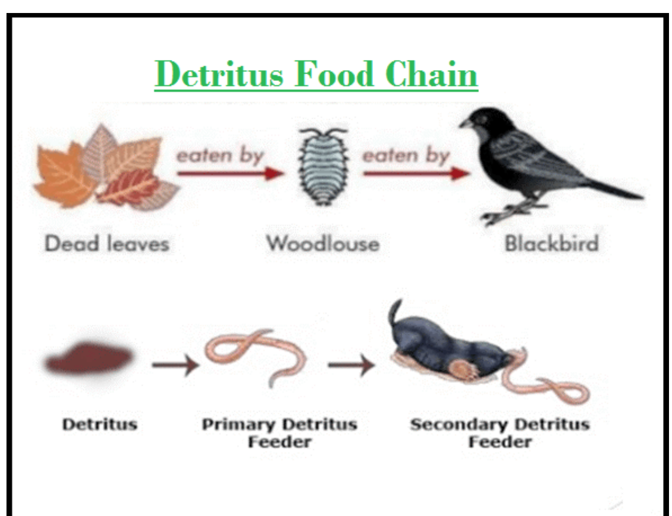


Fig 4 : detritus food chain

Fig 5 : Earthworms in the soil

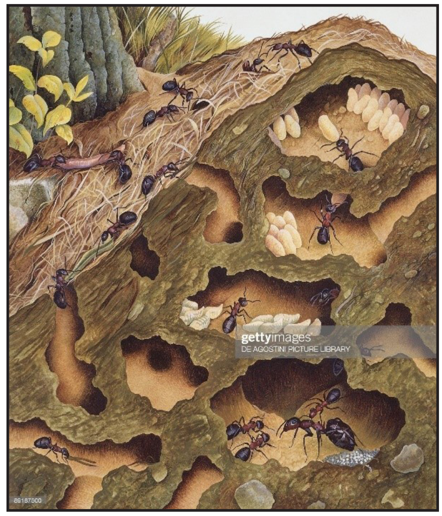


Fig 6 : cross section of an anthill

Fig 7 : Snail on the earth

Fig 8 : Microorganisms relationship with plant roots

cast in the entire texture of the soil, fertility with in the whole soil system is increased.Earthworm are able to increase the amount of Nitrogen present in the ground through excretion of ammonia and urea.

The aeration of the soil is also increased by their burrowing action and improved the circulation of water within the soil layer by the tunnels they made on their paths while increasing the porosity of the ground. Due to the continual burrowing activity spaces with in the soil or the porosity increases. As a result, aerobic bacterial activity and the consequent speed of demolition of organic substances also increases. Burrowing activity of earthworms are enable the soil to be mixed with organic matter from the surface layers to be incorporated into the lower layers, while mineral substances are bringing towards the surface.

The anthill, which is considered a wonderful modification of the soil by burrowing organisms with a complex of chambers generally constructed on several levels and linked together by tunnels and corridors. The tunnels that connect the chambers contribute to the circulation of air and water within the anthill.

As in the case of earthworms, mollusks also help to increase the stability and structure of the soil and making it less vulnerable to process of erosion through the secretion of cutaneous mucous, that have a cementing effect on the particles in the ground. The nutrient content in the soil is increased by the mucus secreted by them and by their dead bodies and help in reducing the carbon to nitrogen ratio of the litter and facilitating decomposition.

The presences of roots are providing a shelter for greater density of microorganisms. Rhizosphere refers to the area of soil that is directly affected by a plant's root system, associated root secretions, and microorganisms. Roots penetrate in to the ground, act on clay minerals and the particles of soil surrounding them, this led to the formation of an area around them in which the water pathway, and the movement of nutrients and microflora is more heavily channeled than in the rest of the soil. There is a significant difference of chemical nature within the rhizosphere than the rest of the soil. The close

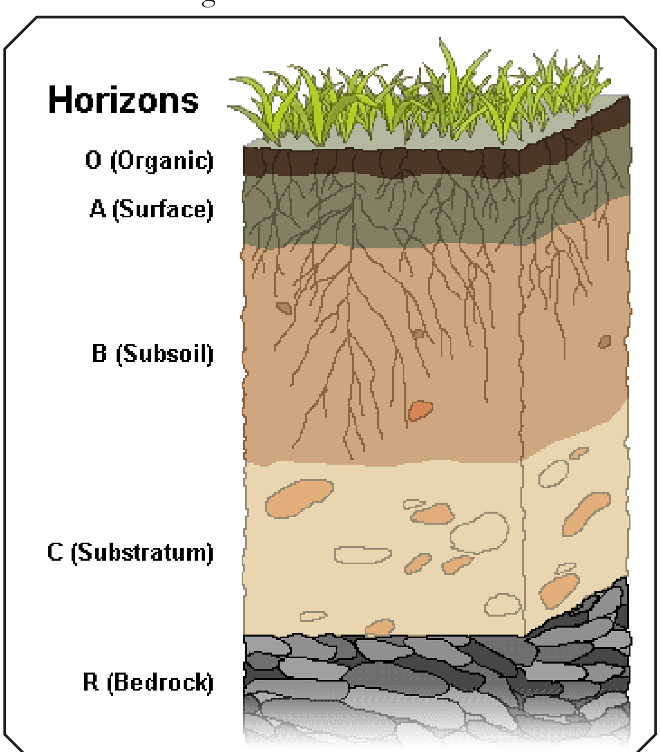


Fig 9 : structure of soil horizons

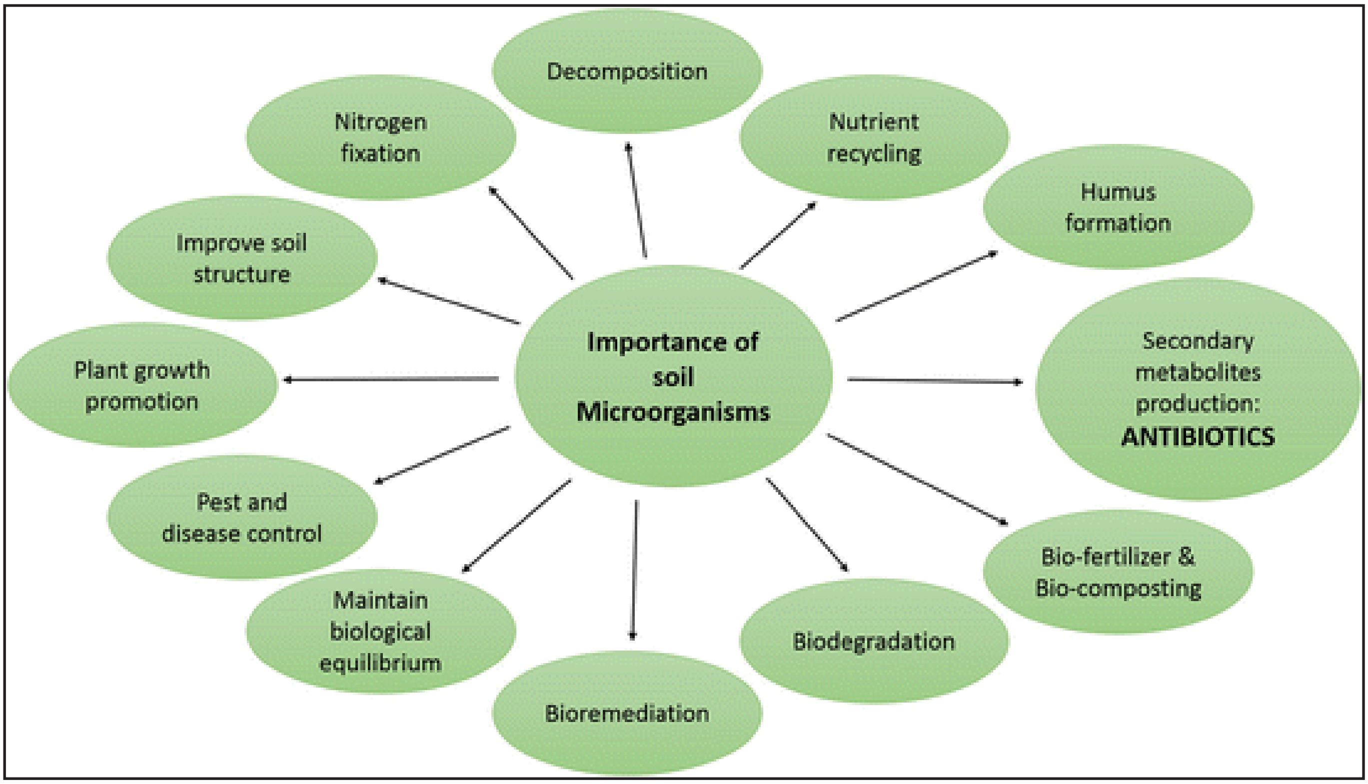


Fig 10 : Summary of the functions of Soil Micro organisms

relationship between the roots and micro-flora is lead to bacteria or fungi becoming an integral part of the roots as in mycorrhizas symbiosis. There are various kinds of interactions between the soil and the plant root system; some are beneficial while others restrict the growth of plants. Numerous soil animals feed directly on the roots of plants.

The distribution of soil fauna.
As most soil developed, distinctive layers can be identified within them. These are the products of natural soil forming processes. These layers are called soil horizons. Soil horizons form a basis for classifying soil.

The A and B-horizons together form the proper soil where great diversity of organisms is observed. Two groups of soil organisms can be identified as those who live in the mineral layer and those who live in the organic layer. The most important factors that determine the life on soil layers are the moisture content and the pH. The other important characters are litter, porosity, etc. other than these factors plant species, plant diversity, composition and animal grazing determine the abundance, diversity,

Fig 11 : Satellite view of Beijing, China in 1978 and 2013. This before and after image shows urban expansion over the years

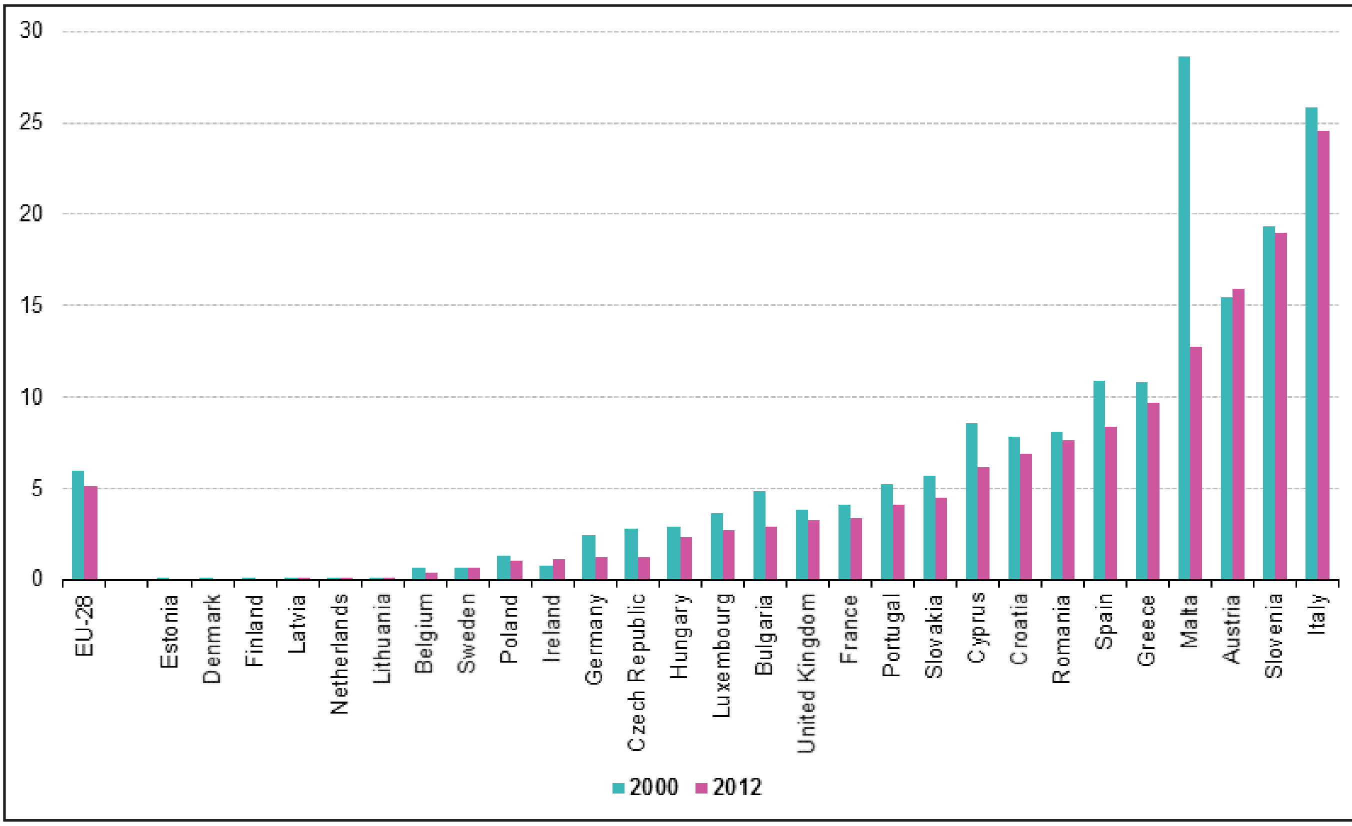


Fig 12 : Estimated soil erosion by water, by country, 2000 and 2012

composition and activity of species on the soil. The soil community is depending on the availability of nutrient resources and the diversity of the microhabitats.

Human impact on soil fauna

Due to the impact of man, the above-mentioned soil faunal diversity had affected severally. Soil had lost its fertility as well as its capacity to carry out their function due to human activities on the nature. The involvement of the man to the disturbance to the natural soil ecosystem runs back to the prehistoric man's age. Up to date the natural soil ecosystem had effected by many ways such as erosion, the loss of fertility and decline in organic matter, compaction, salinization, phenomena of flooding and landslides, contamination and the reduction of biodiversity. Any disturbance to the nature due to anthropogenic activities led to alter physical, chemical and biological properties of soil. It may affect long-term productivity.

Urbanization can be considered as a major effect by man, which causes severe effects on nature. The urbanization process leads to the conversion of indigenous habitat to various forms of anthropogenic land use, the fragmentation and isolation of areas of indigenous habitat, and an increase in local human population density.

Human's participation on agricultural practices is also a major problem, which effect on soil fauna seriously. Hunter-gatherers were adapted to agriculture in the very past of the world from prehistoric period. From that date, human have extensively altered the global environment and caused a reduction in biodiversity. These changes in biodiversity alter ecosystem processes and change the resilience of ecosystems to environmental change. Consequently, any land use change resulting in the removal of perennial tree vegetation will produce a reduction of soil biodiversity. As of the year 2000, about 37 percent of Earth's land area was agricultural land. Due to the increment of agricultural land percentage day by day, the rate of extinction also increased. Agricultural management practices, which effect on the abundance of biomass and diversity of soil litter and animal are influenced by management practices such as variation in tillage, treatment of pasture and crop residue, crop rotation, application of pesticides, fertilizers, manure, sewage and irrigation practices. Tillage operations while practicing is highly effect on soil fauna. Tillage systems can be identified as conventional tillage, minimum tillage and no-tillage. In conventional tillage due to the ploughing soil is inverted and break up the soil, use to burry crop residues and generally destroy the soil structure. In minimum tillage, the number of plowing is reduced and much of plant debris is not affected. There is no any disturbance to the soil by the no tillage practices. According to the above mentioned tillage practices the most suitable method is no-tillage method. The conventional tillage caused a reduction of microbial and other organism richness due to exposure to desiccation, destruction of habitat and disruption of access to food sources.

Aim of the agricultural technology is to obtain a maximum yield. As a result of that, farmers are engaged in monoculture, where a single crop is planted in the field. When this is practiced on large area of land, high yield as expected can be obtain only if the prevailing environmental conditions are optimum for the maximum growth of plants. They may heavily destroy by the environmental changes and from pest attacks. To meet the growing demand the lands that are not suitable for the crop production are also use for growing. Soil erosion may increase when hillsides are used in agricultural practices. The weathered rock particles, humus, sand other light materials on the soil are moved by the means of active transporting agents such as running water, blowing wind.More than 55 percent of this damage is caused by water erosion and nearly 33 percent by wind erosion. These particles are moved as sediments. They are transported from one place and relocated in another place. When the top soil layer is eroded the remaining barren soil is subjected to the direct solar radiation, then the temperature on the earth increased the action

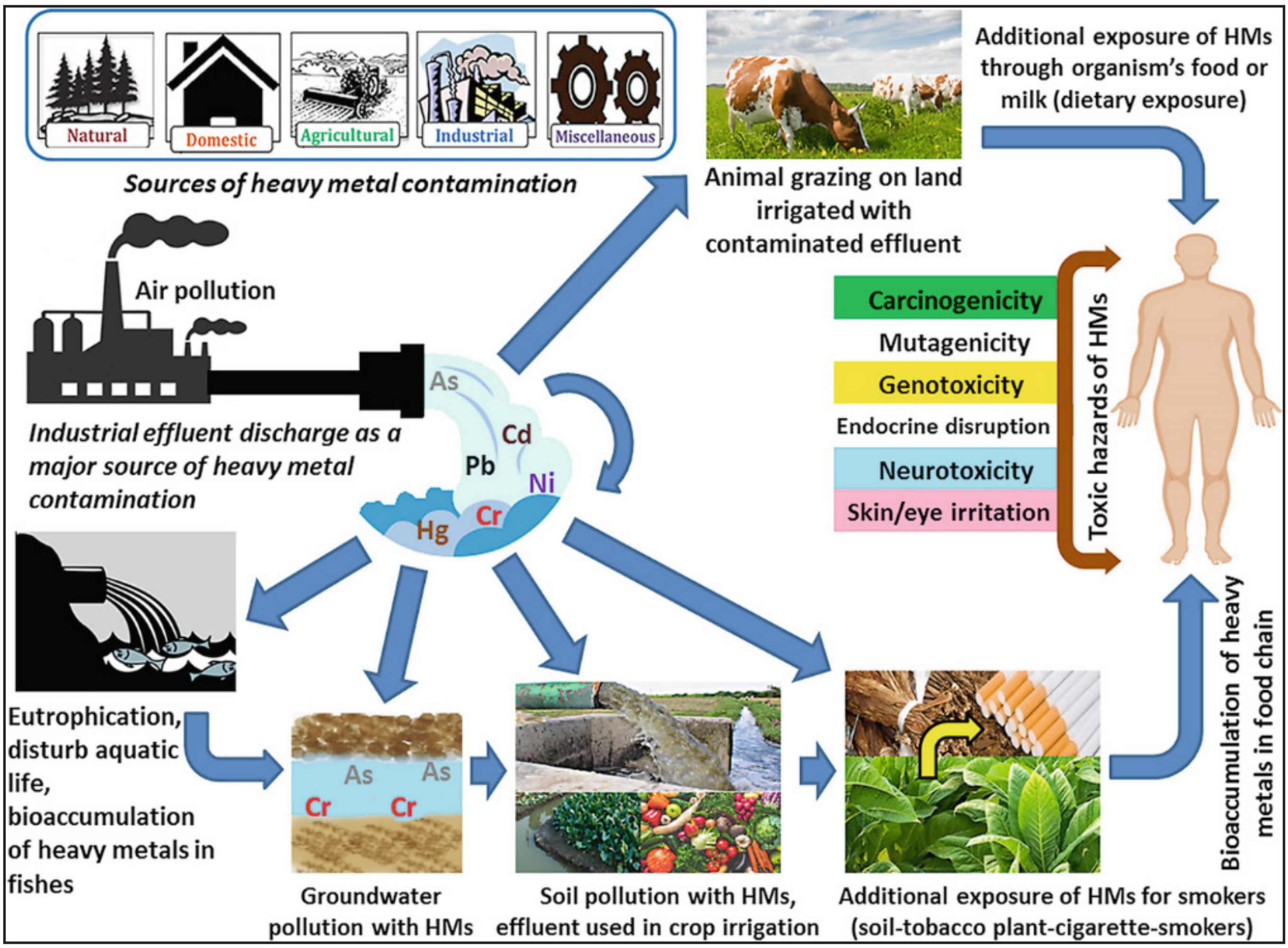


Fig 13 : Bioaccumulation of heavy metals in food chain


Fig 14 : Land of herding and overgrazing exacerbates desertification

of converting litter in to humus is increased. This produced humus is in turn moved away as earlier mentioned sediments through rain or through the wind. As a result of that the soil organisms are highly affected, they lose their primary habitat. The remaining barren soil is not suitable for their living mainly due to the evaporation of the soil water and due to the loss of its fertility. When the top soil coat eroded, gravel marble and large rocks are directly exposing to the sun light, changing the wind patterns prevailing at the environment also.Every year soil erosion and other forms of land degradation rob the world of 5-7 million hectares of farming land. Every year 25 000 million tons of top soil washed away: China's Huang River alone dumps 1 600 million tons a year into the sea. The United States has lost about one-third of its topsoil since settled agriculture began.

To face the increasing demand farmers use fertilizers to improve the fertility of the soil and use pesticides, weedicides to get rid from the pests who damage the cultivation and to avoid the unnecessary plants in the field. Because of these chemicals surface water layer get contaminated. Some of the chemicals are also leached in to the ground water polluting them. Soil fauna can also be harmed by contaminated groundwater. Sometimes the heavy metals present in the fertilizers such as Arsenic, Lead, and Cadmium led inbiological magnification. Biologicalmagnification is the increasing concentration of a substance, such as a toxic chemical, in the tissues of tolerant organisms at successively higher levels in a food chain. Finally, this effect appears on human as they consumed at higher levels in the food chain.

Herding practices for meat, milk and milk products, and hides for tents and clothing is also cause a major problem on soil fauna. When the herding is practicing beyond the sustainable limit, desertification may occur. The hungry animals try to eat the whole plant with the stem and the roots and due to the hoof of grazing animals such as cattle, sheep, deer the soil pulverized. The pulverized soil get eroded easily and as there's no any barriers to the flow of water, the water that fall on the ground may easily run off with the sediments. It may too cause on the habitat of soil fauna.

Due to the anthropogenic activities the nutrient cycles, prevailed in the ecosystems also get altered. As an example can take the Nitrogen cycle.The nitrogen cycle is the biogeochemical cycle by which nitrogen is converted into multiple chemical forms as it circulates among atmosphere, terrestrial, and ecosystems.

There are four key steps in the nitrogen cycle; they are ammonification, nitrification, denitrification and nitrogen fixation.

1.Ammonification. More than 90% of organic nitrogen in the soil exists as proteins. Proteins from dead plants and animals are decomposed by extracellular proteolytic enzymes secreted by microorganisms into amino acids. Resulting amino acids are taken into microbial cells and are then subjected to ammonification in which, amino groups of amino acids are converted into ammonia. In most soil, ammonia is solubilized in water to form ammonium ions. Ammonium ions are utilized by plants and soil microorganisms.

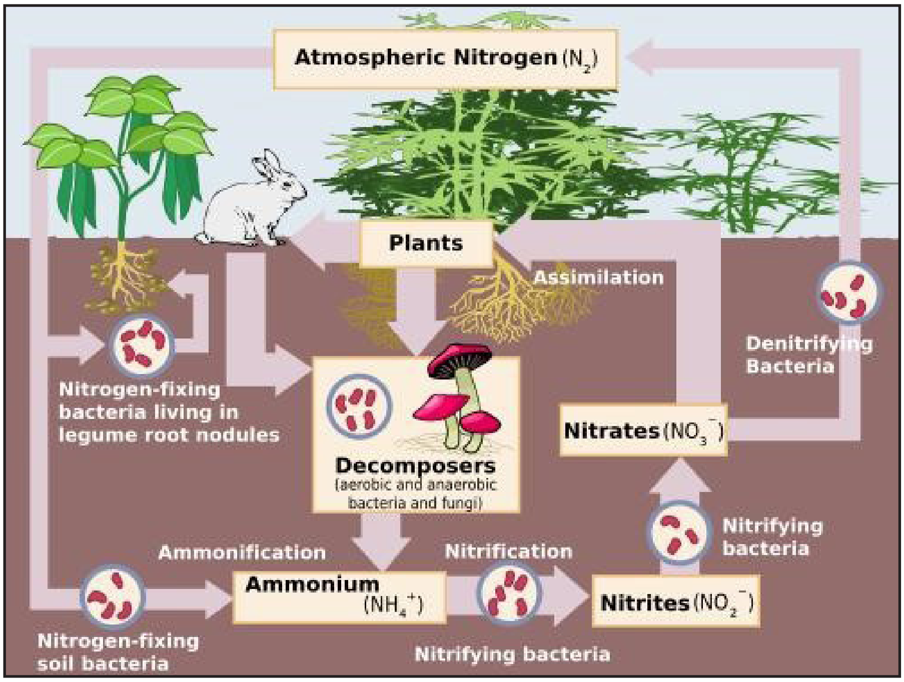


Fig 15 : Nitrogen cycle

2.Nitrification is the biological oxidation of ammonia or ammonium to nitrite followed by the oxidation of the nitrite to nitrate. The transformation of ammonia to nitrite is usually the rate-limiting step of nitrification. This process is done by nitrifying bacteria living in soil in two stages. In the first stage, microorganisms such as Nitrosomonas, oxidizes ammonium ions in to nitrates.

NH4+ NO2-
In the second stage, microorganisms such as Nitrobacter, oxidizes nitrites into nitrates.

NO2- NO3-
Plants utilize nitrate as their source of Nitrogen. Therefore, microorganisms play essential roles in providing nitrogen in bioavailable forms for plants and animals.

3.Denitrification is the use of nitrate by some microorganisms in the absence of atmospheric oxygen and reduces it into N2. This causes loss of nitrogen in to the atmosphere. Pseudomonas species converts nitrate ions into molecular nitrogen through following steps,
NO3- NO2- N2O N2

4.Nitrogen fixation is the process of conversion of nitrogen gas to ammonia is termed as nitrogen fixation. There are two types of nitrogen fixing microorganisms as free-living and symbiotic.
•Free-living nitrogen fixing bacteria- these bacteris are abundant in the rhizosphere. These organisms, exhibit mechanisms to prevent the exposure of nitrogenase enzyme to the atmospheric oxygen. Eg:- Azotobacter

•Symbiotic nitrogen- fixing microorganisms-They play an important role in agricultural crops such as leguminous crops; soybean, beans, peas and peanuts. Plants form root nodules where, anaerobic conditions and nutrients for bacteria are given.

Ammonia is also made through a synthetic process called the Haber process. Nitrogen and Hydrogen are reacting under great pressure and temperature in the presence of a catalyst to make ammonia. There is only one way of producing nitrogen, Denitrification. Denitrification is a microbial facilitated process where nitrate is

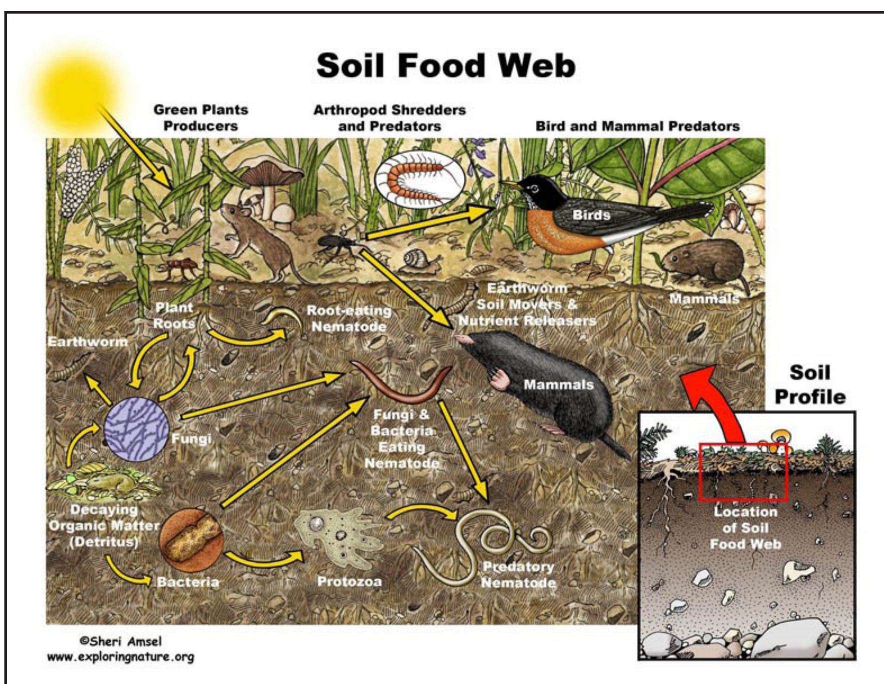


Fig 16 : Soil food web

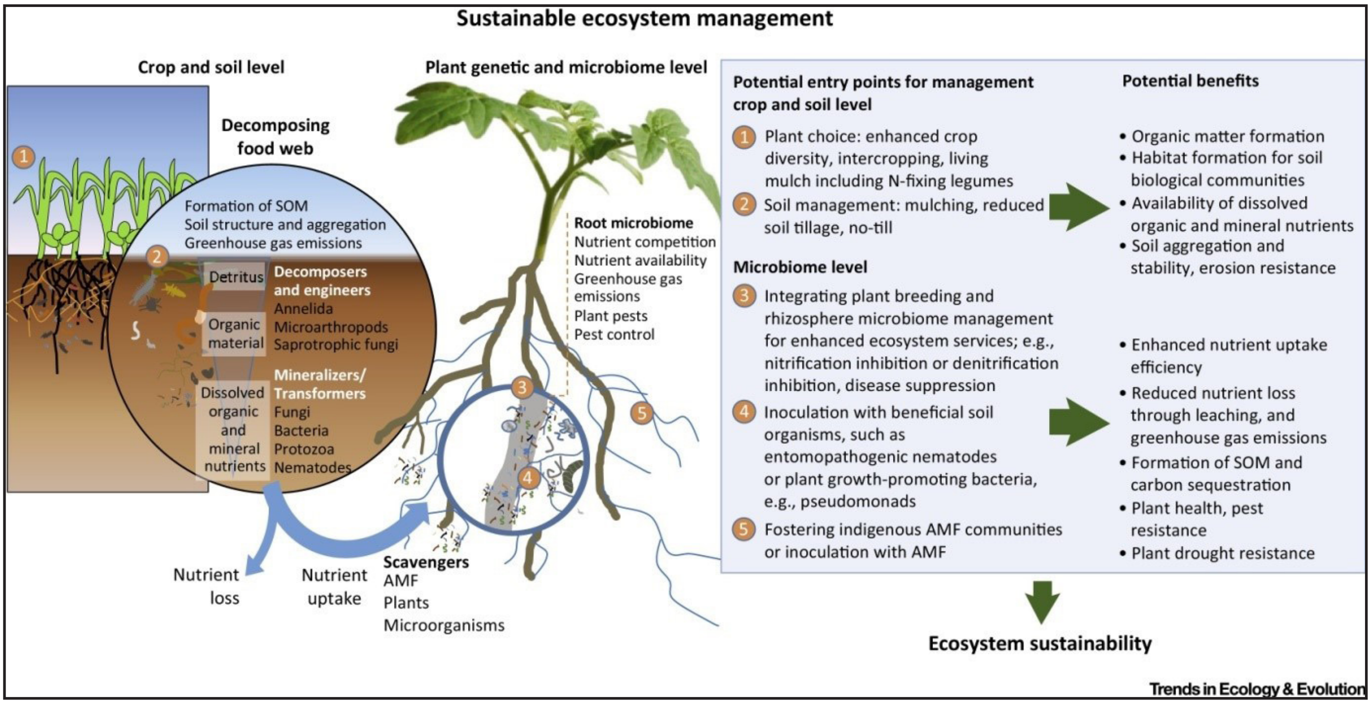


Fig 17 : Sustainable eco-system management

reduced and ultimately produces molecular nitrogen through a series of intermediate gaseous nitrogen oxide products.
Through the human activities such as improper agricultural practices, clear cutting, land clearance, improper irrigational practices the soil fauna get altered. It may affected on the major process of producing Nitrogen in the atmosphere, denitrification. When the soil bacteria who carry out the denitrification get disrupted, the process of emitting Nitrogen in to the atmosphere get disturbed. Because of that an imbalance of atmospheric nitrogen may occur. Plants and animals could not live without nitrogen. It is an important part of many cells and processes such as amino acids, proteins, and even our DNA. Nitrogenis also needed to make chlorophyll in plants, which plants use in photosynthesis to make their food and energy. When the nitrogen content in the atmosphere reduced, the amount of nitrogen that can be consumed by plants in the form of nitrate also reduced. The leaves become yellow in color because they are unable to make sufficient chlorophyll. Leaves in this state are said to be chlorotic.Nitrogen deficiencies also cause leaves to remain small, and drop prematurely, resulting in less photosynthesis occurring in the plant.This makes it crucial that the fields have enough nitrogen in the soil to grow a prosperous crop. Because of that, it may restrict the growth of plants, reproduction of plants and the yield of plants. Plants are the primary producers and they represent the first trophic level in a food chain. When the productivity of primary consumers reduced, the herbivores that are at the second trophic level and the secondary consumers, tertiary consumers in higher trophic levels also get affected. At last as described earlier human, who consumed at higher trophic levels get affected.
Human Impacts on Carbon Cycle
Microorganisms perform a great role in the Carbon cycle too.
All organisms contain a large amount of carbon in organic compounds such as cellulose, starch, proteins and fat. Important first step in the carbon cycle is the Photosynthesis. In here the atmospheric inorganic carbon dioxide is reduced to form organic compounds by photosynthetic organisms. Photoautotrophs such as plants, cyanobacteria, algae and photosynthetic bacteria fix carbon using energy from sunlight. Chemoheteretrophs such as animals and protozoa depend on organic compounds produced by autotrophs to utilize them as their carbon source. through food chain, carbon fixed from carbon dioxide by autotrophs, transferred from organisms at lower trophic levels to the organisms at higher trophic levels. Both autorotrophs and chemoheterotrophs, release a part of their fixed carbon as carbon dioxide to the atmosphere through respiration. This carbon dioxide is again made available for autotrophs. In chemohetotrophs, release

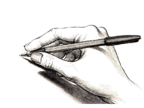
a part of their fixed carbon as carbon dioxide to the atmosphere through respiration. This carbon dioxide is again made available for autotrophs. In chemoheterotrophs, undigested food is released to the environment as feces which are later decomposed by soil microorganisms. Rest of the carbon fixed in organisms, remain within them until they die. Once the organisms are dead, these organic compounds are decomposed and carbon dioxide is returned back to the atmosphere. Micro-organisms mainly bacteria and fungi play a major role in organic matter decomposition. Micro-organisms play another major role in carbon cycle in relation to methane gas. Ocean sediments contain a large amount of methane. However, about 80% of methane generated within ocean is consumed by microorganisms called methanotrophs before it reaches to the atmosphere.

Human activities such as the burning of fossil fuels and deforestation have begun to have an effect on the carbon cycle and the rise of carbon dioxide in the atmosphere. Human activities affect the carbon cycle through emissions of carbon dioxide (sources) and removal of carbon dioxide (sinks). The carbon cycle can be affected when carbon dioxide is either released into the atmosphere or removed from the atmosphere. The greenhouse effect occurs naturally. However, human activity intensifies the process, in which Earth absorbs some energy from the sun in its atmosphere and reflects the rest back toward space. This trapped energy warms Earth's surface. The production and consumption of fossil fuels have increased greenhouse gases in the atmosphere and contributed to global warming.

Human activities have a major effect on the global sulfur cycle too. After the industrial revolution in 19th century, releasing of Sulphur oxides and Nitrogen oxides in to the atmosphere increased. Acid rains are formed when these gases are oxidized in the atmosphere and return to the ground dissolved in raindrops. Sulphur dioxide falls as H_2SO_3 and H_2SO_4 while NO_x falls as HNO_3. Sulphur dioxide and Nitrogen dioxide are very strong phytotoxic; toxic to plants. The combination effects of both the gasses are more toxic to plants than they are alone. As mentioned earlier this cause on the primary producers and its effect appear along with the food chain.The nutritive value of soil is reduced to a greater extent. Acid rain effects can also be seen on the useful microorganisms, which convert the decayed organic matter into essential nutrients for the soil.Excessive acidity on the soil also harmful. pH is a most important factor which determines the survival of organisms with in the soil. Most bacteria and protozoa survive at a neutral pH most fungus are survive at acidic pH while blue green bacteria survive at an alkaline pH. The soil chemistry will be altered at a pH below 3.5. The high acidity cannot be tolerate by most of soil fauna and much of soil organisms are destroyed due to this effect.Bacteria density is reducedand the fungus density increases creating an imbalance of density of microorganisms with in the soil. Finally, this may led to delayed decomposition of organic matter, reduction in the process of humus formation and increases in fungal diseases. Most of plant also cannot bare this acidity. The effects are inhibition of germination and growth of seedlings and causes yellowing of leaves and subsequent death of trees.

As discussed, soil fauna perform a major contribution on the earth. Soil is an eco-system in which the different mentioned creatures interact and contribute to the global cycles that make all life possible. Every handful of soil is likely to contain billions of organisms with representatives from every phylum of living things. Unsustainable anthropogenic activities create disruptive effects on soil fauna affecting their abundance with in the soil ecosystem. When the soil density altered, the function performed by soil organisms on the soil get disturbed.Any disturbance to the soil fauna due to human activities ultimately comeback to the human who did the change on the environment. To maintain the life on the earth we should protect the soil fauna being destroying. Through a sustainable eco-system management, soil fauna can be protected to some extent. Figure 16 shows the way of practicing a sustainable eco-system management.

Dr D.M.Suratissa
Depaetment of Zoology and Environmental Sciences
University of Colombo
Colombo 03
suratissa@yahoo.com



Soil fauna and its role

Dr Chamila Dias

The soil under our feet breathes! But living beings under the earth, and their immense number are not known to many people. However, soil provides life, and is an indispensable resource for life. Biodiversity and coexistence of organisms in the soil, as well as their ecosystem services for human beings as well as for soil development are important.
Soil organisms consists of animals (soil fauna) and plants (soil flora). They are essential components of any soil. This article will provide all information about the animal component of the soil or about the soil fauna.
Soil fauna is categorized into four main groups according to their body size, that is, either length or width of the body. They are the microfauna, mesofauna, macrofauna and megafauna (Wallwork 1970). Figure 1 shows the classification based on body length.
Microfauna are organisms with body size between 20 µm and 200 µm. All animals of protozoa belong to microfauna. Apart from that, small mites, nematodes, rotifers, and tardigrades (water bears or moss piglets) also belong to this category.

Mesofauna are the organisms of body size between 200 µm and 2 mm. Mites and springtails are the main representatives of this group. This group also includes some nematodes, rotifers, tardigrades, small spiders, pseudoscorpions, opiliones, insect larvae, small isopods and myriapods (molluscs). Organisms whose body size is between 2 mm and 20 mm are categorized as macrofauna. This category includes certain earthworms, millipedes, centipedes, snails and slugs, isopods, some small spiders and most insects. Soil megafauna are usually classified as the invertebrates in the soil with a body length over 20 mm. This category includes large soil invertebrates such as earthworms and snails.

The value of soil fauna is rarely taken into consideration. One main reason for this situation is that many of us are not aware of their contribution to our food production system. It is very important to know why these fauna are important as a sustainable earth resource. For a better understanding, it is necessary to learn about the functions of these different organisms.

Soil animals are important in soil formation, maintenance of soil structure, decomposition and nutrient release. Some of the many

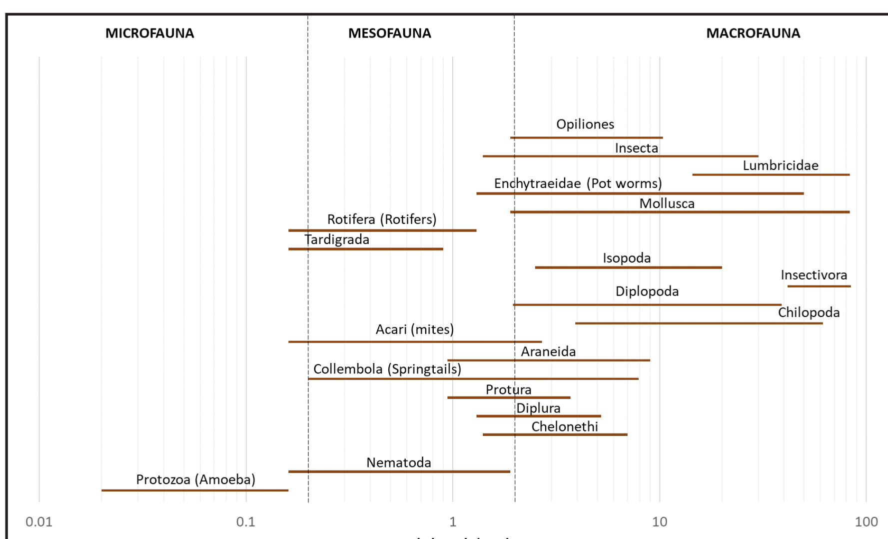


Fig 1: General classification of soil fauna based on body length

Fig 2 : Giant Gippsland earthworm

functions affected by soil organisms include decomposition, nutrient cycling, carbon sequestration, degradation of pollutants, plant protection (through predation of pests) and soil aeration. Thus the food of these organisms is either organic matter and/ or other organisms.
Soil fauna directly and indirectly affect the transport of organic and inorganic materials within the soil systems. Feeding and burrowing activities of larger soil invertebrates, such as earth worms and termites, mix organic matter and mineral particles and modify the physical properties of soil.

Fig 3 : Termites

Earthworms can be called as engineers in our ecosystem, because they are like human engineers, making tunnels in soil both in horizontal and vertical directions. These tunnels are useful in gas exchange within the soil and to transport water. They also breakdown organic matter into small pieces, which enable bacteria and fungi to feed on it to release nutrients back to the soil. This process is known as decomposition. Earthworms also leave their casts (faeces) in the soil during decomposition, which is a good soil fertilizer. Earthworms are sometimes physically introduced into soils for their beneficial effects on soil structure. They also mix organic matter and soil among different soil profile layers. Because of this reason, Charles Darwin named the earthworms as ‘nature’s ploughs’. They are in addition a source of food for many other animals such as birds, mammals (mice), amphibians (frogs) and reptiles. Where many earthworms are found in soil, it is common to find more bacterial and fungal activity. There are approximately 6000 earthworm species found worldwide with different body lengths. A good example is the giant Gippsland earthworms (Megascolides australis) found in Australia, which is shown in Figure 2. Some of these are around 3 m in length. Earthworms are the dominant contributors to soil formation in temperate countries. However, in tropical countries like Sri Lanka, ants and termites play a major role in nutrient recycling and transportation of soil material.

It is well known that termites can cause much damage if they invade residences. Nevertheless, there are many advantageous of termites, because they can decompose dead trees and recycle the resulting material back into soil, helping forests to regenerate faster. Their food sources are decaying plant materials, dead foliage, woody materials, roots, seeds and the faeces of higher animals. They also help to aerate the soil so that water and nutrients can easily reach the plant roots. Termites are social insects that live in colonies. They have a queen, as well as workers and soldiers in their colony. The termite nests or mounds are built in different locations such as within the wood of a dead or living tree, above soil surface, or on tree’s which are known as arboreal nests. They make arboreal nests to protect from floods, and are made of wood and faecal matter to be light in weight.
It is interesting to note that the world’s largest termite mounds are as old as pyramids, and could be seen even via satellite images. Such termite mounds are present

Fig 4 : Termite workers inside a termite tunnel

in north-eastern Brazil, which has the land area of Great Britain. They are built in a regularly spaced array as can be see in Figure 5. This is one of the most exciting engineering works done by a single species of termites. Inside these termite mounds many vertical and horizontal tunnels can be seen. These tunnels help to protect termites from predators and from dry environments.

Anthills, similar to termite mounds is another example of a modification of the soil by ants

Fig 6 : A top view of an anthill

(see Figure 6). An anthill consists of chambers which are connected by many tunnels. These chambers provide space for the fungi to grow. These tunnels help to circulate air and water inside the ant hill. In addition, these chambers provide space for rearing larvae and laying eggs. In the process of creating ant hills, fine soil particles are transported to the soil surface, which are more mineral in nature.

Fig 7 : A snail in a moist environment

Other types of megafauna include molluscs such as slugs and snails, which secrete a mucous (glue like liquid) that has a cementing effect on the soil particles, and thereby assisting the stability and structure of the soil to prevent soil erosion. Hence, snails and slugs are also important for our ecosystem (see Figures 7 & 8).

Mesofauna particularly mites and collembola, help to disperse, and to control fungal growth by feeding on them. Mesofauna usually have no ability to change the soil structure because of their smaller body size. Therefore, they usually use the pore spaces already available in the soil to move within the soil. Their activities are high when the soil is moist. If soil is too dry, their body gets dehydrated. A high mesofauna population and a high population diversity is observed when the soil is more porous, and contain more organic matter. They have different feeding behaviours such as plant feeding, microbial feeding, predators or omnivores. Micro- and mesofauna contribute directly to decomposition of organic matte and nutrient recycling. Bacteria, fungi, protozoa and algae are the primary decomposers of organic matter. They are also involved in humus production, cycling of energy, and some metabolic activities in the soil which facilitates the formation of important chemical components that are important in soil aggregate formation.

Pseudoscorpions or false scorpions are good example for mesofauna.

Fig 5 : Areal view of huge termite mounds in Brazil

They are usually less than 5 mm in length (see Figure 9). They spend most of their lives under mulch, wood and leaf litter, stones and tree bark, and such other places which are hard to see. Unlike scorpions, pseudoscorpions are not harmful. However, they are important in the soil ecosystem as they hunt caterpillars, flies, ants, beetle larvae and nematodes.

Similar to pseudscorpions, Opiliones also act as predators in soil (see Figure 10). Opiliones are also known as daddy-long-legs or harvestmen. They are not harmful to human beings. Presence of them is a good indication of an undisturbed environment.

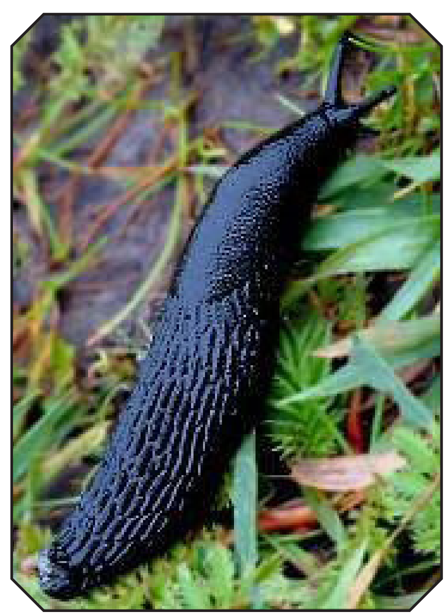


Fig 8 : Black colour Slug (Arion ater) found in a garden of a European country

Protozoa which belongs to microfauna have some main functions in the soil. They are responsible for regulating the bacterial and fungal populations because they feed mainly on bacteria. As they eat bacteria, protozoa get more nitrogen and this excess nitrogen is then released in the form of ammonium. This is a good source of nitrogen for plants and other members of the food web. This usually occur near the root system of a plant.
They also suppress pathogenic microbes present in soils. At the same time, they serve as an important food source for other soil organisms such as nematodes. Protozoa feed mainly on bacteria, but they also eat other protozoa and fungi. Protozoa are classified into three groups based on their shape. They are the Ciliates, Amoebae and Flagellates. Ciliates are the largest, and move by means of hair-like cilia. They eat the other two types of protozoa, as well as bacteria. Amoebae also can be quite large and move by means of a temporary foot which is called a pseudopod. Amoebae are further divided into testate amoebae (which make a shell-like covering), and naked amoebae (without a covering). Flagellates are the smallest of the protozoa (see Figure 11), which use a few whip-like flagella to move. Protozoa eat bacteria and need water in which they move. Like bacteria, protozoa are mainly active in the root zone. As observed in the above examples, diversity in shape and in function among the soil animals, has an important overall influence on ecosystem functions. There are many methods such as density and species richness to describe the diversity of these organisms. Here a small experiment can be carried out to get an idea about the diversity of soil fauna. First on extract can be made to identify live soil micro and mesofauna from a soil sample using heat.

Fig 9 : A Pseudoscorpion

Fig 10 : Goniosoma longipes is a colorful Opilion

What is needed is a collecting container, a 1.5 litre plastic bottle, a mesh, two pieces of gauze of same size and a table lamp with a light bulb of 40 or 60 Watts. These can be found at home.

Then a funnel can be made by cutting the bottle into two parts as shown in Figure 12. Place the funnel on top of the other half of the bottle. Now place the mesh over the funnel. Any type of mesh which could hold the soil sample inside the funnel can be used. Then spread the two layers of the gauze over the mesh. With this set-up, the soil animals can fall through the gauze and the mesh, but the soil remains in the funnel.

Next a container has to be prepared to collect the soil fauna. We will collect the live animals, so we can use a media to collect them using a mixture of plaster of Paris and activated charcoal. The recipe to make this mixture is as follows.

Take one tablespoon of plaster of Paris (8 parts), a half a table spoon of activated charcoal (4 parts) and enough water to mix to a soupy consistency (6 parts). First mix the plaster of Paris and charcoal without adding water. Then add enough water to bring this mixture to a soup like liquid. Pour this mixture into a small plastic or a glass container to a depth of 1cm. Tap the container on a table to make a smooth surface and leave it to dry for several days. Once water is added again, the mixture will re-wet and excess water can be removed. As a different media, 70% ethanol can be used to preserve the animals. Periodically add a couple of drops of water to the containers to keep the organisms alive and moist during the extraction. Next step is to place this collecting container inside the bottle as shown in Figure 12. Now a soil sample can be taken from a forest or any other place and fill it to the funnel.
Switch on the table lamp directly over the funnel and adjust the

distance between lamp and the funnel to be 5 cm to 7 cm apart approximately. The soil temperature should reach about 30-35°C. The temperature can be checked using a thermometer. When heat is applied in this way, soil fauna is highly sensitive to desiccation, and consequently try to escape from the direction of the lamp thereby enabling the collection of them from the bottom of the funnel. Apply heat and light for 2 to 10 days, and check periodically for soil fauna in the collection jar.
Now remove the collection jar and

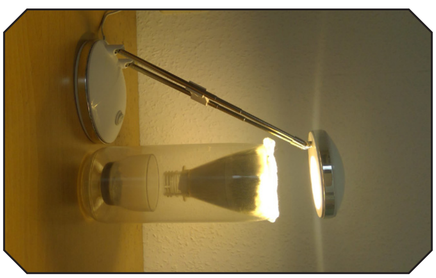


Fig 12 : Experimental set-up to collect the soil fauna

observe it using a light microscope or a hand lens. It is possible to get a small drop of sample and place in a microscope slide and observe. Try to identify the fauna and record the total number of species present and number of fauna present in each species.

It is also possible to take the same amount (volume or weight) of a soil sample from different places such as a paddy field or an agricultural land and to repeat the experiment. This will show the differences that exists among soil faunae in different environments. Higher the number of species found in a soil per unit soil volume, is regarded as a soil rich in species, or in other words, high species richness.

Presence of different soil organisms is important for the maintenance of a productive soil. Reduction in soil biodiversity such as loss of species with unique functions in soil leads to soil degradation and loss of agricultural productive capacity. Every day a part of fertile soil is lost by different ways, mainly due to intensive agriculture. Therefore, it is necessary to take greater care for the soil and its living beings to facilitate a higher species richness. Human activities such as deforestation, large scale pollution, urbanization, as well as agricultural practices such as soil tillage, plant pest management, and fertilisation have negative impacts on biodiversity and the activity of soil fauna. Tropical soils are also exposed to compaction and soil erosion. Heavy metals in soil can have lethal effects on soil fauna. Therefore low-till agriculture, return of organic matter to soil and utilizing diverse cropping systems, as well as avoiding the application of toxic substances can have positive effect on soil fauna.
The multiple roles of soil fauna are often unseen and disregarded. Soils or soil fauna work silently to make our lives better. Therefore, every one of us have a role to play to keep our soil and its life healthy. It could be a very small change in our life style or in habits that would have a great effect on the entire planet. This could be something simple like in the use of personal care products such as soap or cream which does not include harmful chemicals, or the careful use of pharmaceuticals which could affect the microbial functionality or their biodiversity when disposed to the soil. When these substances

Fig 11 : Flagellate Bodo saltans ingesting a bacterium

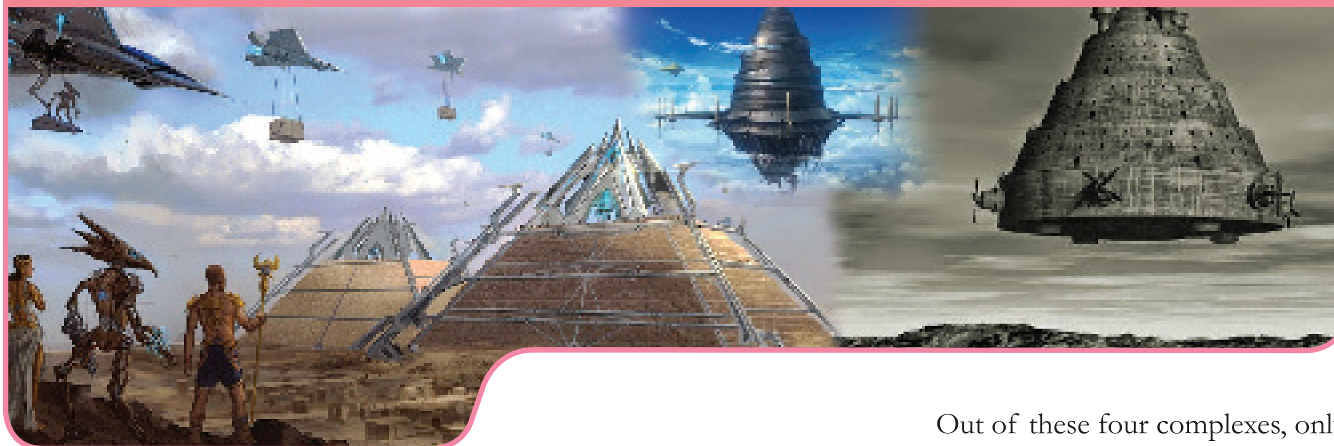
are added to the soil it could be toxic to soil fauna which is known as ecotoxicity. Many countries in the world conduct research on ecotoxicity as it has already become a threat to our soils.

The International Union of Soil Sciences (IUSS) in 2002 proposed 5th of December as the World Soil Day to celebrate the importance of soil as a critical component of the natural system, and as a vital contributor to human well-being (United Nations, 2019). Soil is a non-renewable resource, therefore whatever harm that is done to soil and its organisms, will have adverse reflections an the people. Thus even as individuals, a small contribution towards the health and well being of the soil on this important day, could be a great step forward towards ensuring the sustainable use of earth's resources to serve the mother planet.

Dr Chamila Dias
Research Scientist
Faculty of Environmental Sciences
Technische Universität Dresden,
Germany

Gem Resources In Sri Lanka

R.M.N.P.K. Jayasinghe



Introduction

Gem resources of Sri Lanka are well known throughout the world for their wide varieties of gemstones. Around 20% of the total land area of Sri Lanka is reported to be potentially gem-bearing. This makes Sri Lanka possibly the densest gem bearing country in the world1. According to statistical data published by the Department of Census and Statistics, gems are responsible for about 80% of the total annual mineral based foreign income of Sri Lanka in recent times.

Geology of Sri Lanka

The geological terrain of Sri Lanka consists mainly of 90% of Precambrian metamorphic rocks, 10% of Jurassic, Miocene and Quaternary sedimentary formations, and a very minor amount of igneous rocks.

The high grade Precambrian metamorphic basement of Sri Lanka is mainly subdivided into four major lithotectonic units namely Highland Complex, Vijayan Complex, Wanni Complex and Kadugannawa Complex (Fig.1) which lithologically, geochemically and geochronologically differ from one another 2.

The Highland Complex (HC) consists mainly of charnockites, quartzites, marbles, garnetiferous gneisses and granulites, mixed with a variety of igneous intrusions. The amphibolite grade gneiss terrain of the Vijayan Complex (VC) consists of a variety of gneisses and granitoids. The boundary between the Highland Complex and the Vijayan Complex is rather well defined as shown by their differences in metamorphic grades, structure and the isotopic ages.

The Wanni Complex consists predominantly of scattered relics of supracrustal rocks and meta-igneous rocks of granodioritic gneisses.

The subordinate division of Kadugannawa Complex is exposed in the cores of six elongated, upright, doubly plunging synformal basins or 'Areans' and in one intervening antiform in the Kandy area3,4. Structurally these arenas overlie the gneisses of the Highland Complex. They consist mainly of biotite hornblende and biotite gneisses together with concordant amphibolites, quartzo-feldspathic and pelitic gneisses and metaquartzites.

Out of these four complexes, only the Highland Complex (referred to as HC, hereafter) is considered to form gems. HC is composed of metasedimentary rocks having proper chemistry for the formation of gem minerals.

Distribution of gem deposits in Sri Lanka

According to the formation, gem minerals can be categorized into four types namely, Igneous, Hydrothermal, Matamorphic, and Sedimentary.

Gem bearing beds have been classified into three types as residual, eluvial and alluvial. These three types are recognized based on their occurrence in the geological formations5. Residual gem deposits are developed on their source rocks, formed as a result of weathering and subsequent concentrating, and are characterized with presence of feldspar grains, angular rock fragments, and with gem type minerals of garnet, spinel, corundum, tourmaline, zircon and apatite, preserving their crystal shapes. Eluvial gem deposits are situated on the hill slopes, just below the source rock region of the primary gem minerals, and formed as a result of combined processes of weathering, gravitational movement, and then by deposition in surface traps by preventing further transportation due to their heaviness. They are characterized by angular rock fragments, unsorted sand, together with heavy minerals and gem minerals conserving their crystallographic outlines. Alluvial gem deposits have been formed as a result of weathering, hill slope transportation, fluvial transportation along the sloppy rivers, and then deposition of them on flat terrains. These deposits are mainly found in ancient river beds, ancient flood plains, and present flood plains. There are five major gem fields in Sri Lanka, namely, Ratnapura, Elehera, Bibile, Okkampitiya, and Kataragama (Fig.1).

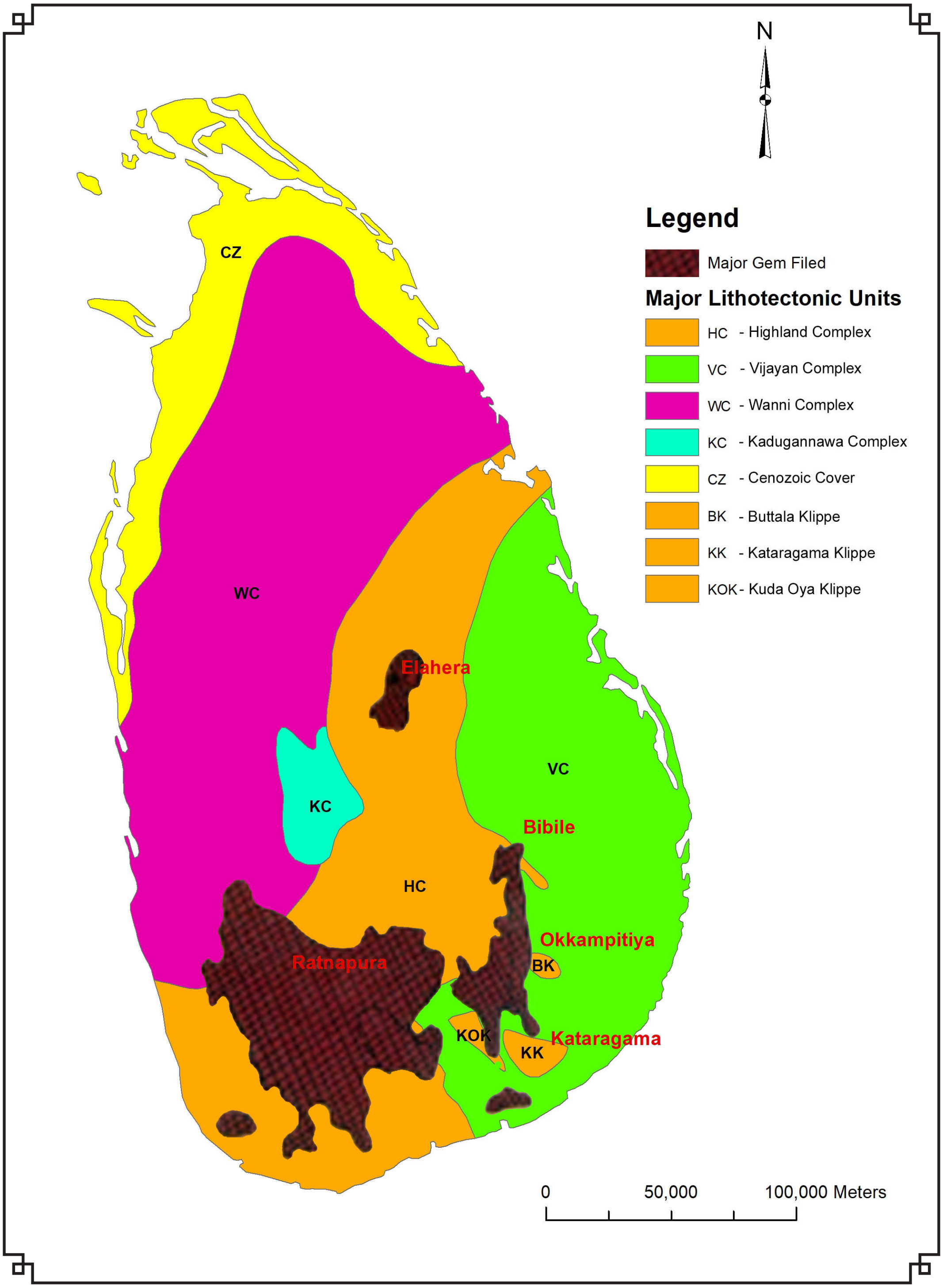


Fig 1 : five major gem fields in Sri Lanka, namely, Ratnapura, Elehera, Bibile, Okkampitiya, and Kataragama

Around 70 gem varities/families have been found in Sri Lanka. These include corundum, chrysoberyl, spinel, beryl, topaz, zircon, tourmaline, garnet, quartz, feldspar families and several other rare gemstones6. They are categorized into two broad groups, namely precious and semi-precious varieties. Corundum (sapphires and rubies) and chrysoberyl are commonly considered as precious gemstones, while spinel, beryl, topaz, zircon, tourmaline, garnet, quartz, and moonstone (Fig.2) are considered as semi-precious gemstones.

Corundum is an aluminium oxide mineral (Al2O3), and it includes ruby which is red in colour, as well as sapphires of other colours such as blue, yellow, pink, orange and colorless etc. They are mainly found in Ratnapura, Elehera, Buttala, Kataragama, Rakwana, Hanguranketha, Nuwaraeliya, Hatton, Awissawella, Haputale, Horana, Morawaka, Ambalantota, Galle, and Matara areas.

Chrysoberyl is a beryllium aluminium oxide mineral ($BeAl_2O_4$). There are two varities, namely, alexandrite and cat's-eye. They are found in Ratnapura, Rakwana, Elahera, Horana, Awissawella, Panadura, Haputhale, Aluthgama, Yakkalamulla, Morawaka, Galle, Matara, and Ambalantota.

Fig 2 : precious gemstones, while spinel, beryl, topaz, zircon, tourmaline, garnet, quartz, and moonstone

Spinel is a magnesium aluminate mineral ($MgAl_2O_4$). They are variable in colour such as red, orange, yellow, green, blue, and black. Spinels are common in gem bearing gravels, and are found in Ratnapura, Elahera, Nilgala, Awissawella, Hatton, Nuwaraeliya, Passara, Horana, Haputale, Buttala, Aluthgama, Rakwana, Kataragama, Morawaka, and Ambalantota.
Beryl is a beryllium aluminium silicate mineral ($Be_3Al_2(SiO_3)_6$). Aquamarine is a gem of the beryl family, which is found as a fairly common constituent of the gem bearing gravels. It is found in Awissawella, Horana, Ratnapura, Haputale, Rakwana, Morawaka, Ambalantota, and Galle.
Topaz is a aluminium fluorosilicate mineral ($Al_2SiO_4(F_2OH)_3$). It can be in various colours such as red, pink, purple, yellow, yellow-gold, orange, orange-pink, brown, sky-blue, blue green, or colourless. These are found in Matale, Ratnapura, Hatton, Passara, Horana, and Haputale.
Zircon is a zirconium silicate mineral ($ZrSiO_4$). Its colour can be brownish or reddish orange, yellow, or colourless. These are found in Ratmapura, Elahera, Nilgala, Awissawella, Nuwaraeliya, Passara, Horana, Haputale, Aluthgama, Rakwana, Matara, Morawaka, and Ambalantota.

Tourmaline is a borosilicate with a complex and variable composition. Its colour can be pink, green, dark green, peach, purple red, blue, blue green, yellow, black, bi coloured, multi-coloured or colourless.
It is a common constituent of gem gravels, and are found in Ratnapura, Nilgala, Awissawella, Passara, Horana, Haputale, Buttala, Rakwana, Morawaka, and

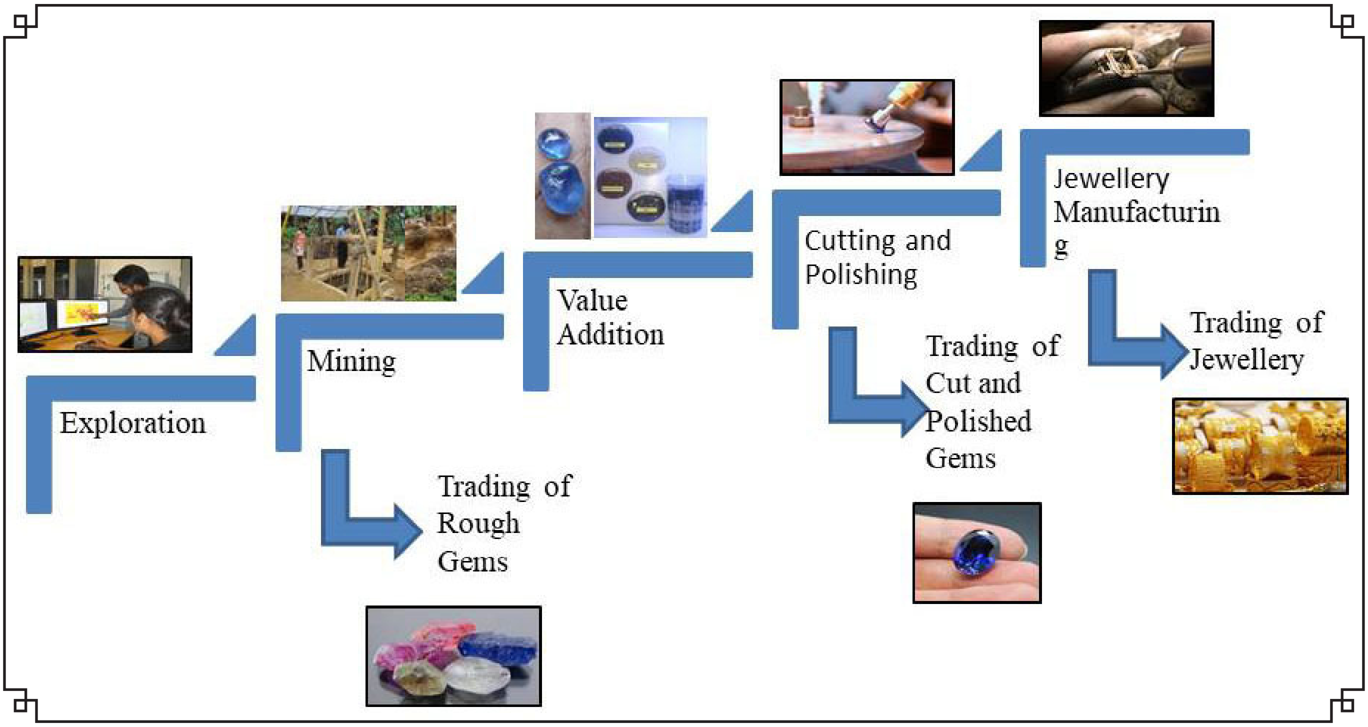


Fig 3 : Gemstones value chain consists of Exploration, Mining, Value Addtion, Cutting and Polishing, Jewellery Manufacturing and Trading

Ambalantota.
Garnets are complex aluminium silicates. They vary widely in chemical composition, and exhibit a variety of colours which may be red, pinkish or purplish red, white, yellow, yellow-orange, orange, green, brown, and black etc. They are found in Ratnapura, Elehera, Polonnaruwa, Nilgala, Awissawella, Hatton, Passara, Ratnapura, Haputale, Buttala, Rakwana, Timbolketiya, Morawaka, Ambalantota, and Matara.
Quartz is a silicon oxide mineral (SiO_2). The water clear and colorless variety is known as rock crystal, while amethyst is purple or violet, rose quartz the pink, and citrine the yellow. It is found in Ratnapura, Awissawella, Nuwaraeliya, and Kandy.
Moonstone is a potassium aluminium silicate ($KAlSi_3O_8$), which is a variety of orthoclase feldspar. It has a characteristic bluish white or milky adularescence. It is found in Kandy, Matale, and Meetiyagoda.
In addition, andalusite, cordierite (iolite), diopside, fluorite, apatite, konerupine, taaffeite, saffhirine, sinhalite, ekanite, enstatite, fibrolite, phenakite, scheilite and scapolite are found as rare gem minerals within gem gravels.

Gem industry in Sri Lanka and its sustainability
Gemstones value chain consists of Exploration, Mining, Value Addtion, Cutting and Polishing, Jewellery Manufacturing and Trading (Fig.3)
Due to the following constraints, this value chain has not been functioning well and consequently this industry has been affected.
•Lack of a proper assessment of the gem resources of Sri Lanka.
•Lack of capital
•Lack of access to the international market
•Lack of access to modern technical support and resources
•Insufficient knowledge in the nature of deposits
•Skills gap
•The vast gaps in gemstone value chain
•Regulatory restrictions and inconsistent policies
•Absence of attractive tax system for private investors
To overcome these hitches, the following strategies can be executed to ensure a sustainable gem industry.
•Undertaking grass-root level exploration in search of high-quality deposits.
A systematic exploration programme should be conducted to identify and assess economically viable gem deposits in the country.
•Financing
The banking and related sectors should be encouraged to extend loans and other financial instruments to the gem and jewellery industrialists.

•Elevating technology
It is necessary for capacity building of R&D institutions in Sri Lanka, and for the expansion of technical service networks such as to quality control, common facilities for instrumentation, testing, and calibration.
•Introducing value added products to the market
In terms of the gaining the highest yield, the raw gem mineral should be transformed to gem studded jewellery, which can either be utilized locally or exported.
•Business development services
Services such as advice, guidance on technology, product quality, marketing must be provided.
•Bridging the gaps in the gemstone value chain
The linkages in the gemstone value chain (Fig.3) should be optimized.
•Improving the existing operations in the gem and jewellery sector
It is necessary to move towards higher technological advancements, increased efficiency and productivity, and move into more value-added products.
•Equip with skilled workforce
High-quality human resources with expertise in the sector, and a skilled labour force are necessary. Hence, vocational training and secondary education should prepare prospective employees.
•Policy Reform
Mines and Mineral Act needs to be revised after studying policies of successful mining nations.
•Fiscal Reform
Fiscal reforms are needed for improving public financial management, introducing a simplified tax system, increasing public and private investments, addressing infrastructure constraints and improving competitiveness. In addition Sri Lanka should revise the taxation regime, and look for more sustainable sources of growth to maintain the tax to gross domestic product (GDP) ratio.
•Prevention of environmental issues
It is necessary to facilitate environmental impact assessment (EIA) requirements of industrialists by providing technical advice and testing services especially at regional levels.

Contributions of Gem and Jewellery Research and Training Institute for the gem and jewelry industry

The Gem and Jewellery Research and Training Institute (GJRTI) is the national arm under the purview of the Ministry of Mahaweli Development and Environment for conducting research and training programmes for regulation, promotion, and development of the gem and jewellery industry. One of GJRTI's objectives is to conduct surveys on Gems in Sri Lanka. Therefore, this institute has launched a project on "Exploration and Assessment of Gem Deposits of Sri Lanka" to identify in-situ places of gem deposits, for developing a gem potential database including maps, to introduce eco-friendly mining methodologies, and to prepare guidelines for sustainable gem mining operations in Sri Lanka. Currently, it is being implemented in several districts and some gem potential maps have been finalized.

As another objective, this institute conducts research on color enhancement of gemstones. Recently researches were able to find possible colour enhancement techniques for low gem quality gem minerals such as Kirikottara, Zircon, Young Geuda, Topaz, Feldspar etc through heat treatment, epitaxial growth, and nano-technologcal methods. Further, this institute conducts research on innovative products with use of other special properties of gem minerals. Recently, it has been possible to introduce innovative products such as water filters, therapeutic products, and durable clay pots.

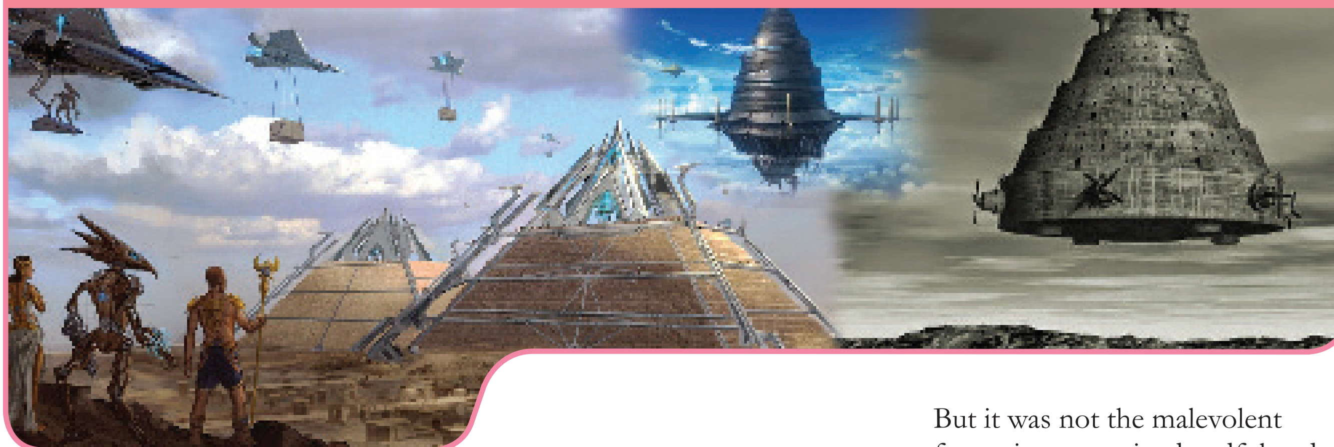
On the other hand, this institute also conducts training progammes such as gem cutting, jewellery manufacturing, gemology, jewellery design, colour enhancement of gems, gem carving, casting and electro plating at NVQ levels for generating a skilled labour force for the industry.

In addition to that, the institute provides technical services, technical advice and state-of-the-art laboratory facilities for the sector. GJRTI continues educating the community through workshops, seminars, and publications.

Mr R.M.N.P.K Jayasinghe
Head/Research Division
Gem and Jewelry research and training institute
Ruwan Sewana",
No: 73/5/A,
Welivita, Kaduwela,
Sri Lanka
naleenlk@hotmail.com

Traditional Wisdom In Sustainable Use Of Earth Resources

M. Asoka T. De Silva



Historical Backdrop

It is on record that with the advent of Buddhism to Sri Lanka, the World's earliest wildlife sanctuary was established by King Devanampiyatissa in 246 BC. Subsequently fostered by the great philosophy of Buddha, conservation of biological as well as all other earth resources, and their sustainable use, became a unique and unparalleled tradition in ancient Sri Lanka. The concepts of biodiversity conservation have since then been ingrained in the cultural and religious beliefs of the people of Sri Lanka. During monarchial rule, forests and animal lives were an important part of the social fabric. Forests were generally owned directly by the king, and considered crown property or Rājasan thaka. Any sort of activity within these Tahansi Këllë or 'Forbidden Forests' was strictly prohibited.

It is known that in ancient Sri Lanka, almost every province of the Kandyan Kingdom had several such 'Protected Areas', where any kind of cultivation, felling of trees, hunting or fishing were strictly prohibited, and punishable by a heavy fine. These laws were enforced by a type of 'Forest Department' comprising the Këllë Korale appointed by the King. The ancient repository of Sinhala Laws Nīti Nighanduwa is known to have recorded that all elephants were the property of the Crown, and killing an elephant had been perceived as one of the most atrocious of all crimes. Monarchs from ancient times upheld this noble tradition. In fact it is known that in the 12th Century AD, King Keerthi Nissanka Malla had proclaimed that no animal should be killed within a radius of seven Gau (equivalent to 35.7 km) of the sacred city of Anuradhapura.

Against this backdrop, it is not difficult to understand the professed psychosocial mindset of our great ancestors who migrated to this resplendent island way back in 543 BC, which has since been eloquently expressed in the following terms:

"The Aryan migrants were the truest children of nature. They lived in nature and with nature. Their outlook on life and of the world was influenced by their conception of the forces of nature. But it was not the malevolent forces in nature, its dreadful and life-crushing manifestations that moulded their psychology. It was rather the benevolent aspect of nature which helped the Aryans in the development of their mental and spiritual faculties to the fullest. They were free from depressing inhibitions, and had no sense of fear and dread in the subconscious mind. Nature taught them to retain naturalness and freshness, to inspire hopefulness, to revel in enjoyment and to maintain a supreme ardour and zest for living. The philosophy of naturalism coloured their religious ideas. They visualized nature's powerful and life-promoting forces. The Aryans attributed to these their happiness and prosperity. The Aryan was in fact, a primitive student of nature. To understand the laws underlying the forces of nature was beyond him. He interpreted their significance from the utilitarian standpoint and appreciated their value in relation to man and society" (Dharma-Vijaya or The Revolt in the Temple, 1953).

Sri Lanka's varied climate and topography has resulted in a rich biodiversity distributed within a wide range of ecosystems. Among the terrestrial ecosystems are forests of varying types, grasslands, and a network of rivers, wetlands and freshwater bodies. These together with the coastal and marine ecosystems such as seagrass beds, coral reefs, estuaries and lagoons, and associated mangrove swamps, constitute the spectrum of natural ecosystems in the country.

Indigenous Knowledge in the Management and Sustainable Use of Earth's Resources

Indigenous knowledge used at the local level by communities was the basis for decision making pertaining to food security, human and animal health, education, natural resource management, as well as all other vital activities for the sustenance of a contended and a satisfying livelihood. Being a knowledge system passed down from generation to generation, usually by word of mouth, it covers all aspects of life, including the natural environment and the earth's resources, which have been matters for survival of communities that generated this knowledge.

With the decline of the hydraulic civilization, Sri Lanka's capital began to shift from the Dry Zone to the Wet Zone, and to the hill country, which eventually became the stronghold of the Sinhala people against invading forces. Population shifts across different agro ecological zones from the Dry Zone to the Wet Zone and to the hill country required an agrarian society to adjust to new environments and try new ways of managing land and water.

In a report presented at a Workshop for the Development of a National Strategy for Incorporating Traditional Knowledge in Development Practices, held in 2002, Hemanthi Ransinghe explained that in the hill country, the people modified their lives to the wetter and more rugged terrain. Paddy cultivation in the deniyas (valley bottoms) was irrigated during the drier periods through canals that collected water from the springs in the hill slopes. Hills performed the function of reservoirs, and the management

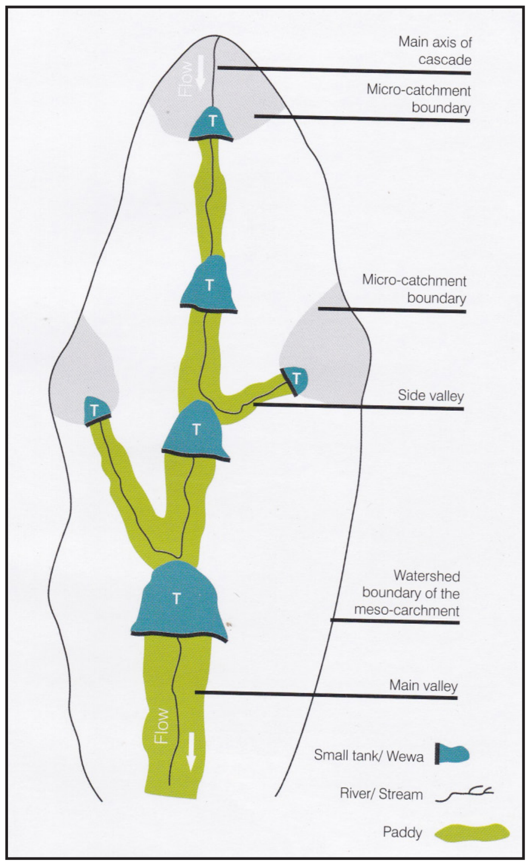


Fig 1 : Diagrammatic Representation of Small Tank Cascades

of watersheds necessarily formed an integral component of the agricultural enterprise. Different ecological segments of the slopes were recognized, as reflected in village names such as Ovita, Ovilla and Ovilkanda according to their location. Valley bottoms around which the settlements arose were named after the valley with the suffix of deniya (e.g. Gurudeniya, Peradeniya etc.). At the lower segment of the catena, forest gardens were developed in the homesteads. Further up, chena cultivation was practiced occasionally on a largely sustainable basis. Hilltops were permanently kept under a thick forest cover, which helped to control soil erosion and regulate water flow.

The Kandyan Forest Gardens and Other Types of Homegardens

At this point it must be noted with great consideration the unique small scale models of homestead farming popularly known as Kandyan Forest Gardens. Though these are now on the decline due to fragmentation of ancestral properties as well as due to commercial considerations, such gardens have been known to demonstrate the highest levels of biodiversity conservation known anywhere.

The Kandyan Forest Garden became a man-made forest consisting of various fruits and other economically useful tree species such as nutmeg and cloves. It essentially copied the diversity and intricate interrelationships of the natural forest. The multi-storied nature of cropping managed to utilize the sunshine optimally and effectively which falls to the garden. Resource utilization in the horizontal layers too were at the maximum in these Gardens. Kandyan Forest Gardens are located between the valley bottoms and high slopes to avoid damp conditions, and benefit from a deep soil cover and seepage of moisture from the upper regions.

The micro environment of a Kandyan homestead provided a suitable base for the continuity of human settlements in a wet montane setting.

Less intensively managed homegardens are found in most other districts of Sri Lanka especially in the low country Wet Zone in the western and southern coastal belts, and in the low country Dry Zone. Except for cocoa and coffee, most of the Kandyan homegarden species are grown less intensively. In addition, fruit bearing species like Rambuttan and Mangosteen were also found in these gardens. Homegardens usually have live fences of leguminous type plants, especially Gliricidia sepium, Kapok etc. The canopy cover of these is not dense and ranges from 25 -75 %. Cattle, goats and poultry are reared in these systems. Legumes thus planted help to increase soil fertility and provide food and fodder. In many homesteads in the Dry Zone, planting of useful tree species is widespread. Drumstick trees are grown in fences or hedges, as their crowns are very light, while the pods are popular and very nutritive. Production of these trees starts within one year of planting, and the bark of the tree is of medicinal value. In some other systems, Sesbania grandiflora is planted in the Dry and Semi-Arid Zones. Local people use the tender leaves and flowers as vegetables. Production in this case is also within one year of planting. It is an important producer of green manure and fodder, especially in the dry season.

Medicinal trees with pasture
Medicinal plant gardens with pasture constitutes another ancient system located in the districts east of central Sri Lanka, and the best examples are found near the town of Bibile. The medicinal trees are scattered in typical savannah grasslands, and are said to have been planted first in the days of Sinhala Kings. Aralu (Terminalia chebula), Bulu (T. belerica) and Nelli (Phyllanthus emblica) are the principal tree species found. Cattle grazing and goat rearing are practiced on the intervening grasslands. Fire hazard is a problem in the dry months of May to August, but the trees can withstand ground fires. Wildlife including elephants move into these areas, from nearby National Parks, but cause no damage to the valuable medicinal trees.

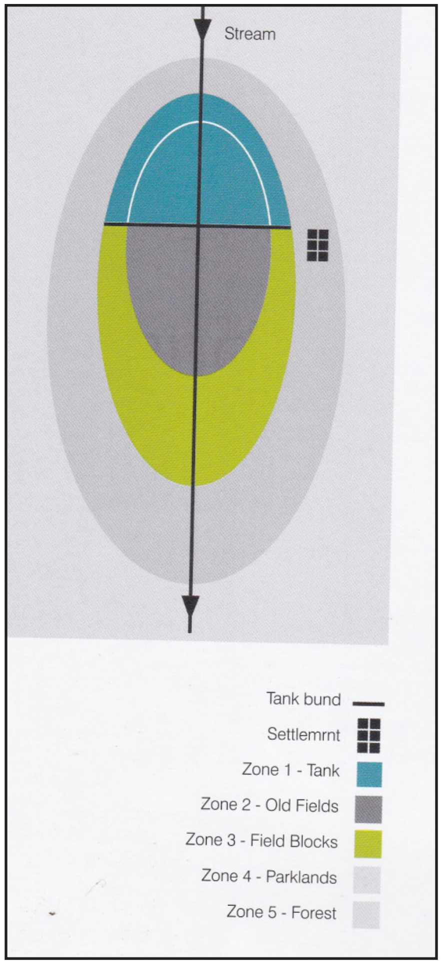


Fig 2 : Diagrammatic Layout of a Typical Traditional Dry Zone Agro-ecosystem

Silvo-aquaculture is a practice restricted to the mangrove forest areas along the coast. The country has around 12,000 ha of mangrove forests which produce timber, fuel wood, bark, fish and shell-fish. Prawns are cultivated in some areas near Negombo, Colombo and Kalutara along the west coast. The mangroves provide the spawning grounds for prawns and other shell-fish and many types of fish. The mangrove forests along the north-western and eastern coasts are also familiar breeding grounds for indigenous and migratory water birds. Mangrove fuelwood is used by villagers and small industries that make bricks and tiles.

Traditional Socio-cultural Beliefs in Harnessing of Earth's Resources
Traditionally people of Sri Lanka had a simple way of life in close harmony with the natural environment. Local communities had a vast storehouse of traditional knowledge and experience passed down through generations. Much can be learnt from their skills in sustainable management of complex ecological systems. According to their beliefs the sun gave life to both humans and animals, while paddy seeds water and all other essentials in life also had their origin from the sun. The moon produced the ocean tide which had a tremendous influence on man and his environment. They believed that so long as the sun and the moon rose in the sky, the rivers would flow wetting their land and bestowing enormous benefits to them. They cultivated their fields, planned their food and clothes based on the belief that they are part of the larger environment.

They based their calendar according to the increases and decreases in the size of the moon, and therefore the twelve month calendar was named Duruthu, Navam, Madin, Bak, Vesak etc. These names had a significance relevant to that particular period and their life pattern was linked with these divisions. Thus farming and production timings were set apart for those particular months that were environmentally most suited for such activity. This was their pattern of sustainable development.

The Strategies Adopted by Wannietto in the Management of Earth's Resources

Wannietto, or the Veddhas constitute a group of people who live on hunting and gathering of food in forests. They performed an important function in the protection of the forest cover. They considered themselves as wardens or guardians of their hunting grounds. Wannietto had a tremendous affection for forest resources and developed a protective attitude towards it. According to the leaders of Wannietto, Lord Saman, the God of Adam's Peak granted them a warrant to look after the well-being of life in Sri Lanka's extensive forests.

Wannietto were able to utilize the products of forests, causing no damage to resources therein. This is firstly due to the fact that their needs were limited to basic requirements such as food and shelter. Secondly, Wannietto had no specific goals or targets to achieve in their lives. There was no competition among the members of the community to reach certain targets. Thirdly, the population numbers of Wannietto were small, and the annual demand for resources was very low. The renewable forest resources were ample to supply the meagre demands of Wannietto. Fourthly, the ancestors of Wannietto did not indulge in any form of monetary transactions. As such their demands were to fulfill the unity among the members of the community, and to help in preserving and maintaining the traditional environmental knowledge that was passed down from their ancestors. The social and environmental values that came from generation to generation are considered as unwritten laws among Wannietto.

The true Wannietto are basically hunters and food gatherers. Hunting provided them with meat, hides, teeth and bones that were used as raw materials. Teeth and bones of some species were considered to be items of medicinal value too.

One of the basic strategies adopted by Wannietto in hunting is not to destroy animals haphazardly. A hunting group would always decide on the type of animal that they wish to kill on a particular day. For instance, if a decision has been taken to kill a deer, other edible species of animals were spared in hunting areas.

These unwritten laws were cultural adaptations of Wannietto to prevent wastage and over exploitation of faunal resources in forests. Wannietto refrained from frequent killing of animals belonging to one particular type in order to prevent over exploitation. The protective attitude they extended towards female animals facilitated reproduction of wildlife. Wannietto always spared the suckling animals. Moreover, animals which are about to litter were also reprieved. It was also revealed that Wannietto were discouraged from killing animals which were quenching their thirst at water holes or water bodies. Over exploitation, wastage and frequent hunting of wildlife resources were minimized by adopting methods such as sharing the carcass and preserving meat. Methods of meat preservation adopted by Wannietto are as follows:

(i)Sun drying;
(ii)Smoked meat; and
(iii)Immersion of meat in bees' honey and placing in a trunk of a tree, or a cavity in a granite rock.

The leaders of Wannietto have adopted special methods in trapping animals that did minimum damage to the environment.

1.'Habaka' or wooden trap was used to catch animals such as wild boar, iguana and hare.
2.Thadiya is a mobile trap which was placed in front of anthills or cavities in tree trunks to trap animals that come out from their habitats. The basic principle adopted in constructing this trap is not to destroy the habitats of species.
3.Lula was a contraption meant to trap large animals such as deer and sambar.
4.Manda parrots, Watuwa and medium sized birds were caught by using Manda.

Wannietto carefully observed the foot paths of groups of sambar, and placed pointed poles or sticks to trap them. The method of using hunting dogs is also frequently practiced by Wannietto. Hare and wild boar were located by following their hunting dogs. Most common equipment used by Wannietto were the bow and arrow to kill animals such as deer and sambar, who were located at a considerable distance.

Some beliefs and attitudes followed by Wannietto however, helped indirectly in protecting certain faunal species in forests. Elephants, cobras and peacocks were considered as deities. Porcupines were spared as they were treated as the dead relatives (uncles) of Wannietto.

Although Wannietto are hunters and food gatherers, some engaged in "chena" or shifting cultivation. It has been shown that products of chena cultivation were preserved by following methods that were practiced for several generations. For instance, dried fruits of Diyalabu (Lagenaria siceraria) were used to store grain which were mixed with wood ash. Green-gram and kurakkan were stored by mixing with the sap of Nika (Vitex negundo) to prevent insect attacks.

Traditional knowledge on plant species facilitated Wannietto to select fire wood that retain heat for a long time. Kuratiya (Memecylon arnottianum), Kara (Canthium coromandelicum), Seru (Cymbopogon – Citratus) and Vellang are a few examples. It has been reported that Wannietto refrained from using wood that produced excess of smoke, which they apparently realized would pollute the air. The popular timber tree Milla (Vitex pinnata L), was known to emit an excess of smoke, and hence was never burnt. It seems obvious that Wannietto were aware that excess of smoke could polluted the air, and consequently of their living environment, which itself constitute a life supporting earth resource.

Chena cultivation is widely practiced amongst Wannietto. Selection of a suitable land for cultivation was an important factor in determining high production. Sloping land with rock outcrops were avoided as they are highly vulnerable to erosion. Forest lands along rivers and oyas were preserved. Lands where there were fruit bearing trees were not cleared for chena cultivation. As the location of termite hills was a good indicator of high water retention capacity of soils, Wannietto preferred such lands for cultivation.

Traditionally, Wannietto have not lived in permanent dwellings. Even today their housing requirements are minimal. In construction of huts, large trees were not felled, instead branches of trees were cut to obtain their needs. Some of the commonly used species are as follows:

Liniya (Helianthus annuus)
Ehala (Cassia fistula)
Weera (Dryptes sepearia)
Kon (schleichera oleosa)
Wa (Cassia siamea)

The roofs of their dwellings were thatched with Iluk (Imperata cylindrica) grass.

Wannietto were able to find a wide range of naturally produced food items such as yams and plants from the forests. The problem of over exploitation and exceeding carrying capacity did not arise as these vegetables were available in plenty. Wild yams such as Katu-ala (Dioscorea pentaphyll), Gonala (Dioscorea intermedia), Alala, Dubada and Hiran-ala were a good source of carbohydrates. Seed of Hal (Vataria copollifera), Beraliya (Shorea megistophylla), and Madu (Cycas), and the plant heart of Kitul, Indi, Madu, and Thala were ground to flour and used for various preparations. Wild bread fruit and banana are known to have been used from prehistoric times. In addition, a large number of other forest plants such as wood apple, Indi, Weera, Palu, Longan, velvet tamarind, tamarind, donga, timbiri, ulkenda, have been used as fruits.

Herbal plants such as Monerakudumbiya (Vernonia cinerea) and Hulanthala (Ageratum conyzoides) were frequently consumed by Wanniatto.

It is clear that that Wannietto were able to obtain their basic needs from the environment without causing any loss or damage to earth resources.

Sustainable Conservation of Water, Soil and Ecosystems through Landscape Agriculture

Some of the initial design observations of small tank networks have been described as "Cascades" by Prof C. M. Madduma Bandara in 1985. A cascade is defined as a connected series of tanks organized within the meso-catchment of a dry zone landscape, storing, conveying and utilizing water from an ephemeral rivulet (see Figure 1).

Dr. C. R. Panabokke, in a study carried out in 2002, claimed that in an earlier study it had been revealed that 71 river basins located within the dry zone accounted for 15,499 small tanks, some of which are now abandoned, while 90% are clustered as cascades.

It is significant that in the operation of small tank cascade systems, the drainage from paddy fields in the upper tiers of the cascade flowed into downstream tanks for reuse in paddy fields in the lower tiers. The efficient operation of such a system no doubt required a high level of skills in management and co-ordination, because negligence or complacency at any one stage in this delivery chain could have disastrous consequences in the lower reaches of the system.

In a field study in some remote villages of the Anuradhapura District, Dr. M. U. A. Tennakoon (2005) had apparently discovered from village elders that the small tank network systems were well known among themselves as Ellangāwa in these ancient villages. This term had been in common use among residents of many of the ancient village organizations of the Anuradhapura District.

It is therefore clear that land use associated with such small tank cascades also required a profound knowledge of resource management, because the ultimate result is the transformation of a natural system with its diverse and fixed assets into an agro-ecosystem which entails a turnover of resources. This traditional village land use pattern is based essentially on a 3 tier arrangement that comprise the paddy field, the home gardens and the chena, which ensures self-sufficiency in food, and stability of the home economy.

The landscape architecture characteristic in traditional land use had been investigated by Dr. M. U. A. Tennakoon in 1986, who showed how the gravity-guided tank irrigation system, widely practiced in the drought-prone northern dry zone had helped to save field crops from water shortages in ancient times. This land use system had apparently evolved to fit in with the topographical and drainage pattern of the land. Although there may be some variations, in different areas, the ancient village land use system is believed to conform to a basic pattern consisting of 5 broad zones as given below, and illustrated in Figure 2.

1.Zone 1 comprises the main irrigation tank (the nerve centre) formed by throwing an earth dam across a seasonal stream.
2.Zone 2 is the "Old Paddy Field" (Purāna Wela) which consists of the land that lay below in closest proximity to the tank. This paddy field has almost a guaranteed supply of water and manpower, by virtue of its location.
3.Zone 3 represents an expansion of irrigated agriculture beyond the periphery of the Purāna Wela by farmers, where individually owned plots which are generally larger in extent than those in the old paddy fields are cultivated.
4.Zone 4 is situated further away from the tank, where irrigation is almost impossible. A greater part of Zone 4 lies along the sides of the zone 3 Field Blocks, and is home to short grasses, isolated trees as well as shrubs, and hence named as "Parklands".
5.Finally there is the Zone 5 which occupies a large extent of the village land, comprising mainly forest, and is located as a continuous girdle (similar to Zone 4) round the tank.

It must be noted that the cardinal policy objective of Sri Lanka's ancient rulers was to provide all means necessary to produce their own food and nutritional needs by ensuring a bounteous supply of water.

In the maintenance of irrigation structures each Pangukaraya had the specific responsibility to contribute his physical and human resources capability for the repair and maintenance of irrigation streams and canals that served his requirements. In fact water management was generally through rules, regulations, rituals, customs and participation of the community. In tank desiltation, every Pangukaraya was expected to clear a section of the tank bed.

One of the most dominant cultural traditions practiced in the dry zone by the inhabitants of ancient agrarian societies was the ritual known as the 'pot ceremony' or Mutti Mangallaya, a self correcting sustainable agricultural activity practiced in the hydraulic society of Sri Lanka. It is a genuine participatory management system founded on collective conscience, enshrining community based commitments, rights, obligations, and decision making. This ceremony has been studied and reviewed by numerous Sri Lankan and foreign scholars because of its unique and cost effective regulatory process for ecosystem protection, irrigation, water management and organized crop production. This ceremony continues to be practiced even to this day in some areas of the Anuradhapura and Kurunegala Districts

Indigenous Knowledge in Water Resource Management
The type of irrigation technology that was developed in the hill country, not only enhanced water supplies down-stream, but also contributed to the mitigation of landslides and soil erosion. In the hill country, the hills were utilized as reservoirs' that fed the canals that encircled them along the contours. These canal systems in turn fed the contour terraced rice fields (hel malu) that controlled the supply of water efficiently.

In larger irrigation schemes like the Minipe left bank canal, it was possible to capture the waters of the upper watersheds of many streams that drained the Dumbara (Knuckles) ranges. The adoption of this principle could be seen in several other sites of ancient irrigation works.

Two other forms of indigenous water management practices, and attempts that have been made to adapt them to present situations are reflected in the bethma system, and the harnessing of rain water through a properly managed crop calendar in harmony with the advance of seasons.

With regard to social and cultural aspects of indigenous water management that contributed to promote community spirit and bind the society together, some ceremonies such as mutti mangalya seem to prevail in some rural areas of the Nuwara Kalawiya. However, recent attempts are reviving the Vel Vidane system or këlë koralë and the introduction of Vari Sabha Mandapa had only limited success. Crop diversification on the other hand as a means of increasing water use efficiency and productivity, has demonstrated encouraging results.

Certain forms of traditional land tenure and land use within the purana village setting appear to have become somewhat obsolete in the current day context. The fragmentation and dispersal of paddy plots over the entire yaya as a precaution against various risks such as droughts and damage by wild animals and cattle is considered unsuitable in the present context, and attempts have been made for consolidation into larger individual holdings. Similarly, other arrangements such as kurulu paluwa in the paddy fields and the jala gilma in the upper tank beds and tis bambe near the gangoda had come under increasing pressures due to increasing population and demand for land. The spread of tavalu cultivation in the tank-beds has gradually eliminated the gas gommana that protected the tank from excessive siltation. It appears that the time had come to preserve at least a few traditional village tank systems that still retain such sustainable elements for the benefit of the rural population.

The ancient water and soil conversation systems of Sri Lanka are classic examples of man's active adaptation to nature. They include river diversion systems and storage systems, themselves consisting of small, medium and large reservoirs. A third item called vettiya has also been identified as having an unique dual function of both diversion and storage. These systems had been constructed over a long period of time, beginning in about the mid first millennium BC.

D. L. O. Mendis claims that the proven stability and sustainability of these ancient water and soil conservation ecosystems over many centuries has been considered to have evolved based on the following seven stage hypothesis.

1.Rain-fed agriculture
2.Seasonal or temporary river diversion using sticks and stones to build river diversion structures, in order to assist, or take advantage of the natural seasonal flooding of a river, for flood or inundation irrigation agriculture on river banks.
3.Permanent river diversion and channel irrigation systems, using permanent diversion structures made of stone and brick masonry, sited on good rock foundations.
4.Construction and operation of weirs and spillways on contour channels using technology similar to that necessary for construction of permanent river diversion structures.
5.Invention of the sluice (sorowwa) with its access tower (bisokotuwa) based on the experience of operation of weirs and spillways on contour channels.
6.Construction of storage reservoirs incorporating the sluice for control and issue of irrigation water to the fields.
7.Damming perennial rivers, using the sluice for temporary river diversion during river closure, or by the twin tank method.

Another important consideration is the ancient earth embankment without a sluice, and with its ends curved in the downstream direction, which had been mistakenly considered as breached, or as abandoned small tanks on topo-sheets. According to D. L. O. Mendis, a large number of these found in Southern Sri Lanka are called Vetiyas by local peasants, and are now recognized as unique water and soil conservation devices, with both diversion and storage functions, the latter in the soil itself, not on the surface as in small tanks. The small tank is stable and sustainable with a drought resisting capability of a large reservoir to augment it. The ancient vetiya, with its dual function, like the electron, in maintaining the water table, is scientific in modern forms. Vetiyas, small tanks, and small river diversion structures called amuna or anicut, together make up micro water and soil conservation ecosystems, while large reservoirs and channels constitute macro ecosystems.

Yet another marvel in soil and water conservation was the idea of King Dhatusena, who conceived the idea in the 5th Century AD, of forming a massive lake by throwing back the waters of the Kala Oya with an embankment which submerged 300 square miles of its watershed, and consequently joining Kalawewa and Balaluwewa together. This embankment is said to comprise a stupendous spill made of hammered granite, excellently dressed and flattened at the crest, with an intervening bund in the low land between the Kalawewa and Balaluwewa, allowing for the exit of flood waters.

The King it is said ensured that the water from this large lake would ultimately be carried in a giant canal 40 feet wide, the Yoda Ela, a distance of 54 miles to Anuradhapura to feed the city tanks. This canal also known as Jaya-ganga, meanders over the first 17miles at an unbelievable gradient of no more than 6 inches per mile. Thereafter it is led into deep gorges across saddles between watersheds flowing gently along the surface of the terrain bordering the traditionally preserved thick jungle corridors, drawing rain water and the flood waters of small streams.

Thus apart from the technological ingenuity of this complex hydraulic system, it conforms and measures up to the best principles of ecology, soil conservation, and water management, whereby the canal, apart from conveying the surplus water from the reservoir system and the flood waters of the cross streams, scientifically taps and drains optimally the precious resource from the sub-soil springs of the surrounding micro-climatic ecosystem, while also ensuring least loss of water through surface evaporation. It is the traditional wisdom and knowledge system of our fore-bearers that ensured the performance of such a multiplicity of functions by the ancient reservoirs and canal networks, that continues to baffle the present day environmentalists, engineers, scientists, and development planners, many of whom have been the unfortunate participants and witnesses to the tragic mistakes of modern times.

Mr M. Asoka T. De Silva
6/9, De Silva Road,
Kalubowila,
Dehiwela

SAND – AN ENDANGERED EARTH RESOURCE

Sand is a resource that seems to be in infinite supply. We cannot do without it, but if we use less sand, we might stop this precious resources from slipping through our fingers.

Between 60 and 75 percent of the sand we mine goes to make concrete. It is cheap, which is why we use twice as much of it as all other building materials combined.

Dredging sand from the sea floor stirs up a soup of particles. When the sediment settles, it blankets coral reefs and plants, stopping them feeding and photosynthesizing.

Sand mining has degraded marshes in south-east Brazil, an important habitat for the critically endangered Sao Paulo marsh antwren.

The impact of the 2004 Indian Ocean Tsunami would have been less severe in Sri Lanka, if not for the removal of dunes that would have protected the coast.

Boats transporting sand may also carry invasive species like the Asian clam, while sand pirates have harvested so much from islands in Indonesia that at least 24 of them have disappeared.

The solution is to decrease our need for sand. We may need to change the way we build: a new wave of architecture might change that.