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SUSTAINABLE DEVELOPMENT OF WATER RESOURCES, WATER SUPPLY AND ENVIRONMENTAL SANITATION

The role of trees in the bioremediation of drinking water – a research experiment in Nawakkaduwa, Kalpitiya

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The Kalpitiya Peninsula is a low-lying sand peninsula located on the North West coast of Sri Lanka. Of special significance is the underlying Gyben-Herzberg lens of fresh water that is extensively pumped for irrigation and potable water supply. Ground water quality throughout the peninsula had been good until massive amounts of inorganic fertilizer and chemical pesticides began to be used in agriculture which increased ground water concentrations of nitrate, nitrite, chloride and potassium beyond WHO drinking water standards. There is seen a correlation between ground water quality and land use. The National Water Supply and Drainage Board (NWSDB) were thus compelled to abandon many wells constructed in the Kalpitiya peninsula since the water was contaminated with nitrates and nitrites. In 2004, they contracted with the Neo Synthesis Research Centre (NSRC) to conduct research on the bioremediation of the contaminants. Thus far the results are very encouraging.

Introduction

The land use planning promulgated by conventional agriculture includes among many other facets, the intensive use of agrochemicals, the monoculture of one or two crop species, the removal of all other vegetation, the introduction of new crop varieties and pressure on the land to support three cropping cycles.

The intensity of conventional agriculture in sensitive environments is rife with negative impacts. For instance, in many countries, ground water from shallow aquifers is used to supply potable water as well as for irrigating crops grown with the use of chemical fertilizers and pesticides. The leaching of these agrochemicals into the ground water table has had a significant impact on ground water quality. Few, if any studies on the leaching of agrochemicals have been undertaken in developing countries even though the use of both chemical fertilizers and pesticides are high. (L.R. Lawrence & D.S.P. Kuruppuarachi, 1986)

The Kalpitiya Peninsula that is located on the west coast of Sri Lanka is a good case in point. The climate is characterized by high temperatures throughout the year and an average annual rainfall of 800-900 mm that occurs only between October and January.

Sandy regosols occupy the central portion and a greater part of the elevated beach plain that is adjacent to the lagoon in the Kalpitiya Peninsula. The dune sands are mainly present on the seaward side of the beach plain. Of special significance is the underlying Gyben-Herzberg lens of fresh water that is present in the beach plains with a flat to gently undulating topography. This permits stable human settlement and agricultural production on this landscape even in the very dry environment (C.R. Panabokke, 1996).

Despite the dry environment that prevails in this region, the underlying shallow fresh water supplies have permitted viable coconut plantations as well as sustained human settlement. However, the past forty years has seen the intensive cultivation of seasonal high value crops such as chillies, onions, tobacco, potatoes, and other vegetables cultivated under lift irrigation from shallow wells.

The fresh water lens is extensively pumped for irrigation and potable water supplies, and the recharge is from direct infiltration from rainfall and return irrigation flows. The development of the shallow aquifer has altered the natural

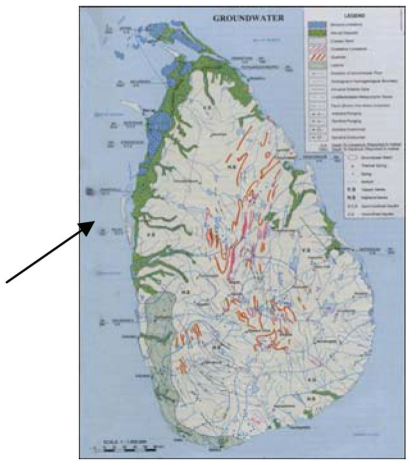

Figure 1. Map of Sri Lanka showing location of Kalpitiya

flow regime and now ground water flow within the aquifer is dominated by the abstraction from the shallow irrigation wells. Ground water quality over large areas of the peninsula is good and is of the calcium bicarbonate type. However within the cultivated areas, ground water concentrations of nitrate, chloride and potassium are exceptionally high. The nitrate and chloride concentrations in cultivated areas were in the ranges of 10-15 mg of N/ L and 100-300 mg/ L respectively, whereas those in the uncultivated areas in the range of 0-2 mg of N/ L and 500-100 mg/ L respectively (L.R. Lawrence & D.S.P. Kuruppuarachi, 1986 et. al). There is a clear correlation seen between ground water quality and land-use.

Agricultural activities

Farmers in the Nawakkaduwa area have fairly large land holdings, ranging from 3 to 25 acres in some instances. They grow crops like chillies, onions, tobacco as monocultures, while coconut is their only tree crop. They use agrochemicals in doses far in excess of the recommendations given by the Department of Agriculture. Chemical fertilizers like Urea, Ammonium Sulphate, Triple Super Phosphate (TSP) and Muriate of Potash are used along with specialty fertilizers for chillies, onions and coconut. Almost no organic fertilizer is used. The same story is true in the application of chemical pesticides and fungicides. The other problem is that since crops are grown as monocultures, where all farmers grow the same crop at the same time, the threat of pest attacks and disease, in epidemic proportions, is possible, hence the need to use increasingly excessive volumes of pesticides. (NSRC, 2004) In 1962, the volume of NPK fertilizers used was in the range of 80 000 Tonnes. In 1988, the value increased to 200 000 Tonnes! (Department of Agriculture, 1990). There are no other crops, either annual or perennial, that are used in intercropping, and no active cultivation of green manures to facilitate compost production.

Farmers use the water pumped from shallow wells to irrigate their fields. Farmers use up to 75 000 L of water per acre per day or if computed, 35% of the cost of production is devoted to the cost of watering. (NSRC 2004, et al) Hence, with the rising cost of agrochemicals and that of fuel (for operating pumps) for watering, the cost of production is becoming increasingly unprofitable. What is even scarier is the impact on human health with the increased leaching of salts through the sandy soils into the ground water.

Photograph 1. Spraying agrochemicals in Nawakkaduwa

Investigations to assess water quality

The most damaging impact has been to the fresh water lens that has got contaminated by the leaching of salts. This subject has been studied in the Jaffna Peninsula in 1986 (S. Nagarajah, B.N. Emerson, V. Abeykoon and S. Yogalingam, 1986) and in Kalpitiya from 1988 to 1992, both studies confirming that farm and domestic wells were contaminated with nitrate pollution from the continuous and liberal use of organic manures and inorganic fertilisers (Adrian Lawrence, A.M. Mubarak, Prof. Kuruppuarachi,1992). The transport and behaviour of Carbofuran, a well known pesticide in the aquifer was also monitored and it was found that the pesticide leached into the ground water table and was broken down into a less toxic compound that remained in the ground water.

Implications to human health

The implications of contamination to the ground water supply on human health have also been assessed. Some of the grave effects of high nitrate intake on human health are the incidence of Methaemoglobinaemia and gastro intestinal cancers. Methaemoglobinaemia describes the condition wherein the oxygen carrying capacity of the blood is reduced. It is a condition mostly restricted to babies and very young children and is often referred to as the blue baby syndrome. Nitrates and nitrites are also reduced to N-nitroso compounds that are known carcinogens in rodents. A research study conducted by the University of Ruhuna on the nutritional and physiological effects of nitrates in drinking water in Kalpitiya showed that 64% of the infants suffered from malnutrition and potential Methaemoglobinaemia. In addition, the lack of proper sanitation was evident since the faecal samples contained high levels of bacteria, viral, protozoan pathogens and helminthes (University of Ruhuna, 1995) The preliminary survey conducted by NSRC to assess the socio economic status of the beneficiaries in Nawakkaduwa revealed that out of 109 families interviewed, 20 families had experienced still births, which meant that nearly 19% of the population was directly affected! (NSRC, 2003)

The restoration effort

In 2001, the National Water Supply and Drainage Board (NWSDB) began the construction of several wells to supply and distribute potable water. However, after testing the water from those wells, it was found that more than 50% of the wells were contaminated and unfit for human consumption. The water had a high content of nitrate, nitrite, chloride and potassium. In 2003, the NWSDB awarded the Neo Synthesis Research Centre the contract to conduct research on possible ways to mitigate the problem of nitrate and nitrite contamination in drinking water.

The drinking water well that is located in Nawakkaduwa village was the worst affected. Hence, initial discussions were held with villagers who were the potential beneficiaries of the well water. They agreed that their present management of the land was causing the contamination of the well, but stated that they knew of no other alternative to the agricultural practices that they presently engaged in. They stated that if they saw a viable alternative land management practice on the ground, they would adopt it.

Objectives

Therefore, the main thrust of our work involved:

a) The establishment of a demonstration model in bioremediation around the well on which the drinking water well was located. The landscape design adopted would be tree dominant and include the cultivation of annual crops using only organic regimes.
b) The assessment of the costs and benefits accrued from the practice of conventional agriculture as practiced by farmers in Kalpitiya with a view to compare it with organic agriculture.
c) The efficacy of the experiment in bioremediation be assessed by periodically investigating the levels of the contaminants in the water in the model well, the piesometers around the model well and in the two wells located on either side of the model well, namely that of Chooti and that referred to as the sea well.

Rationale

Tree dominated vegetation or forest vegetation is being lost at a rapid rate and the pressure on land for agriculture is one of the primary causes of forest destruction.

Natural forests are integral for environmental stability since they, at all stages, fix and cycle energy or carbon, regulate hydraulic flows and conserve nutrients (Senanayake, F.R. and Jack, John 1998). In addition, forests provide man with food, fuel wood, medicine, fiber, fodder and timber. Forests provide habitat for biodiversity and are fundamental to life. Forests or tree dominant vegetation, we are also finding out, play an important role in the bioremediation of water.

Dietz and Schnoor (2001) state that "one of the most promising frontiers of environmental research is bioremediation; the use of natural means to breakdown or degrade hazardous substances into less toxic compounds and thus repair environmental damage. Underneath the broad umbrella of bioremediation there are two main categories: microbial remediation and phytoremediation.

Microbial remediation, the use of fungi or bacteria to break down pollutants, is a proven method for environmental remediation. For microbial remediation to be successful there must be a nutrient source, and the conditions must also be chemically hospitable for the organisms to thrive.

Phytoremediation, or the use of plants to repair and restore damaged sites, is a relatively new technique that promises to be sustainable, low maintenance, and versatile.

Current remediation strategies, including phytoremediation, can be separated into two categories: containment and removal. One simple solution for preventing underground pollution from spreading is to plant trees above and around the contaminated area. Trees can move great quantities of water from their roots up into the atmosphere through the process of transpiration. This effect is so great that it can locally affect underground water flow. So if trees are planted around the area of an underground contamination source, the constant pull on the water upwards by the trees will prevent the pollutant from spreading away from the site."

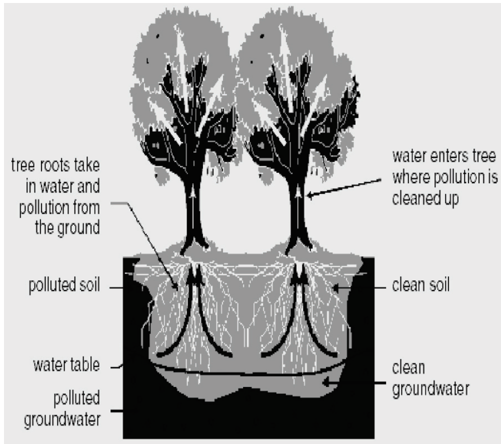

Figure 2. Adapted from "A Citizen's Guide to Phytoremediation"

The US Environmental Protection Agency published a "Citizen's Guide to Phytoremediation" in 2001 which states the following: "Phytoremediation uses plants to clean up pollution in the environment. Plants can help clean up many kinds of pollution including metals, pesticides, explosives, and oil. The plants also help prevent wind, rain, and groundwater from carrying pollution away from sites to other areas.

Phytoremediation works best at sites with low to medium amounts of pollution. Plants remove harmful chemicals from the ground when their roots take in water and nutrients from polluted soil, streams, and groundwater. Plants can clean up chemicals as deep as their roots can grow. Tree roots grow deeper than smaller plants, so they are used to reach pollution deeper in the ground.

Once inside the plant, chemicals can be:

- stored in the roots, stems, or leaves
- changed into less harmful chemicals within the plant
- changed into gases that are released into the air as the plant transpires (breathes).

Plants grown for phytoremediation also can help keep harmful chemicals from moving from a polluted site to other areas. The plants limit the amount of chemicals that can be carried away by the wind or by rain that soaks into the soil or flows off the site."

The time it takes to clean up a site using phytoremediation depends on several factors:

- type and number of plants being used
- type and amounts of harmful chemicals present
- size and depth of the polluted area
- type of soil and conditions present

According to Schnoor (Schnoor, P.E., DEE, 1997) phytoremediation is best applied at sites with shallow contamination of organic, nutrient, or metal pollutants that are amenable to one of five applications: Phytotransformation, Rhizosphere Bioremediation, Phytostabilization, Phytoextraction, or Rhizofiltration

Of the applications described, Phytotransformation and Rhizosphere Bioremediation are focused on here.

PHYTOTRANSFORMATION refers to the uptake of organic and nutrient contaminants from soil and groundwater and the subsequent transformation by plants. Phytotransformation depends on the direct uptake of contaminants from soil water and the accumulation of metabolites in plant tissue. Potential applications include phytotransformation of petrochemical sites and storage areas, ammunition wastes, fuel spills, chlorinated solvents, landfill leachates (including biochemical oxygen demand (BOD) and chemical oxygen demand (COD), and agricultural chemicals (pesticides and fertilizers).

The direct uptake of chemical into the plant through roots depends on the uptake efficiency, transpiration rate, and the concentration of chemical in soil water (Burken and Schnoor, 1996). Uptake efficiency, in turn, depends on physical-chemical properties, chemical speciation, and the plant itself. Transpiration is a key variable that determines the rate of chemical uptake for a given phytoremediation design; it depends on the plant type, leaf area, nutrients, soil moisture, temperature, wind conditions, and relative humidity.

Further, "When selected plants are grown in a contaminated substrate, the root system of those plants function as a highly dispersed, fibrous uptake system to form giant underground networks that function as solar-driven pumps that extract and concentrate essential elements and compounds from soil and water. Absorbed substances are used to support reproductive function and carbon fixation within shoots." (Burken and Schnoor, 1996 et.al)

The Tree Remediation Process (Argonne National Laboratory, 1999) describes the application of engineered agronomic processes to environmental remediation problems of soil and water.

With the proper coaxing, trees can effectively root into aquifers at least 20 feet deep. Once established (1-2 years) these root systems can begin pumping water at a rate of 1 to 2 million gallons per two hundred trees per acre per year, creating a significant pumping regime for a given area. Therefore, by planting trees in close proximity over a contaminated aquifer, or as a border around a site, a barrier to the movement of contaminated ground water can be effected.

In 1988 in Oconee, Illinois, U.S.A. an experiment in tree mediation was conducted in soil and ground water that was contaminated with nitrates, ammonium and pesticides. The depth of the ground water table was 6-10 feet.

The objective was the prevention of off-site migration of contaminant plume and soil clean up.

After collection and assessment of baseline data on soil and ground water, a phytoremediation program was established using selected trees and grasses. The results were dramatic; soil pesticide levels fell in the three years following the implementation of the phytoremediation program in 1988. The growth of the trees at a rate of between 6 and 8 feet per year resulted in a steady decline in nitrogen and pesticide levels in the ground water.

Once an organic chemical is translocated, the plant may store the chemical and its fragments into new plant structures via lignification (covalent bonding of chemical or its fragments into lignin of the plant); or it can volatilize, metabolize, or mineralize the chemical completely to carbon dioxide and water. The addition of plant root systems creates an ecology in soils that is suitable for bioremediation.

While trees are known to have the ability to affect the nutrient status and the pH of the soil that they grow in (Dunham, 1991), trees have also been seen to demonstrate the capability of accumulating various elements like Be, Co, Zn, Cd, Sn, Pb, Mn, Ni, Ce, As, Ag and Au in their leaves and in the humus layer under the tree (Remezov Pogrebnyak, 1969) In addition, most plants assimilate nitrogen from the soil water in the form of nitrates and ammonium compounds for growth (Taylor, D.J., Green, N.P.O., and Stout, G.W., 1997).. The form of nitrogen taken up by the plants has a strong influence on soil pH. Plants dominantly taking up nitrate (using the enzyme nitrate reductase) will release bicarbonate and/or hydroxyl ions to maintain an internal charge balance, thereby raising the soil pH. Plants mainly taking up ammonium will release protons to maintain their charge balance, and this will lead to soil acidification (Ken Killham, 1994)

Rhizosphere bioremediation

Phytoremediation of the rhizosphere increases soil organic carbon, bacteria, and mycorrhizal fungi, all factors that encourage degradation of organic chemicals in soil. Rhizosphere bioremediation is also known as phytostimulation or plant-assisted bioremediation. Jordahl (1997) showed that the numbers of beneficial bacteria increased in the root zone of hybrid poplar trees relative to an unplanted reference site. Denitrifiers, Pseudomonas spp., BTEX degrading organisms, and general heterotrophs were enhanced. Also, plants may release exudates to the soil environment that help to stimulate the degradation of organic chemicals by inducing enzyme systems of existing bacterial populations, stimulating growth of new species that are able to degrade the wastes, and/or increasing soluble substrate concentrations for all microorganisms.

Description of the work done

a). Establishment of the demonstration model

The landscape of the demonstration model would be restored primarily using the silvicultural technique of Analog forestry (Falls Brook Centre, 1997).

Analog forestry seeks to establish a tree dominant ecosystem that is analogous or similar in architectural structure and ecological function to the original climax or sub climax vegetation community or natural forest. The forest community so formed will also be analogous in terms of whole forest products and services, such as the production of clean water, environmental stability or biodiversity conservation.

The closest natural forest would thus provide the model for us to base our restoration strategies on since it is the best example of a mature ecosystem in the area.

Hence, we visited the forest patch in Daluwa in order to identify the ecological functions the forest performed, the architectural structure, floristic species composition in terms of height and growth categories seen in the forest and the surface biodiversity recorded. In addition we looked at the forest soil and soil macro fauna.

The mapping of the vegetation of the forest was undertaken using the notation developed by Kuchler and Zonneveld and later modified by Senanayake (F. Ranil Senanayake, 1989).

Landscape design of restoration model

The data gathered provided the basis for the establishment of an analog forest on the land located in the village of Nawakkaduwa. The design of the landscape used native and exotic species, offering both ecological and utility benefits to the land owner. The adoption of this technology could provide the land owner with an alternative to the present land management practices he engaged in; an alternative that would generate an income, provide clean food, water and habitat for biodiversity.

The landscape design of the model well area involved three main aspects:

1. The watershed of the water source or the immediate area around the well is referred to as the buffer zone, where several deep rooted, mostly native trees that had long and short growth cycles, were planted in a dense manner so as to form a 'root mat' below the surface. The main objective was to facilitate the uptake of the contaminants by the roots of the trees.
   Some of the species used were Kumbuk (Terminalia arjuna), Mee (Madhuca longifolia), Palu (Manilkara hexandra), Thimbiri (Diospyros malabarica), Halmilla (Berrya cordifolia), Wetakeiiya (Pandanus kaiida), Karanda (Pongamia pinnata), Surya (Thespepsea populnea), Murunga (Moringa oleifera).
2. The fence area of the demonstration model was developed using several species that could withstand the salt laden sea breeze and serve as wind breaks. Trees like Mudilla (Barringtonia speciosa), Kasa (Casuarina equisetifolia), Watha Bhanga (Pisonia alba), Murunga (Moringa oleifera) and Kotta (Ceiba pentandra) were planted.
3. The surrounding area was developed as a production area where both perennial and annual crops were grown using organic cultivation regimes. Many fruit plants like Papaya, Banana, Mango, Guava, Pomegranate, Sapodilla, Anona, Lime, Lemon, Mandarin, Orange, Avocado, Jak, Grape, Passion, and new varieties like Acerola were planted. Further, plants that had medicinal value like Nelli (Phyllanthus embelicus), Bulu (Terminalia bellerica) and shrubs like Katukarosana (Picrorhiza kurrooa), Tippili (Piper longum) and Aloe (Aloe vera) were promoted.
   While farmers in the Kalpitiya Peninsula only cultivate annual crops like chillies, onions, tobacco, and melons, several varieties of vegetables were grown successfully in the experimental plot that included Snake gourd, Bitter Gourd, Ridge gourd, Amaranthus sp., Maize, Spinach, Ladies Fingers, Cucumber, Pumpkin, Long Bean, Tomato, Spring Onions, Winged Bean, and several varieties of chillies.

Photograph 2. Planting around the model well

Photograph 3. Production area in demonstration model

Several green manures were propagated, and formed the basis of the compost produced using other raw materials like cow/ goat dung as well as minerals like rock phosphate.

Further, the sandy soil was periodically treated with a special soil mix containing several carbon rich inputs like Coconut peat and straw. In 2004, 67 000 Kg of carbon rich inputs were added to the soil.

One of the reasons for adding carbon, in excess, was to facilitate humification and provide habitat for the soil meso fauna that are brought in with the addition of cow and goat dung. The addition of carbon is also intended to provide ideal conditions for 'denitrification' which subject has already been described earlier on in this article.

Biological pesticides and liquid fertilizers were used to control attacks from pests and diseases.

b). A study to assess the efficacy of conventional agriculture

The economics of conventional agriculture with specific regard to the quantum of water used in cultivation is also an important area for study. Surveys carried out on the 3 most dominant crops namely, chillies, red onions and tobacco in the past year have revealed that the greatest expenditure farmers in Kalpitiya incur is related to watering their crops. They need to water their fields twice a day since there is no moisture retained in the sandy soil that is bereft of mulch. The average water use is almost 75,000 L per acre per day as opposed to 12,600 L used to water our one acre demonstration model that is watered only once a day and has a thick sheet of mulch (NSRC 2004, et. al.)

c). Investigation of the water

Investigation on water quality commenced from January, 2004.

Hypothesis: The vegetation established around the model well would uptake the nitrates and nitrites and thus reduce the contaminants in the water.

Methodology: 8 piesometers were established in the root mat created by the vegetation around the model well.

1. Baseline tests were conducted on the water from the model well to determine:

- Physical properties (colour, odour, taste, turbidity, total Solid at 103-1050, Oil and Grease).
- Chemical properties (pH at 250 °C, Electrical Conductivity at 250C, Total Alkalinity (as CaCO3), Total Hardness (as CaCO3), Chloride (as Cl), Total Residual Chlorine (as Cl2), Free Ammonia (as NH3), Albuminoid Ammonia (as NH3), Nitrate (as N), Nitrite (As N), Fluoride (as F) at 250 °C, Total Phosphate (as PO4), Total Iron (as Fe), Sulphate (as SO4), Phenolic Compound (as phenolic OH), Calcium (as Ca), Magnesium (as Mg), Copper (as Cu), Manganese (as Mn), Zinc (as Zn), Aluminium (as Al), Arsenic (as As), Cadmium (as Cd), Cyanide (as CN), Lead (as Pb), Mercury (as Hg), Selenium (as Se), Chromium (as Cr).
- Micro Biology (Total Coliform count and E.coli).

  These tests were carried out at the Laboratory of the National Water Supply and Drainage Board, Getambe.

2. Monthly tests were carried out on water in the 8 piesometers established around the well, the model well and from the two wells located on either side of the model well, namely that of Chooti and the sea well. The tests are carried out to determine the standard physical and chemical properties were potable water and include the following:

   Physical properties: colour, odour, taste & turbidity

   Chemical properties: pH at 250 °C, Electrical Conductivity at 250 °C, Total Alkalinity (as CaCO3), Total Hardness (as CaCo3), Chloride (as Cl), Free Ammonia (as NH3), Albuminoid Ammonia (as NH3), Nitrate (as N), Nitrite (As N) & Total Iron (as Fe).

   These tests are carried out at the Laboratory of the National Water Supply and Drainage Board, Getambe.
3. Rainfall and ambient temperature of the Kalpitiya peninsula, where data is collected from the Metrological Department.

Results

a) Establishment of the demonstration model

The native trees established around the well displayed fast growth rates. This was evident in the increase in shade conditions in the model, where the canaopy closure increased to almost 50%, over the whole area, in the three year period. The same phenomenon was seen in the growth rates recorded for the planting in the production area.

Further, the cultivation of crops hitherto not grown in the Kalpitiya peninsula like pineapple, avocado, and cinnamon revealed that the sandy soils were capable of supporting a vast diversity of crops.

The cultivation of annual crops like vegetables, using organic regimes of cultivation, was eminently successful. While some casualties were recorded, the experience of growing a vast diversity of vegetables taught that the time management of a cropping cycle taking into account localized weather and rainfall patterns could enable sustainable organic vegetable cultivation.

The growth of the surface biomass was fast and led to the rapid humification of sandy soils.

There was a dramatic increase seen both in the number of birds, butterflies and frogs as well as in the macrofauna (earthworms, pill bugs etc) in the soil.

b) A study to assess the efficacy of conventional agriculture

The compilation of the data collected has revealed that the greatest expenditure farmers, in Kalpitiya, incurred were related to watering their crops. They need to water their fields twice a day since there is no moisture retained in the sandy soil that is bereft of mulch. The average water use is almost 75,000 L per acre per day as opposed to 12,600 L used to water our one acre demonstration model that is watered only once a day and has a thick sheet of mulch (NSRC 2004, et. al.) 26

c). Investigation of the water

1. The results of the baseline tests conducted on the physi-

cal, chemical and microbiological properties of the well water revealed that:

Physical properties:

All the parameters tested were within permissible limits except for the excessive presence of oil and grease.

Chemical Properties:

The water contained high levels of nitrogen in the form of nitrate, nitrite, free ammonia and albuminoid ammonia. There was also recorded an excess of phenolic acid residue.

Microbiological properties:

The presence of both E. coli and coli form bacteria.

2. The results obtained by testing the water in the piesometers from February 2004 to February 2005 show that a significant decrease in the levels of nitrates. The concentration of nitrates (N) in the model well water in February 2004 was 58.5 mg/L; in 2005 30.8 mg/L and in 2006 27.2 mg/L. There were decreases seen in the levels of Nitrite (N), and in the parameters tested, but none as dramatic and as consistent as that seen in the levels of nitrates.
3. The rainfall in the Kalpitiya area did appear to have an impact on the physical nature and chemical concentrations of contaminants in the water. Of significance were:

   Levels of conductivity increased during the monsoon rains and declined with the cessation of the rains. The advent of rain altered the pH levels where the addition of rainwater increased pH value. The alkalinity levels were high during the drought period, and declined during the rains possibly due to dilution. The turbidity levels of the well water increased with the addition of rainfall and decreased during the drought.

Box 1. Nitrate levels recorded over time

Graphical representations of the decreasing trend seen in nitrate levels recorded over time from February 2004 to February 2006 are presented herewith.

Figure 3a displays the nitrate levels in the 8 piesometers and the model well while the decreasing is represented in Figure 3b.

Likewise, Figure 4a shows the levels of Nitrate recorded in the Model, Sea and Chooti's wells and Figure 4b shows the trend thereof.

Discussion

Denitrification plays an important role in the bioremediation of nitrates and nitrites that have leached into the soil water and has rendered it unsuitable for human consumption. Denitrification refers to the process that occurs during the completion of the nitrogen cycle, and refers to the reduction of nitrates and nitrites to nitrogen or oxides of nitrogen through microbial activity (biological denitrification) or to the chemical reduction of nitrites and other unstable nitrogen compounds (chemical denitrification).

There is thus the possibility of two types of biological processes taking place for remediation:

1. Assimilation
2. Dissimilative denitrification

Assimilation refers to the actual uptake of nitrates by the roots of plants for protein synthesis and where the outputs of nitrogen or ammonia are released through respiration into the atmosphere.

Dissimilative denitrification requires the following conditions:

- The presence of nitrate, metabolizable carbon compounds and the complete absence of oxygen at the site of reduction. Soil organic matter, plant roots and organic manures provide the metabolizable carbon compounds.
- The concentration of oxygen is reduced to a sufficiently low level when the soil air is displaced by water, as after heavy rainfall, irrigation or flooding.
- The soil does not need to be devoid of oxygen since denitrification can occur at micro sites like soil aggregates in the rhizosphere that are water saturated areas and hence oxygen is "restricted; these conditions can then be considered as anaerobic."
- The rate of denitrification increases with temperature and is highest in a soil pH of between 6 and 8.

Box 2. The process of denitrification

The process of denitrification is a stepwise reduction:

Nitrate ($NO3$) → Nitrite ($NO2$) → X → Nitrous Oxide ($N2O$) → Nitrogen ($N2$) gas, where the intermediate X might be nitric oxide, NO, though this is not certain.

Many bacterial genera possess enzymes for each step in the reduction of nitrate to nitrogen gas. Many genera with the capability to denitrify are found in soils, but it is difficult to know which are the most active. Species of Pseudomonas and Alcaligenes have commonly been isolated and bacteria from both genera are known to denitrify. (Wild, 1996)

Trees, it is clear, play a vital role in bioremediation; be it in the uptake of contaminants or in the interaction tree roots have with microorganisms.

The decreasing trend in nitrate levels could be attributed in part, to the process of assimilation taking place in the ground water/root interface. The growth of the canopy cover of the vegetation in the area around the well is concomitant with the growth of the root mat. This was evident when project staff dug around each piesometer. The landscape design of the area around the model well consisted of a buffer zone, a production area and dense fence planting. The trees used in the buffer zone planting immediately around the well comprised of pioneer, sub climax and climax species. Hence, even though species like Timbiri (Diospyros malabarica) and Palu (Manilkara hexandra) grow slowly, other fast growing, pioneer species like Thespepsea populnea and Moringa oleifera grow rapidly to establish a canopy cover and with it the skeleton of the root mat.

The decrease in the levels of nitrate could also be attributed to the process of dissimilative denitrification taking place in the ground water/root interface. Since all the conditions required for dissimilative denitrification are met with in Nawakkaduwa, the assumption that the process was occurring is valid.

Examining the facts, the water in the well is contaminated with high levels of nitrate. Over 67,000 Kg of carbon in the form of coconut peat and straw were added to the sandy soil. The conditions that exist between the tree roots and the ground water (micro-sites) could possibly be anaerobic because of exudates (ex., tannins) given out by the roots. The conditions could alternatively be such that the bacteria performing the function of nitrate conversion use the extra electron of oxygen in the nitrate by reduction. The Kalpitya Peninsula is located in the arid zone and hence is subject to high temperatures, low rainfall and low relative humidity. The pH value of the water was also between 6 and 7. Hence with the combination of factors favorable for dissimilative denitrification in place, that probability is very high.

Conclusions and recommendations

The roles played by tree roots, soil organic matter and denitrifying bacteria are a subject worthy of further research and discussion. However, the collection of data over an extended period of time will enable the possibility of statistical testing for enhanced verification. In addition, there will be the need to monitor the movement of water and the contaminant in the various wells and piesometers when the process of mass extraction takes place. It is then that the efficacy of this technology can really be gauged. Having said that it must be remembered that the growth of the root mat vis a vis the growth of tree cover should also be taking place in synchrony with the reduction of the contaminant in the aquifer. This is our conclusion and after the third year of experimenting, it seems like more than just a distinct possibility.

The apparent success enjoyed by the Project in the first years resulted in many farmers requesting us to extend the fruits of our labor to their drinking water wells. Presently, the Project also receives support from the United Nations Development Programme to execute bioremediation processes in 40 public wells in the Kalpitiya Peninsula.

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Appendices

Box 1 Nitrate Levels recorded over time
Box 2 Dentrification
Figure 1 Map of Sri lanka showing Kalpitiya
Figure 2 Phytroremediation
Figure 3a Nitrate levels in piesometers & model well
Figure 3b Trend Graph of nitrate levels in model well & piesometers
Figure 4a Nitrate Levels in Chooti's, Model and Sea

Wells
Photograph 1 Spraying agrochemicals in Nawakkaduwa
Photograph 2 Planting around model well.
Photograph 3 Production areas in demonstration model

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