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HUMAN WASTE - A POTENTIAL RESOURCE: CONVERTING TRASH INTO TREASURE BY EMBRACING THE 5 R'S PHILOSOPHY FOR SAFE AND SUSTAINABLE WASTE MANAGEMENT

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Keywords: Culture of Consumerism; Culture of Disposables; Packaging Culture; Australians and Americans as Superconsumers and Waste Generators; Waste – A Misplaced Resource; Traditional Societies – Recycling Societies; Modern Society – Throwaway Society; Waste – Source of Greenhouse Gases; Vermiculture Movement for Efficient and Cost-effective Waste Management.

1. INTRODUCTION

Waste is being generated by the human societies since ancient times. Ironically waste was not a problem for the environment when men were primitive and uncivilized. Waste is a problem of the modern civilized society. Materials used and waste generated by the traditional societies were little and 'simple' while those by the modern human societies are large and 'complex'. With modernization in development drastic changes came in our consumer habits and life-style and in every activity like education, recreation, traveling, feeding, clothing and housing we are generating lots of wastes. The world today generate about 2.4 billion tones of solid waste every year in which the Western World alone contributes about 620 million tones / year.

Discarded products arising from all human activities (cultural and developmental) and those arising from the plants and animals, that are normally solid or semi-solid at room

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temperature are termed as solid wastes. Municipal solid waste (MSW) is a term used to represent all the garbage created by households, commercial sites (restaurants, grocery and other stores, offices and public places etc.) and institutions (educational establishments, museums etc.). This also includes wastes from small and medium sized cottage industries.

We are facing the escalating economic and environmental cost of dealing with current and future generation of mounting municipal solid wastes (MSW), specially the technological (developmental) wastes which comprise the hazardous industrial wastes, and also the health cost to the people suffering from it. Developmental wastes poses serious risk to human health and environment at every stage – from generation to transportation and use, and during treatment for safe disposal. Another serious cause of concern is the emission of greenhouse gases methane and nitrous oxides resulting from the disposal of MSW either in the landfills or from their management by composting.

Dealing with solid household waste in more sustainable ways involves changes not only to everyday personal habits, consumerist attitudes and practices, but also to the systems of waste management by local government and local industry and the retailers.

This chapter reviews the causes and consequences of escalating human waste, the increasing complexity of the waste generated, and the policies and strategies of safe waste management. It also provides 'food for thought' for future policy decisions that government of nations may have to take to 'reduce waste' and divert them from ending up in the landfills, drawing experiences from both developed nation (Australia) and a developing nation (India).

2. Cities as the Centers of Mounting Municipal Wastes

Cities have become major 'centers of consumption and waste generation' all over the world. In fact a city 'consumes' as well as 'produce'. This is called 'urban metabolism'. City use some 75 % of world resources and release a similar proportion of wastes. According to UN Population Fund Report (1990), a city with one million population consumes 2000 tones of food and 9,500 tones of fuel, generating 2000 tones of solid wastes (garbage and excreta) and 950 tones of air pollutants; consumes 6,25,00 tones of pure water and secrete 5,00,000 tones of sewage. (UNEP, 1996).

United Nation Environment Program (UNEP) worked out the urban metabolism of London city. Greater London with a population of 7 million consumed 2,400,000 tones of food; 1,200,000 tones of timber; 2,200,000 tones of paper; 2,100,000 tones of plastics; 360,000 tones of glass; 1,940,000 tones of cement; 6,000,000 tones of bricks, blocks, sand and tarmac; 1,200,000 tones of metals every year and produced 11,400,000 tones of industrial and demolition wastes; 3,900,000 tones of household, civic and commercial wastes and 7,500,000 tones of wet, digested sewage sludge. Everyday London dispose off some 6,600 tones of household wastes. (UNEP, 1996).

3. Modern Culture of Consumerism: The Root of Waste Problem

The root of waste problem is the '*culture of consumerism*' and is directly proportional to the affluency of the human societies. To this has added the '*culture of disposables*'. Large number of goods in the society are being manufactured for only 'one time use', and to be discarded as waste after use. Modern urban culture of using 'canned and bottled foods', 'frozen foods', 'take-away foods', exchange of 'greeting cards' on all occasions, using 'disposable' home equipments (spoons, cups, plates, tumblers and safety razors), medical instruments (syringes, sharps and needles), office equipments (writing pens and utilities), and plastic bags in all grocery shopping has escalated the solid waste problems.

People all over the world consume food and the 5 P's (paper, power, petrol, potable water and plastics) in their daily life without realizing the environmental consequences and costs of the waste generated in their production, distribution, and consumption. Every commodity processed from natural resources, and every consumer product, from 'shampoo to champagne' has an environmental cost and generally causes some damage to the environment, 'before use', as a source of pollution during production, and 'after use', as waste (Eklington and Hailes, 1989).

3.1. Waste Generation Is Proportional to Resource Consumption and the Way We Use Resources

Consuming resources and generating wastes are 'two sides of the same coin'. The way we use resources to maintain our 'quality' of life, assumes as much significance in waste generation as the sheer amount of resources that we use. For instance, one kilogram of steel might be used in a construction that lasts hundreds of years or in the manufacture of several cans thrown away just after a few uses. A few kilograms of PVC plastic materials might be molded into durable home and office furniture, water and sewer pipes, and remain useful for decades or might be used to manufacture plastic bags to be used just once or twice and then thrown away as enduring waste.

Packaging Culture Proliferate Waste Generation

Packaging materials have become part of our modern culture and generate huge amounts of waste. Manufacturers and retailers see packaging as a way to attract purchasers. Everything needs fine packaging today, from cornflakes to computers, from gifts to garments, from flowers to foods. Life today cannot be imagined without plastic bags, glass bottles, paper boxes, tins and cans. Plastics are versatile, convenient and light weight — good packaging material — but ultimately end up as a non-biodegradable waste in the landfills to remain intact for centuries.

On average each European Union citizen is currently responsible, directly or indirectly, for the generation of some 172 kg of 'packaging waste' every year. Packaging waste generation increased by 10 % in the EU between 1997 and 2002. Per capita consumption of plastics increased by almost 50 % from 64 kg / year in 1990 to 95 kg / year in 2002. Only UK managed to actually reduce, and Austria stabilize the generation of packaging waste since 1997. (GEO, 2006).

Plastic consumption in Australia has increased from negligible quantities in the early 1940s to enormous quantities today. Plastics made up around one-third of all rubbish collected on Clean Up Australia Day (Clean Up Australia 2004). Even though Australians reduced their use of plastic shopping bags by around one-fifth between 2002 and 2004, each person was still using almost one bag per day (EcoRecyle 2006). Australians use 6 billion plastic bags every year much of that end up in landfills. These bags form litter, infest and block waterways, kill animals.

The 'Ecological Footprint' of Global Human Population

The Measure of Resource Consumption and Waste Generation. An ecological footprint is an estimate of the average area of productive land and water required to maintain a given population's resource consumption and waste generation. (Table 1). In this instance we simply use it to indicate the comparable cost and sheer significance of waste generation. Australia with a small population of just 19.5 million, is part of the North developed world, and Australians are 'super-consumers' and 'super-waste makers'.

Table 1. Ecological Footprints of Human Population on Earth Reflecting Resource Consumption Vis-à-Vis Waste Generation (2002)

	Total Population (millions)	Total Ecological Footprint (global ha/person)	Total Energy Footprint (global ha/person)	Total Biocapacity* (global ha/person)
World	6 225.0	2.2	1.2	1.8
High income˚ countries	925.6	6.4	4.1	3.4
Middle income countries	2 989.4	1.9	0.9	2.1
Low income countries	2 279.8	0.8	0.3	0.7
Australia	19.5	7.0	4.0	11.3
United Kingdom	59.3	5.6	3.6	1.6
China	1302.3	1.6	0.7	0.8
Asia Pacific (regional)	3448.4	1.3	0.6	0.7
Canada	31.3	7.5	4.6	15.1
USA	291.0	9.7	6.3	4.7

Source: Global Footprint Network (2005).
*Biocapacity includes cropland, grazing land, forest and fishing ground.
˚High income countries includes Australia.

In developing Asian countries, consumption and waste generation is growing at an unprecedented pace and populous countries like China and India are becoming consumerist. The 'consuming class' in India is estimated at around 100 million, and in China at 200 million; traditional conservative Indians believing in modesty, simple living and saving, are gradually giving way to rich generations highly influenced by the consumerist North (UNEP, 2006). China manufactures, packages, transports, distributes nationally and for export over 60 billion pairs of disposable wood chopsticks which use up over 32 million trees, harvested unsustainably, indeed China risks being without forests within ten years.(<http://blog.bcchinese.net/bingfeng/archive/2006/01/25/51815.aspx>).

4. Waste Generated in the Rich vis-a-vis in the Poor Societies of World

The United Nations Environment Program (1992) carried out a study of per capita waste generation in the low, middle and the high-income countries and found it to be 0.5, 1.5 and 3.5 kg. per day per person respectively. The solid wastes generated in the rich affluent societies of the developed nations are exceptionally large in quantity and varied in quality (components). Of these, a considerable part is hazardous waste.

4.1. Waste Generated in the Rich Developed Countries of World

The World Watch Institute (1991), Washington, reported that 14 out of 16 members of OECD countries showed increase in generation of MSW per person between 1980 – 85. In the US, each sunset sees a new mountain of nearly 410,000 tones of garbage. (Toth, 1990). The countries of the European Community (EC) throws away an estimated 2 billion tones of solid waste each year. Only Japan and West Germany produced less waste, but after unification MSW in Germany skyrocketed. Americans, Canadians and Australians are great waste makers. They generate roughly twice as much garbage per person as West Europeans or Japanese do. In his /her lifetime an average American wear and discard 250 shirts and 115 pairs of shoes; use and discard 27,50 newspapers, 3900 weekly magazines and 225 pounds of phone directories; consume 12,000 paper grocery bags, use 28,627 aluminum cans weighing 1022 pounds, use 69,250 pounds of steel and 47,000 pounds of cement. The Scandinavian nations generate much less waste than the Americans and Europeans. (WWI, 1991; UNEP, 1996).

Table 2. Average Per Capita Municipal Solid Waste (MSW) Generated by Some Developed Nations Country Waste Generation Per Day (in Kg)

Country	Waste Generation Per Day (in Kg)
USA	1.80 – 2.60
Japan	1.38 - 2.10
France	1.10 – 1.90
Singapore	0.87 – 1.37
Germany	0.75 – 1.85
Italy	0.69 – 1.75

Source: WWI (1990):‘*State of the World’* (These are 1990 Values which must have increased).

Table 3. Urban Waste Generated in Some Developed (Rich) Countries

Urban Waste Generated in Some Developed (Rich) Countries	
Country	Annual Generation (In tones)
USA	20,00,00,000

Table 3 – Continued

Canada	1,26,00,000
Australia	1,00,00,000
Spain Netherlands	89,28,000 54,00,000
Belgium Sweden	30,82,000 25,00,000
Switzerland	21,46,000
Denmark	20,46,000
Norway New Zealand	17,00,000 15,28,000
Finland	12,00,000

Source: Dorling Kindersley '*Blueprint for Green Planet'* ;London (1987).

4.2. Waste Generated in the Poor Developing Countries of World

In the low and middle income developing countries of Asia, Asia-Pacific and Africa, waste is a luxury, only produced by the wealthy minority which of course is increasing with the growing economy and the exploding population. What is most concerning is that the waste is not regularly collected by the municipal authorities and often becomes a horrible site of piled and rotting waste on street corners with stray animals (dogs, pigs and cows) feeding on the scraps. Domestic waste heaps often becomes sites of defacation and discharge of human excreta and illegal dumping of hazardous wastes by scrupulous industries with potential health threats. Municipal waste services often swallow between a fifth and a half of city budgets, yet much solid waste is not removed. Even if municipal budgets are adequate for collection, safe disposal of collected wastes often remains a problem. (Holmes, 1984).

Another ugly feature in these countries are that waste is often picked up by poor people called 'rag-pickers' for whom waste reuse and recycling is a way of life, and many poor societies survive here by scouring the garbage of the rich for valuable scraps. They collect recyclable wastes (mainly papers, plastics, glasses and metals) from the street corners and even the dumpsites and sell them to the recycling industries to earn for their livelihood.

Table 4. Average Per Capita Municipal Solid Waste (MSW) Generated by Some Developing (Poor) Nations Country Waste Generation Per Day (in Kg)

Country	Waste Generation Per Day (in Kg)
Pakistan	0.25 – 0.60
Indonesia	0.33 – 0.55
India	0.15 – 0.51
Nigeria	0.16 – 0.46

Source:WWI (1990);*'State of the World'* (These are 1990 Values which must have increased).

4.3. Typical Waste Components in the MSW Generated in Both Rich Developed and Poor Developing and Underdeveloped Nations

Several waste components have been identified in the municipal solid waste (MSW) of both the rich and poor societies of world. It ranged from twelve (12) to fourteen (14) and a considerable portion of this waste is 'Organic' while others are 'Inorganic.' Ironically, there is relatively high amount of food waste in poor developing and underdeveloped nations as compared to the rich developed nations. In contrast, there is high amount of paper and garden wastes in rich nations and low in poor nations. However, very little (or none) food waste finally reach the waste dump-sites in poor nations as they are scoured and scavenged by stray animals – pigs, dogs and cattle and even by the poor street beggars. Paper, cardboard, plastics, leather, wood and metals also do not reach the dump-sites and are picked up by 'rag-pickers'. (WHO, 1976).

Table 5. Solid Waste Components in MSW of Low, Middle and High Income Countries (In % age)

Waste Components	Low-Income	Middle-Income	High-Income
Organic			
Food Waste	40 – 85	20 – 65	6 – 30
Paper	1 – 10	8 – 30	20 – 40
Cardboard	-	-	5 – 15
Plastics	1 – 5	2 – 6	2 – 8
Textiles	1 – 5	2 – 10	2 – 6
Rubber	1 – 5	1 – 4	0 – 2
Leather	-	-	0 – 2
Garden Wastes	1 – 5	1 – 10	10 – 20
Wood	-	-	1 – 4
Inorganic Glass	1 – 10	1 – 10	4 – 12
Tin cans	-	-	2 – 8
Aluminum	1 – 5	1 – 5	0 – 1
Other Metals	-	-	1 – 4
Dirt, Ash etc.	1 – 40	1 – 30	0 – 10

Source: Tchobanoglous et, al., 'Integrated Solid Waste Management'; McGraw-Hill (1995).
Low Income = Underdeveloped African, Asian and Pacific Nations;
Middle Income = Developing Asian, African, Pacific and South American Nations.
High Income = Developed European and North American Nations and Australia.

Table 6. Typical Solid Waste Components in the MSW of an European Society Waste Components Percentage (%)

Waste Components	Percentage (%)	
	Germany	Switzerland
1. Paper and paper products	19.9	26.6
2. Metals	8.7	
3. Glass	11.6	5.6
4. Plastics	6.1	11.5

Table 6 – Continued

5. Textiles	1.5	2.8
6. Minerals	2.9	1.1
7. Wood, leather, bones, rubber	2.3	3.1
8. Compounded materials	0.8	0.7
9. Sieving fractions (0-12 mm)	8.6	9.2
10. Sieving fractions (12-50 mm)	15.6	8.1
11. Residue	26.8	27.1
12. Total unidentified fraction	51.0	44.4

Source: Tchobanoglous et, al., '*Integrated Solid Waste Management*'; McGraw-Hill (1995).

Table 7. Typical Solid Waste Components in the MSW in U.S. Society (in % age)

Organic		Inorganic	
1 Food Waste	9.0	10. Glass	8.0
2. Paper	34.0	11. Tin cans	6.0
3. Cardboard	6.0	12. Aluminum	0.5
4. Plastics	7.0	13. Other Metal	3.0
5. Textiles	2.0	14. Dirt, Ash etc.	3.0
6. Rubber	0.5		
7. Leather	0.5		
8. Yard waste	8.5	Total = 100.00	

Source: Tchobanoglous et, al., '*Integrated Solid Waste Management*'; McGraw-Hill (1995)

5. Changing Character of the MSW in Modern Society: Increasing Amounts of Toxic Materials

The character and composition of the municipal solid wastes (MSW) are changing in the modern human society. Significant changes have occurred in the composition of municipal solid waste (MSW) ever since the technological revolution of the 20th century. They are no longer only 'organic' waste, as it used to be in the earlier societies. The technological development which mainly influenced the character of the MSW was the fossil fuel driven 'industrial revolution' and the agro-chemicals driven 'green revolution'. Waste components that have an important influence on the composition of the MSW are food waste, paper and plastic wastes, the white goods and the hospital wastes. What is the matter of more serious concern is that all 'living organisms' including the human beings have become exposed to chemicals for which there has been no evolutionary adaptation and experience. The chemicals in the hazardous wastes mixed up with the MSW are completely 'foreign' to living organism. (Sinha and Sinha, 2000).

5.1. Changing Quality and Quantity of Food Wastes in the MSW

The quantity and quality of residential food waste has changed significantly over the years as a result of technical advances in food growing (use of agro-chemicals) and food processing and packaging (use of chemical preservatives), and public attitudes towards food procurement i.e. relying more on processed and packed takeaway foods rather than cooking food at home from raw materials. However, due to education and awareness about the nutritive values of home cooked food, now people are moving back again towards home cooking.

Two technological developments that have had a significant effect on generation of food waste are the development of the 'food processing and packaging industries' and the 'use of kitchen food waste grinders' in modern homes. Because of kitchen grinders the grinded food wastes are delivered directly into the sewer systems rather than being disposed as MSW. In these modern homes, the percentage of food wastes, by weight, has decreased from about 14 % in the early 1960s to about 9 % in 1992. In the packed and takeaway food culture, the generation of food wastes in homes have reduced, but it has increased significantly in the food processing industries and the food outlets. In homes, and the food outlets there are more paper and plastic wastes due to over-packaging of processed foods, than food wastes itself.

5.2. Proliferating Plastic Wastes in the MSW

Percentage of plastics in MSW has also increased tremendously during the last 50 years. The use of plastic has increased from almost non-measurable quantities in the 1940s to between 7 - 8 %, by weight, in 1992. It is anticipated that the use of plastics will continue to increase, but at a slower rate than during the past 25 years. (UNEP, 1996).

5.3. Escalating Electronics Waste in MSW : Heading for E-waste 'Tsunami'?

Electronic waste is a growing concern as technology changes and new generations of electronic products and equipments more sophisticated, improved and upgraded versions continue to invade the market and the minds of consumer's. The unfortunate part is that the price of the new models and upgraded versions is continuously falling giving more temptation to the consumers for discarding the old ones and replacing with the new.

The UNEP working group on Sustainable Product Design described the e-waste essentially as a chemical waste. Electronics industry uses several hazardous chemicals including toxic heavy metals (lead, cadmium, mercury, chromium, barium etc.), acids and plastics, chlorinated and brominated compounds in production process. Developers of electronic products are introducing chemicals on a scale which is totally incompatible with the scant knowledge of their environmental or biological characteristics. (O, Rourke, 2004). More than 2 million tons of e-waste ends up in landfills every year and there is serious threat of leaching lead (Pb) and other heavy metals that may seep into groundwater supplies. Incineration results into emission of dangerous dioxins and furans as e-waste contain considerable amounts of plastics, brominated and chlorinated compounds. (Sinha, et. al., 2006).

Recent study indicate that e-waste make up approximately 1 % of the MSW waste stream in all developed nations and mercury (Hg) from the e-waste has been cited as the main source of this heavy metal in the general MSW. E-waste in MSW is creating serious health and environmental problems for the MSW landfills and the waste workers, and for the MSW incinerators. In Europe the e-waste is growing at three times the rate of other MSW and mixing with it. 'USA today is virtually sitting on a mountain of obsolete PCs'. A report produced by the Silicon Valley Toxics Coalition (a grassroots coalition that performs research and advocacy on health and environmental issues related to electronics industries in the U.S.) in 2001 suggest that if all the consumers decided to throw out their obsolete computer at the same time, the country would face a 'tsunami' of e-waste scraps between 2006 and 2015. The report called 'Poison PCs and Toxic TVs' was released by another grassroots organization California Against Waste (CAW). (Anonymous, 1999).

Developing Countries as the Electronic Junkyards of U.S. and Industrialized Nations : An Untenable Choice Between Poverty and Poison

There are reports about Asia, mainly India, China, Taiwan, Vietnam, Singapore and Pakistan, being made as the high-tech dumping ground of U.S. An estimated 20 million computers become obsolete each year in the U.S. and an estimated 200 tons of these computers end up in these countries in the name of 'reuse' and 'recycling'. Low labor cost and weak environmental regulations have made these countries dumping grounds of e-waste destined for recycling and final disposal in landfills. A pilot program that collected electronic scrap in San Jose, California estimated that it was10 times cheaper to ship CRT monitors to China than it was to recycle them in the U.S. It is still legal in the U.S., despite international law (The Basel Convention, 1989) to the contrary, to allow export of hazardous waste without controls. (It may be recalled that U.S. has not yet signed the Basel Convention (1989) which prohibits trans-boundary movement of hazardous wastes). Industry insiders indicate that about 80 % of the e-waste goes to Asia and of that 90 % ends up in China. (Puckett et. al, 2002)

A report by Basel Action Network and the Silicon Valley Toxics Coalition '*Exporting Harm: The Techno-Trashing of Asia*' asserts that 50 to 80 % of e-waste collected for recycling in the U.S. is exported to developing nations. BAN produced a film on the report which shows the Guiyu village in Guangdong province in China as 'electronics junkyard'. Some 100,000 men, women and children make US $1.50 a day dismantling e-waste by bare hands to retrieve the valuable metals and materials. Circuit boards are melted over coal grills to release valuable metals giving highly toxic dioxin fumes. Riverbank acid baths are used to extract gold. Lead-containing cathode ray tubes from monitors and televisions are not of much market value and hence are dumped in some wastelands. Toner cartridges are pulled apart manually, sending clouds of toner dust into the air. Soil and drinking water at Guiyu are contaminated by lead much above WHO limits- soil by 200 times and water by 2,400 times. Water has to be trucked from 30 km away. At one point of time both China and India were willing to take the e-waste for almost free. For poor countries of the world it is an untenable choice between 'poverty and poison'. (Puckett et. al, 2002)

In November, 2002 officials from eight Asian nations met in Tianjin, China, under the auspices of Basel Convention (1989) to prevent their nations from being made the dumping grounds of hazardous e-waste in the name of free trade (export and import) for recycling discarded electronic products. It was represented by India, Malaysia, the Philippines, Singapore, Sri Lanka, Thailand, and Vietnam. Resource persons came from Canada, Japan, the U.S. and the Secretariat of the Basel Convention. Financial support was provided by Australia, Japan and Canada. China has now banned and India also follows. (Sinha, et. al., 2006).

5.4. The White Goods and Bulky Items in MSW

There are 'bulky items' which include large worn-out or broken household, commercial or industrials goods such as furniture, lamps, bookcase, filing cabinets, etc. There are 'consumer electronics' wastes which include worn-out, broken, and no longer wanted items like stereos, radios, computer and television sets. There are 'white goods' as waste which include worn-out and broken household, commercial and industrial appliances like stoves, refrigerators, dishwashers, cloth washers and driers. The rejected auto-parts like tires, batteries and accessories also constitute important constituents of MSW. About 230 to 240 million rubber tires are disposed off annually in landfills or in tire stockpiles. (UNEP, 1996).

5.5. The Biomedical Wastes in MSW

The biomedical waste from hospital and clinics and slaughterhouses contain about 85 % as general refuse, but 10 % is hazardous wastes contaminated with infectious pathological agents, and 5 % is non-infectious but potentially toxic (chemicals) and radioactive and hence hazardous. Dressing and swabs contaminated with blood and body fluids; syringes, needles and sharps; surgically removed placenta, tissues, tumors, organs or limbs are potentially infected wastes from hospitals. There are several 'disposable' items made of PVC and thermocol now being used in medical organizations. Hospital wastes are of special category and require special care for final disposal. WHO has provided strict guidelines for their safe disposal. (WHO, 1976).

6. THE COMPLEX SYNTHETIC WASTES INVADING HUMAN ENVIRONMENT

Human ingenuity has created some 'new and synthetic materials' in the wake of technological revolution. They contain both organic and inorganic chemicals and resins and creates more 'complex' type of waste after being discarded. Nature do not possess any organism and mechanism to biodegrade them.

The processing of some new materials discovered by technology such as '*semiconductors*', '*optical fibers*', new class of '*ceramics*', and '*composites*' requires the use of large amount of toxic chemicals which eventually ends up as hazardous wastes in the MSW. These technological wastes are often toxic and are posing danger not only for the environment, but also for the human health. It has already caused several accidents, deaths and disabilities among the municipal waste workers.

6.1. The Non-Biodegradable Wastes: Potential to Remain Long in Human Ecosystem

The synthetic wastes are 'non-biodegradable' because they cannot be decomposed and can remain in the human ecosystem for years and decades polluting the environment. Common examples are all forms of plastics, x-ray films, celluloid films, cells and batteries, several chemicals and all synthetics.

What nature cannot do, human beings are trying to do through the knowledge of environmental biotechnology. Genetically tailored bacteria are being created which would possess the necessary enzymes to degrade the synthetic wastes. Some strains of bacteria and fungi have been identified in nature too, which has the arsenal to degrade some of the complex organic chemicals. Efforts are also being made to create 'biodegradable synthetics' using 'starch' as the raw material. They can be degraded in 4-6 weeks. (Sinha and Sinha, 2007).

6.2. The Hazardous Wastes : Permeating the Human Society

Wastes containing toxic chemicals, radioactive substances and infectious materials which poses potential risk to human health and environment are categorized as 'hazardous wastes'.

Toxicity, radioactivity, flammability, chemical reactivity, corrosivity, non-biodegradability, carcinogenicity, mutagenicity, infectiousness, oxidizing and leachating are some of the characteristics of hazardous wastes. (WHO, 1983).

Many primary and manufacturing industries using toxic chemicals generate hazardous waste (solid or liquid) in the production process. They can be referred as 'industrial hazardous wastes' (IHW). Many of our favorite cultural activities depend on products the manufacture of which creates industrial hazardous waste. Glaring examples are 'glass and metal', 'paper and plastic', 'leather and textile', 'painting and dyeing', 'printing and publication' and 'photography and dry cleanings'. Consumer industries today use a variety of chemicals to produce 'consumer goods' a number of which are now 'disposables'. When these items are consumed and discarded by society, they eventually end up as hazardous wastes in our homes. This can be referred as 'household hazardous waste' (HHW). Prime examples are torch dry-cells and batteries, pesticides / disinfectant cans and bottles, fluorescent tubes and electric bulbs, detergents and shampoos, lead-acid car batteries, auto tires and waste oils, and the expired medicines.

As we enjoy the benefits of consumer goods (furniture and fixtures, white goods, electrical and electronic goods, automobiles, processed and packed food and drinks etc.) produced by consumer industries, we also generate considerable amount of hazardous wastes as by-products when we discard them after use or change the 'old' version with 'new'. They can be referred as 'consumer hazardous waste' (CHW). Industries producing products that sustain our modern life-style and living habits generate tremendous amount of hazardous wastes. Glaring examples are the 'agro-chemical industries' (to boost our food production) and the 'petroleum industries' (which drives our automobiles). (Raghupati, 1994; Sinha and Herat, 2004).

Household Hazardous Wastes (HHW) : The Poison in Our Homes

Household hazardous wastes are either solids, semi-solids, or liquids. In addition trace chemical compounds can exist as a solute within a liquid solvent, as a gas adsorbed onto a solid, or as a component of the gaseous emissions from MSW.

Plastics contain organochlorine compounds, organic solvents in PVC; paints contain heavy metals, pigments, solvents and organic residues; home pesticides contain organochlorine and organophosphates compounds; oil and gasoline contain phenols and organic compounds, heavy metals, salt acids, ammonia and caustics; textiles may have metal dyes and organochlorine compounds; carpets can contain chemical stain resisters, pesticides, solvent-heavy glues, VOCs laden underlayer; curtain treated with stain resisters and backing can give off VOCs; dry-cleaned clothes give off VOCs; chip board and plywood furniture releases formaldehyde; fibre-glass based insulation of ceiling cavity gives off VOCs; window sealants give off toxic fumes; bathroom air fresheners release VOCs; and the carcinogenic benzene can be formed in the garage from the car exhaust. Virtually all of the mercury in MSW is due to the disposal of household dry cell batteries (mercury, alkaline, and carbon-zinc types). A smaller amount of mercury may come from the disposal of broken home thermometers. (Sinha, et. al., 2005 a)

Several toxic chemicals are commonly used today in modern homes that also results into generation of HHW. They are usually mixed and disposed with the MSW. Some glaring examples of toxic chemicals used in modern homes that contributes in the generation of household hazardous wastes (HHW) are-

1) Perfumes and cosmetics used by the women contain some 884 ‘neurotoxic’ chemical compounds. (*Report of National Institute of Occupational Safety and Health in the US*).
2) Paper whitener is toxic. The chemical used in it has potential to kill.
3) Cadmium is present in food processing equipment, kitchenware enamels, pottery glazes and plastics and relatively high levels in the sea foods.
4) Lead is present in paints and dyes, toys and newspapers, solder and batteries, lead water pipe;
5) The highly toxic polychlorinated biphenyls (PCBs) are added to paints, copying and printing paper inks, adhesive and plastics to improve their flexibility. Fish food contain generally higher levels of PCB’s. High levels of PCB’s were reported from the breakfast cereals in Sweden and Mexico as a result of contamination by ‘packaging materials’.
6) Containers of paints and enamels used in homes and in automobiles. They contain dangerous chemicals like glycol, ether, ammonia, benzene and formaldehyde and continue to give out toxic fumes at least for 7 years.
7) Containers of pesticides, insecticides, herbicides and fungicides are available in modern homes to eradicate pests and insects in garden plants, cockroaches and spiders in kitchens and storerooms.
8) Many relatively innocuous items, such as plastics, glossy magazines, and flashlight batteries used in homes, contain metallic elements.
9) Metals like cadmium (Cd), chromium (Cr), mercury (Hg), and lead (Pb) are present in several household items. After combustion with MSW metals are either emitted as

particulate matter or vaporized into air. Mercury pose a particular problem because it volatilizes at a relatively low temperature, 675 °F. (UNEP, 2004).

Very little is known about the amount of HHW generated in various countries. UNEP (2006) reported that The Netherlands generate 41,000 tonnes of HHW every year. The University of Arizona, US, made a survey and found that about 100 hazardous items (containers) are discarded per household each year. Australian study made in Melbourne in 1990-92 also found 89,576 kg of hazardous wastes from households. (CSIRO, 1996).

Mercury in the MSW from Household Wastes Has the Potential to Kill : A Case Study from U.S.

It is interesting to note that if the tons of 'household batteries' generated in California is calculated for whole of U.S., the total amount would be 160,000 tons per year. Given that a typical household battery weighs 50 grams, the corresponding number of batteries is 2,910,000,000. It is estimated that more than 2,700,000,000 battery units were purchased in the US in 1990. If half the household batteries were 'alkaline', and assuming that each battery contained about 1200 mg of mercury (Hg), then, based on the data reported above, 1923 tons of mercury (Hg) would enter the environment each year in California alone. This mercury is enough to kill 8,730,000,000 people based on a lethal dose of 200 mg per person (Tchobanoglous et. al., 1993).

Such situation exist in all metropolitan cities of world, in both developingand the developed countries. Clearly, proper disposal of these household batteries in the MSW is an important issues that must be addressed. If not collected separately, all these household batteries get mixed up with MSW and is disposed in the 'ordinary sanitary landfills' instead of the 'secured landfills'.

The Hazards of Disposable Baby Nappies in the MSW

More than 20 billion disposable baby nappies (equivalent to some 2.7 million tons of solid waste) are ending up in the landfills every year the world over. They contain hazardous chemical 'sodium polyacrylate' (a super water absorbent) responsible for several medical conditions in infants, including hampering of genital growth in male child. On an average disposable nappies occupy landfill space of 0.40 m^2 per child per year in Australia. They are 2 % by weight in total solid waste but occupy 3.5 % of total landfill space. They are also disturbing the natural microbial biodegradation processes of organic wastes in the closed landfills by absorbing all water internally. (Brahambhatt and Saeed, 2005).

6.3. The Nuclear Waste : Radioactive Substances Invading the Human Environment

Nuclear wastes are the result of our urge to generate nuclear energy without emission of greenhouse gases (which is in fact a myth as it requires 18 years of CO_2 producing fossil fuel energy (in uranium mining and enrichment, building reactors etc.) to produce one calories of nuclear generated energy. (Report of Friends of Earth, 2000). Nuclear waste are produced regardless of whether nuclear fission is controlled (such as for energy generation in reactors), or occurs explosively, as in the atom bomb. The resulting fission products, isotopes of approximately 30 elements, have mass numbers in the range of 72 to 162, are for the most parts solids, and emit beta particles, together with electromagnetic reaction (gamma rays) which are exceedingly penetrating. The chemical separation of fission products and their conversion to nuclear fuel are the most important sources of radioactive wastes. The radioactive wastes can be in all the three forms – solid, liquid and gaseous and two categories of radioactive wastes are mostly encountered- the Low Level Radioactivity Waste (LLRW) and the High Level Radioactive Wastes (HLRW). (IAEA, 1991).

Eight tons of liquid radioactive waste result per year from the typical average-size, nuclear reactor. The 'nuclear reactors' mostly generate HLRW in the form of plutonium-239 (Pu^{239}). Other two most significant fission products are strontium-90 (Sr^{90}) and cesium-137 (Cs^{137}) with half-life of 19.9 and 33 years respectively. They are routinely emitted from the reactors and continue to release radiation energy over long periods of time (several generations of the human race). Even dismantling (decommissioning) of retiring nuclear reactors produce enormous amount of radioactive wastes and contaminate vast land area. There are 439 nuclear power reactors in operation around the world mostly in France and Japan. They would all retire in years to come.

Uranium mining and processing (enrichment) produces huge amount of solid and liquid radioactive wastes which is highly hazardous. The extraction of uranium from the earth crust leaves vast quantities of wastes as 'tailings' which contain up to 80% of the original radioactivity of the extracted ore. After mining uranium is further enriched to produce 'nuclear fuel'. Depleted uranium hexafluoride (DU) is a radioactive waste by-product of enrichment. For every 1000 tones of processed uranium fuel , 100,000 tones of mined wastes as tailings and 3,500,000 liters of liquid waste is produced. They migrate into the environment through air, soil and water. Processing of uranium ores produces considerable volumes of alpha emitters, mainly radium-226. The half-life of Ra^{226} is 1600 years and gives rise to a toxic gas 'radon'. (IAEA, 1991).

7. Waste : Potential Source of Greenhouse Gases (Methane and Nitrous Oxide)

So far, not much attention was paid towards this aspect of waste generation. Marked increases in the amount of waste generated has also contributed to emission of greenhouse gases carbon dioxide, methane and nitrous oxides. A major issue of concern today is emission of greenhouse gas methane (CH_4) resulting from disposal of MSW in landfills and this may be between 45 – 60 %. This is mainly due to anaerobic degradation of the organic waste components in the landfills as oxygen becomes deficient due to compaction. Methane is 20-25 times more powerful GHG than carbon dioxide (CO_2) in absorbing the infrared solar radiation.

Studies have also indicated high emissions of nitrous oxide (N_2O) in proportion to the amount of food waste. N_2O is mainly formed under moderate oxygen (O_2) concentration. (Yaowu et. al., 2000). Molecule to molecule N_2O is 296 times more powerful GHG than carbon dioxide (CO_2). Yaowu et. al., (2000) has studied the emission of both methane and nitrous oxides from aerated food waste composting.

In fact, improved recycling of waste can significantly contribute to abatement of GHG emissions. However, convention microbial composting (biological recycling) of organic wastes also emits methane (Wang et, al., 1997) due to ‘anaerobic sites’ appearing in the inner layers of compost piles. However, it can be reduced significantly by improving ‘aeration’ in the waste biomass by periodical turning or through mechanical aerating systems. (Toms et. al., 1995). Significantly, vermicomposting of waste by waste eater earthworms decrease the proportion of ‘anaerobic to aerobic decomposition’, resulting in a significant decrease in methane (CH_4). Earthworms can play a good part in the strategy of greenhouse gas reduction and mitigation in the disposal of global organic wastes. Currently we are studying the potential of GHG emissions by various systems of biodegradation of wastes (Aerobic & Anaerobic Composting & Vermicomposting by Earthworms). (Chauhan & Valani, 2008).

8. Safe Management of Waste : A Techno-Economic Problem

Both rich developed and the poor developing nations of world have become conscious towards safe waste management in the changing situation where the human waste is no longer ‘simple and organic’ to be salvaged by nature in course of time but getting more complex and even hazardous, and threatening to remain in the human ecosystem for long time. Safe management of all waste becomes imperative for the safety and security of the society and it require the input of knowledge of diverse disciplines of material science, political science, economics, geography, sociology, demography, urban planning, public and environmental health, communication, conservation, and civil and mechanical engineering.

Waste management has been termed as ‘Cradle- to- Grave’ management i.e. from point of generation to final disposal, involving safe storage, transport and treatment- and in all these steps, the generator owes the main responsibility. The collection and disposal of waste involves huge expenditures in the development of landfills, waste collecting vehicles, precious fuel (petrol and diesel) and labour costs.

8.1. The Nature’s Technology at Work : Salavaging the Organic Wastes

The organic wastes in the MSW are ‘biodegradable’ and are decomposed in nature by diverse microorganisms – bacteria, fungi, actinomycetes and the protozoa. Among the biodegradable wastes some are ‘rapidly’ degraded while others are ‘slowly’ degraded over time. It may take time from few days to several months and years to degrade the organic wastes, but it does happen ultimately. Some organic materials in the waste decomposes rapidly (3 months to 5 years), while others slowly (up to 50 years or more). The relative ease with which an organic waste is biodegraded (decomposed) depends on the ‘genetic makeup’ of the microorganisms present and the ‘chemical makeup’ of the organic molecules (mainly carbon structure that the organisms use as a source of energy and biodegrade in the process). Carbons in sugars, lipids and proteins are easily decomposed than the carbon in lignin, while the carbon in plastics are not at all biodegraded.

The biodegradability depends to a large extent on the lignin content (present in wood fibers) of the waste. Lesser the lignin content, rapid will be the biodegradation rate of that organic material. Nature has those 'decomposer microorganisms' (mainly bacteria and fungi) in soil, air and water which perform the task. This is how the natural ecosystems on earth has been operating since life evolved. Had there been no decomposer organisms, the earth would have been full of animal and human excreta, animal carcasses and vegetable matters (leaves and twigs) and dirt, and life impossible. The biodegradable waste include all plant, animal and human products, the kitchen waste in every home and restaurants, wastes from the agriculture farm, food processing industries, slaughter houses, fish and vegetable markets, and paper and cotton wastes. All these wastes mainly contain organic matters.

The process of biodegradation (decomposition) in nature can be enhanced to several times by introducing decomposer organisms such as the earthworms or even the bacterial biomass directly into the waste biomass. This is being done these days to dispose the mounting organic wastes rapidly. The process is called 'composting' and the byproduct is NKP rich biofertilizer.

Table 8. Rapidly and Slowly Biodegradable Organic Constituents in MSW

Rapidly Biodegradable	Slowly Biodegradable
Food Waste	Textiles
Newspaper	Rubber
Office Paper	Leather
Cardboard	Yard Waste (Woody portions)
Yard Waste (Leaves and Grass Trimmings)	Wood
	Misc. Organics

Source: Tchobanoglous et, al., '*Integrated Solid Waste Management*'; McGraw-Hill (1995).

Table 9. Biodegradability of Some Organic Components in the MSW

Component	Lignin Contents (% of volatile solid)	Biodegradability (% of vs)
Food Waste	0.4	82
Newspaper	21.9	22
Office Paper	0.4	82
Cardboard	12.9	47
Yard Waste	4.1	72

Source: Tchobanoglous et, al., '*Integrated Solid Waste Management*'; McGraw-Hill (1995).

8.2. Sanitary Landfills - The Ultimate Graveyard for Wastes : An Economic and Environmental Burden

Sanitary landfills constitute the ultimate graveyard for the safe burial of all human waste in the womb of 'mother earth'. There is an enormous range of materials found in landfills. 'Today's landfill is tomorrow's time capsule,' writes Blatt (2005). Experience have shown that modern landfills although made with great engineering skills are unable to contain the toxic 'landfill gases' and the 'leachate discharge' into the environment. They are proving to be a techno-economic burden and a curse in disguise. The cost involved in landfill construction is not only up-front, but also in its monitoring and maintenance, for controlling landfill gases and the leachate collection etc., which is long term, often up to 30 to 50 years. The up-front development costs for new landfills in U.S. varied from US $ 10 million to $ 20 million in 1992, before the first load of waste was placed in the landfill. This must have gone up substantially by now. (Tchobanoglous, 1995).

Health and Environmental Concerns of Waste Landfills : The Uncontrolled Release of Greenhouse and Toxic Gases into the Environment

Methane (CH_4), carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2), oxygen (O_2) and nitrogen (N_2) are the principal landfill gases. Methane and carbon dioxide are known greenhouse gases and molecule to molecule methane (CH_4) is 20 – 25 times more powerful greenhouse gas than carbon dioxide in absorbing the infrared solar radiation. Methane can cause explosion when present in air in concentrations between 5 and 15 %. Ammonia (NH_3), hydrogen sulfide (H_2S) and the Volatile Organic Compounds (VOCs) are in trace amounts. They are products of biochemical reactions occurring in the landfills. Landfill gases migrate horizontally and migration distances greater than 300 m have been observed with 40 % concentration.

Gas samples collected from over 66 landfills in UK showed the presence of 116 organic compounds, many of which are classified as VOCs. (UNEP, 1996). VOCs are mostly evolved from the newly placed MSW and specially which also contains hazardous wastes (HW). The increasing quantities of ‘household hazardous wastes’(HHW) in the modern society and their disposal along with the MSW, is posing a serious problem for the landfill engineers.

Table 9. Typical Hazardous Chemical Constituents Found in MSW Landfill Gases

Chemical Constituents	% (By Dry Volume Basis)
Methane	45 – 60 (Greenhouse gas)
Carbon dioxide	40 – 60 (Greenhouse gas)
Nitrogen	2 – 5
Oxygen	0.1 – 1.0
Sulfides, disulfides, mercaptans, etc.	0 – 1.0
Ammonia	0.1 – 1.0
Hydrogen	0 – 0.2
Carbon monoxide	0 – 0.2
Trace constituents (In VOCs)	0.01 – 0.6

Source: Tchobanoglous et, al., ‘*Integrated Solid Waste Management’*; McGraw-Hill (1995).

Table 10. Concentrations of Toxic Trace Compounds Found in MSW Landfill Gases

Compound	Mean Value in Parts Per Billion (ppb) by Volume
Acetone	6, 838
Benzene	2, 057
Chlorobenzene	82
Chloroform	245

Table 10.- Continued

Compound	Mean Value in Parts Per Billion (ppb) by Volume
1,1 Dichloroethane	2, 801
Dichloromethane	25, 694
1,1 Dichlorethene	130
Diethylene chloride	2, 835
trans- 1,2-Dichloroethane	36
Ethylene dichloride	59
Ethyl benzene	7, 334
Methyl ethyl ketone (MEK)	3, 092
1,1,1-Trichloroethane	615
Trichloroethylene	2, 079
Toluene	34, 907
1,1,2,2-Tetrachloroethane	246
Tetrachloroethylene	5, 244
Vinyl chloride	3, 508
Styrenes	1,517
Vinyl acetate	5,663
Xylenes	2,651

Source: Tchobanoglous et, al., '*Integrated Solid Waste Management'*; McGraw-Hill (1995).

Some hazardous chemicals like 'vinyl chloride' is going to the landfills by way of plastic bags. Residents are throwing their kitchen wastes mostly packed in grocery plastic bags. Earlier, there was also a practice to dispose some 'industrial solid wastes' (ISW) with MSW in the landfills, which have now been banned. However, to minimize the emission of VOCs, a vacuum is applied and air is drawn through the completed portions of the landfill.

Trace gases although present in small amounts, can be toxic and pose grave risk to public health and environment. Trace compounds may carry 'carcinogenic' and 'teratogenic' compounds into the surrounding environment. Half-lives of various trace compounds in the VOCs have been found to vary from fraction of a year to over a thousand years. (Heath, 1983).

The Uncontrolled Release of Leachate and the Threat of Contamination of Groundwater and Surface Water

The liquid (waste juice) that collects at the bottom of the landfill is known as 'leachate'. It is the result of percolation of precipitation, uncontrolled runoff, and irrigation water into the landfill. Leachate can also include water initially contained in the waste as well as infiltrating groundwater. Leachate seeps downward to the base of the landfill by gravity and poses a potential health risk to public as it can percolate into the groundwater aquifer and contaminate it. Concern is growing worldwide about wastes leaching heavy metals that may seep into groundwater supplies. Leaching into soil and groundwater will occur regardless of whether the landfill is sealed or not. It has become a common knowledge that all landfills leak. Even the best 'state of the art' landfills are not completely tight throughout their lifetimes and a certain amount of chemicals and metal leaching will occur.

Landfill leachate contains a variety of chemical constituents including heavy metals (Pb, Cu, Ni, Cr, Zn, Cd, Fe, Mn, Hg, Ba, Ag), arsenic, cyanide, fluoride and selenium, and organic acids derived from the solubilization of the materials deposited in the landfill and from the products of chemical and biochemical reactions occurring in the landfills. (Tchobanoglous et, al.,1995). Disposal of consumer electronics mixed with MSW accounts for 40 % of lead (Pb) in the landfills. Mercury (Hg) will leach when circuit breakers are destroyed, PCBs will leach when condensers are destroyed. When plastics with brominated flame-retardants or cadmium containing plastics are landfilled, both PDBE and cadmium (Cd) may leach into the soil and groundwater. (Miller, 2004).

8.3. Thermal Destruction (Incineration) of Waste

High temperature incineration of wastes especially the hazardous chemical and biomedical wastes is considered to be the safest remedy to get rid of it. It enables detoxification of all combustible carcinogens, mutagens and teratogens. Destruction is done in stages. In the first stage the waste is thermally decomposed at 800 °C in a refractory lined chamber to produce ashes and volatiles. The ashes are removed and the volatiles with gases are led to second stage where they are heated to around 1200°C with additional air. It is the only environmentally acceptable means of disposing some complex organic wastes like chlorinated hydrocarbons, polychlorinated biphenyls (PCBs) and dioxins. These chemicals are persistant, non-biodegradable and highly toxic.

However, the conventional incinerators emit dangerous ‘dioxins’, ‘furans’ and other highly toxic pollutants when inorganic chemical dyes in plastics are incinerated. Dangerous dioxins may also be formed if some organic materials are incinerated at too low temperatures. But, the modern, well-regulated incinerators have dramatically reduced such toxic emissions. It has been observed that injection of lime and activated carbon significantly remove the ‘dioxins’ and ‘mercury’ from the gases by 95 %. However, people in most countries are opposing incinerators and landfills in their neighborhood.

Plasma Arc Incineration System

High temperature incineration using ‘plasma arc furnaces’ is a growing technology for the management of hazardous chemical and biomedical wastes. In plasma arc system a thermal plasma field is created by directing an electric current through a low-pressure gas stream. Plasma fields can reach temperature from 5000 °C to 15,000 °C. This intense high temperature zone can be used to dissociate the wastes into its atomic elements in the combustion chamber. Heat generated from the plasma torch can melt and vitrify solid wastes. Organic components can be vaporized and decomposed by the intense heat and ionised by the air used as the plasma gas. Oxygen may also be added in the primary chamber to enhance combustion. Metal-bearing solids are vitrified into a monolithic non-leachable mass. (Hasselriss, 1995).

The system is hermetically sealed and operated below atmospheric pressure to prevent leakage of process gases. Dioxin formation is prevented. The vented gas is held in the tank and recycled into the furnace. The clean gases are released into the atmosphere through an exhaust stack. The destruction and removal efficiency (DREs) of organic compounds are greater than 99.99 %. There is less public opposition to such incineration system. Plasma technology's inherent ability to eliminate risks of future liabilities from waste disposal through a single step treatment is an added advantage. A mobile plasma arc system would also reduce or eliminate public health risks associated with the hazards of accidents or spills resulting from the transportation of toxic or hazardous wastes by road or rail.

Plasma Arc Technology has proved to be an ideal and economically viable method to successfully treat even the carcinogenic asbestos waste, the nuclear power plant wastes and for safe disposal of arms and military waste worldwide. Temperatures in the order of 1,000 °C are necessary to irreversibly transform asbestos into a non-hazardous material. Plasma treatment transformed the asbestos waste into a harmless vitrified slag.

Japan has been using the plasma arc technology on large scale to vitrify its municipal solid wastes (MSW) to reduce the volume of its MSW going to the landfills. Land starved Japan cannot afford to have large number of landfills on its island. The slag produced by the plasma arc pyrolysis is recycled into glassy bricks used as construction materials in buildings.

General cost of waste treatment by plasma arc technology range between US $ 400 and $ 2,000 per ton, depending on the characteristics of the waste. PAT is however, a capital intensive technology due to its initial equipment costs. A new plasma waste processing plant can cost between US $ 3 million and $ 12 million depending on size, the hazardous nature of the waste and the complexity of the treatment process. (Hasselriss, 1995).

Combining Incineration with Energy Generation : Killing two Birds in One Shot

Although waste incineration has been discredited worldwide particularly due to emission of 'dioxins' and 'furans', most European nations have waste incinerator plants combined with energy recovery plants, and several categories of wastes (with high calorific value) including the hazardous wastes are used as fuel to achieve the dual objectives of waste disposal and electricity generation. The 'waste-to-energy' movement started with the 'oil crisis' in the Middle East and the increased cost of oil in the 1970s. Denmark and Sweden are leaders. They incinerate 65 % and 55 % of their MSW respectively and also produce thermal electricity from steam generation. Of the 12 MSW incinerator plants in Netherlands, 5 generate thermal electricity. Some large German cities operate combined incinerator plants providing up to 5 – 10 % of the total electricity demand. U.S. has few incinerators and incinerates 16 % of its MSW currently, but recovers energy from almost 80 % of the plants. The U.S. National Energy Strategy (1991), projected 7 fold increase in the electricity generation from MSW incineration plants by 2010. Nearly three quarters of the Japan's 1900 MSW incinerators, recover energy. (UNEP, 1996).

9. EMBRACING THE 5 R'S PHILOSOPHY OF WASTE MANAGEMENT THROUGH WASTE AND CONSUMER EDUCATION

As the generation of waste has increased in volume and also become more complex in nature (due to mixing of non-biodegradable plastic wastes and household hazardous wastes) traditional waste management systems have proved inadequate and inappropriate. Landfills are not the lasting solution to the waste problem. Worldwide consensus is emerging to discourage incineration and landfill disposal of wastes. In accordance with the EU Landfill

Directive of 2001, the UK government is now phasing out the landfills for waste disposal. Several U.S. states have banned landfill disposal of e-waste.

9.1. Waste and Consumer Education for the Wasteful Modern Society

Environmental education about consumption and waste is a kind of 're-education' of the already educated but ignorant modern wasteful society. Waste generation involves the entire population, so broad cooperation is necessary for sustainable and efficient waste management. Partnerships are required between people and governments to deal with waste collection and disposal. Waste and consumer education aims to raise public awareness about the stresses on municipal councils and enable communities to understand their role and share in the financial responsibilities needed for efficient management of solid wastes.

Educational programs must involve consciousness-raising on these fundamentals:

- Waste is an inevitable by-product of all individual and social activities and is proportionate to daily consumption.
- Waste is a potential resource and every individual needs to commit to help recover waste by reuse and 'recycling'.
- Waste generation can be minimized — it can never be eliminated — through changing the patterns of production and consumption of goods and materials either used most and/or that are used once then end up as waste.
- Judicious consumption of food and the 5 P's — paper, plastic, power, petrol and potable water — can help minimize waste generation on a large scale.

However, there are series of issues that consumers have no control over and that require government interventions at the level of production and distribution, involving manufacturers and retailers.

The Consumer Power of Acceptance / Rejection Can Positively Influence Consumer Industries Counteracting Vested Commercial Interest : India Showed the Way in 1940s

Consumer power can change things provided they are aware. By accepting or rejecting consumer goods for sale, buyers can positively influence the production process, conveying messages to industries and retailers to reduce waste at source both in quantity as well as in quality (hazardous). Consumers can also influence government and industrialists' policies to manufacture goods that are durable, and also re-useable and recyclable after one use. Consumer boycotts, which represent the kind of non-violence preached by the great Indian saint, Mahatma Gandhi, back in the 1940s, counteract the vested commercial interest of manufacturing industries promoted by media for commercial gain.

Consumer Education: Women Holds the Key

Consumerism is a growing human culture all over the world. Shopping is a key activity in market based modern societies and grocery shopping for domestic consumption is done mostly by women all over the world who are keenly aware of the various shelf products. They also observe the invasion of diverse consumer products in the market through media and assess their values for family consumption.

However, buying less and narrowing choices are seen as infringements on people's rights. Individuals and householders who care about the environment can feel powerless. Therefore policy makers, program coordinators, and educators need to address a series of complex issues associated with educating about consumerism and waste generation.

A news poll survey conducted in mid-2005 found that five out of ten women compared with three out of ten men were saying 'No' to plastic bags and only two in ten women but more than a third of the men surveyed preferred to use plastic bags rather than reusable ones (Clean Up Australia 2006) ; (Also on <http://www.noplastics.org.au>).

International Efforts and Role of UNEP, WWF and WWI

The United Nation Environment Program (UNEP) and the World Wide Fund for Nature Conservation (WWF) and the Washington based World Watch Institute (WWI) are playing important roles in educating people at an international level, creating mass awareness about waste problems as well as other environmental issues. UNEP sponsored the first Clean Up the World Campaign, 17-19 September 1993. Several million people, from 79 countries, actively participated in that campaign, which combined dual objectives, environmental sanitation and resource generation. The campaign followed up on the first 'World Clean Up Movement' in Sydney, Australia, initiated by Australian yachtsman, Ian Kiernan, on 8 January 1986. Kiernan gathered around 40,000 Sydney siders to collect more than 5000 tons of rubbish from different parts of the city. The first Clean Up Australia Day, 1990, involved almost 300,000 volunteers.

Programs have been developed to influence consumers and to encourage them to rethink about their patterns of consumption which can reduce waste. The Japanese Environmental Agency (JEA) has launched a scheme called 'Household Eco-Account Books' that encourages the citizens to live sustainabily in an environmentally friendly manner and also save money by consuming resources judiciously and by embracing the philosophy of 3 R's for waste reduction, reuse and recycling. In Norway NGOs run a program that builds householders awareness on environmental impacts of consumer products, especially on its contribution to piling municipal solid waste (MSW) and also the household hazardous wastes (HHW) as several consumer products in modern homes may contain hazardous chemicals and materials.

9.2. Educating about the Golden Rules of 5 R's : Refusal, Reduction, Reuse, Recycling and Responsible Behavior

People and policy makers need to embrace the '5 R's environmental philosophy for sustainable waste management. In the waste management hierarchy 'waste refusal and reduction' is the best option, 'waste reuse and recycling' the better option than the 'waste disposal' in landfills. (Sinha et. al. 2005 c). It is imperative to educate the masses to -

1. *Refuse* to accept articles and materials that generate / create more waste, especially those that generate toxic and hazardous wastes;

2. *Reduce* waste at source by consuming resources as little as possible and which is enough to enjoy a minimum quality of life;
3. *Reuse* articles and materials several times and as much as practicable before discarding them as waste and insist on buying durable, reusable and recyclable articles and products and 'repair' household goods before rejection as waste;
4. *Recycle / recover / retrieve* new materials / energy from discarded waste products and assist the recycling industries by separating the recyclable waste from the non-recyclables faithfully at source; and to behave with
5. *Responsibility* (for both consumer societies and producer industries) with regard to judicious use of resources and reduction in waste generation in everyday activities.

If people (society) and producers (industries) embrace the 5 R's golden rule majority of the waste will be taken care of and very little will be left for 'treatment' or to 'contain' them and finally to dispose them in landfills.

The environmental organization 'EcoRecycle' of Victoria, Australia (2006) proposed a 'waste management hierarchy' which emphasizes that waste 'reduction / avoidance' should be the first option and 'disposal' the last. Waste reuse and recycling comes after reduction. If this management plan is sincerely implemented, there will be very little waste left to be disposed finally. (Figure 1).

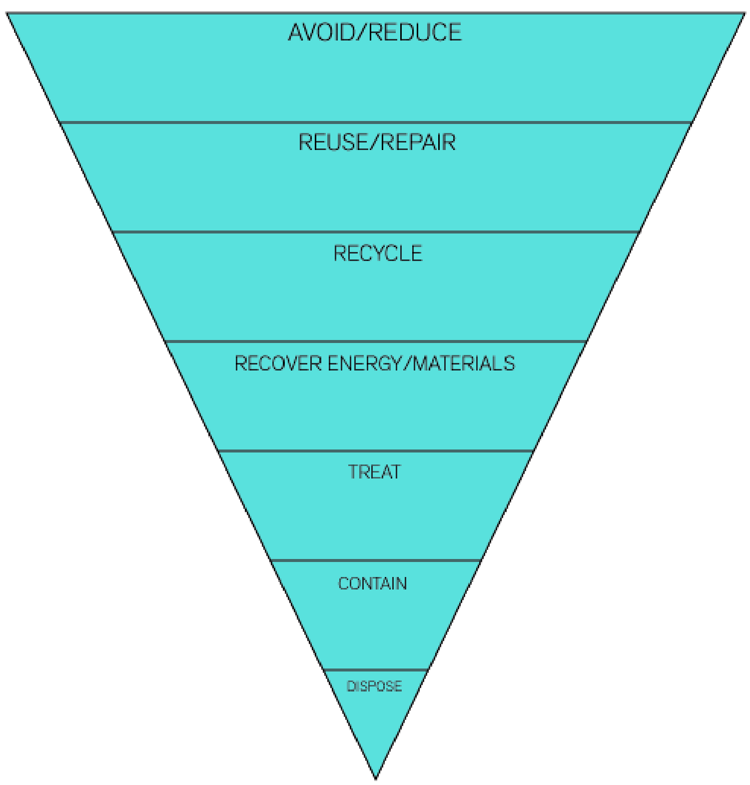

Figure 1. Source: EcoRecycle 2006.

The Power of Refusal : It Can Prevent Misuse of Resources

In the 1980s, the Women Environmental Network (WEN) of the UK campaigned against over-packaging of food products and refused to buy those products that were heavily wrapped with plastics and papers . Women groups went into supermarkets, ripping off all the unnecessary extra layers of paper and plastics and handed them back to the managers. WEN has campaigned against several environmentally unfriendly consumer products such as paper handkerchiefs and toilet rolls made from newly produced paper refusing to accept them. (Belamy 1995).

Way back in the 1940's the great Indian philosopher and educator M.K. Gandhi, used this 'power of refusal' against the mighty British Empire (although in a different context) to generate awareness among the masses.

Box 1. Responsibility of Consumers : Check Before Shopping and Refuse to Accept Articles That Can Generate More Waste Upon Use

1. Refuse to accept non-biodegradable plastic bags for grocery and other shopping — force manufacturers and retailers to offer environmentally friendly alternatives.
2. Refuse to accept any plastic or paper bag for small or just a few articles that you can carry instead in your pockets or personal bags — always carry easily tucked away cloth or alternative bags for shopping.
3. Refuse to accept articles over-packed in plastic and paper, which have no eco-label (are not produced through clean methods of production), and have the potential to generate more waste when used.

The Wisdom of Waste Reduction / Prevention : It Conserves Material Resources

This is the best option in the waste management hierarchy. Preventing waste is like preventing a 'social disease' to occur. Waste reduction means conserving resources, that otherwise constitute waste, with further economic and ecological benefits, including: conserving valuable raw geo-chemical and biological resources, water and energy (fossil fuels) used in the manufacture of products; saving money otherwise spent on constructing and maintaining waste landfills; reducing health and environmental impacts of air, water and soil pollution and global warming. Science and technology, the industry and the society all have to play critical role towards waste reduction. If people judiciously use and reduce the consumption of 5 P's (paper, plastic, power, petrol and potable water) in daily life, it would dramatically reduce all the three wastes- the solid, liquid and the gaseous from the environment.

Society has to begin the process of reducing waste at source – the home, office, or factory- so that fewer materials will become part of the disposable solid wastes of a community. Efforts must be made to reduce the quantity of materials used in both packaging and obsolescent goods. Waste reduction may also occur at the household, commercial, or industrial facility through 'selective and judicious buying and consuming' patterns and the reuse of products and materials. Source reduction is an option that will conserve resources and also has economic viability.

Technology Has Improved Efficiency of Resource Use and Reduced Waste Generation by Consumers at Source

Technological advancement has undergone a process of 'dematerialization' for reducing the consumption of resources (metals, plastics, glasses etc.) in manufacturing products, with consequent reduction in waste generation. Many packaging items (cans and bottles), consumer 'electronic goods' and even the 'automobiles' have become lighter, slikker and smaller. Since 1977, the popular 2-liter PET plastic soft drinks bottles have been reduced from 68 grams each to 51 grams, a 25 % reduction in material used per bottle. One hundred 12 fluid ounce aluminum cans which weighed 4.5 pounds in 1972, only weighed 3.51 pounds in 1992, a 22 % reduction in material use. Steel beverage cans have also been downsized and are now 40 % lighter than they were in 1970. This means that people can still enjoy a good quality of life while consuming smaller amounts of resources from the environment and generating lesser amount of waste. Lesser resource use would also mean 'lesser energy consumption' and 'lesser waste generation', thus benefiting the environment in every way. (WWI, 1991).

The Wisdom of Waste Reuse : It Extends the Life of Material Resources

There are several articles like bottles and jars made of glasses and tough plastic materials, large tins, metallic cans and cansisters which can remain in our economy and ecosystem for very long time (if not discarded as waste) just by simple cleaning and washing.

Box 2. Recipe and Responsibility of Consumers to Reduce and Re-use Waste in Daily Life

1. Buy in bulk and concentrates.
2. Buy durable not disposable products.
3. Buy products packed in reusable and refillable containers.
4. Chose products without or as little packaging as possible.
5. Take Your Own Bags, Box or Basket (TYOB). Insist on reusable cotton bags or durable synthetic bags for grocery shopping; keep a few used shopping bags in your car.
6. Select paper bags/wrap only if needed and avoid plastic bags/wrap.
7. Reuse paper/envelopes only printed/photocopied on one side printed.
8. Use rechargeable batteries.
9. Use refillable ink fountain pens and biros.
10. Avoid using greeting/invitation cards.
11. Avoid wrapping, or sparsely wrap, presents etc.
12. Avoid paper napkins — carry cotton handkerchiefs.
13. Save electronic copies of data or print and photocopy on both sides of paper.
14. Prepare meals at home (not take-away/convenience foods).
15. Avoid frequent use of canned, bottled, packed, processed and preserved foods and eat raw, fresh foods (good for human and environmental health).
16. Avoid peeling fruits and vegetables to reduce kitchen wastes (and preserve nutrients for digestion) and compost any food scraps and leftovers.
17. Carry food and edibles to school/workplace/friends' place in reusable boxes.
18. Repair clothes and garments, toys, tools and appliances.
19. Go to garage sales rather than throwing away old things or buying new ones.
20. Use safe retreated car tyres.

Box 3. Responsibility of Producers (Industries) to Reduce Waste

1. Producers of consumer goods and products MUST embrace the philosophy and principles of 'cleaner production', which emphasize producing 'more with less', thus conserving resources and reducing waste.
2. Producers MUST embrace the ethical principle of producing durable, re-usable and recyclable goods, which can remain in use for longer periods of time even through changes in the purposes of their uses before being discarded.
3. Producers MUST inform consumers about the recycling potential of their products and be committed to 'take back' products after use for recycling, to recover maximum useful materials from them to reduce the amount of final waste.

It do not involve any complex industrial processing, use of chemical and energy for their reuse. They might have been originally made for some other use, but now can be reused for different purpose- especially for storing and packaging. It should rather be termed as 'resource reuse'.

The Wisdom of Waste Recycling : Retrieving New Materials / Energy from Waste and Conserving Virgin Raw Materials and Natural Resources

Waste recycling is a technological process to reuse waste materials involving physical, chemical and biological processing to recover useful materials from them. It converts waste into a resource, conserves primary and virgin raw materials from environment (geo-chemical and bio-chemical natural resources), saves tremendous amount of water and energy and protect the environment. Hidden environmental protection values of recycled goods, include the energy and water saved, the pollution and deforestation prevented.

Government and People's Support is Paramount for Recycling to Succeed

Recycling combines social, economic, and ecological values. The opportunity to recycle provided by local and state governments has seen an almost fourfold increase in the Victorian recycling industry in Australia in the years 1993–2003 (EcoRecycle, 2006). EcoRecycle estimates that re-processors have saved: water equivalent of filling 17,500 Olympic sized swimming pools; greenhouse gas equivalent to that produced by 580,000 cars; and, 'enough energy to power every household in Victoria (Australia) for 7 months' (EcoRecycle, 2006).

Consumers can support recycling by buying goods which bear 'recycled' stickers from their manufacturers. People can indirectly support and promote recycling industries by separating the recyclable from non-recyclable wastes and can directly participate by recycling domestic, e.g. kitchen, wastes through composting. Policy makers could encourage or regulate for all recycled goods to bear a tag recording the origin and life history of the goods, i.e. identifying from which waste it was produced and how it has saved damage to the environment. Such initiatives allow consumers to confidently reuse and recycle products. A demand for recycled goods in society can be created by education.

Box 4. Responsibilities of Consumers (Society) in Promoting Waste Recycling

1. Separate recyclable wastes — glass bottles and jars, aluminum and steel cans, plastic bottles, milk cartons, paper, cardboard, magazines and phone books — from other household wastes faithfully for collection by councils or deliver them to recycling centers / industries.
2. Buy recycled goods. This will encourage promotion of recycling efforts by the government and industries.
3. In order to make recycling an effective strategy, people must understand more about the qualities of materials in everyday items. For example, several vitreous materials that look like, and shatter like, glass are *not* recyclable. Even a minute amount (such as 5 grams per ton) of these vitreous materials found in some ceramic mugs and plates, cups and crockery, mirror, broken drinking glasses, flower vases, light globes and laboratory glass, can contaminate a load of recyclable glass and render it useless.

Box 5. Responsibilities of Producers (Consumer Industries) Towards Waste Recycling

1. Producer industries MUST produce / manufacture consumer goods that are 'potentially recyclable'. 2. Producers should have a policy to 'take back' their own products to recycle them;
2. Producers should provide necessary information to its prospective buyers on the matter of using, handling, conservation, disposal and recycling potentialities of its products.
3. In designing new products, the industry must assess its potential and even suspected adverse impact on its consumers health and the environment.

10. Waste Recycling : A Growing Global Business Where 'Waste' (Trash) Is Turned into 'Resource' (Treasure)

Waste is no longer considered as a discarded product to be disposed off from the human ecosystem. Wastes are in fact now considered as a 'misplaced resource' to be brought back into the human ecosystem through the reuse and recycling technologies. Recycling means that otherwise wasted items are returned back to the country's economy to make either the same product again, another product or other products. This saves cost on landfill disposal, save landfill space, and prolongs the life of the primary resources used to make the product. (Fairlie, 1992).

Recycling can involve mechanical / biological / chemical / thermal processing of waste using some energy, water and chemicals to effectively and efficiently reconvert the waste into 'secondary raw materials' to manufacture new products or recover 'energy' from them in the form of fuel gas or heat. Several of the items of domestic, industrial (non-hazardous) and commercial wastes viz. paper, leather, rubber, cotton rags, metals and glasses, wood and plastics can be recycled in the material recovery and reprocessing industries to get valuable new products.

Science and technology has provided a tool in the hands of mankind to renew all those 'non-renewable resources' on earth which otherwise cannot be 'renewed' by nature's mechanism. This would also save tremendous energy, preserve forest, prevent soil erosion and pollution and above all arrest emissions of greenhouse gases (GHG's) and reduce global warming.

Some economies in the developed nations of Europe and America, and also in Australia, is retrieving back 80 to 85 % of the materials from the waste as useful products for societal consumption or to be reused in developmental activities and only less than 20 % are going to the landfills for final disposal. (Goldoftas, 1989).

10.1. Global Trade and Exchange for Recycling

The old saying *'one persons trash is another person's treasure'* is becoming true as 'waste trade and exchange' between nations for recycling is entering into new era both economically, ecologically and politically. Japan, Germany, France, Hong Kong, U.K., U.S. and also Australia is recycling their wastes on large scales. Japan recycles 65 % of its MSW into usable products and 40% of its waste paper into high quality paper.

A computerized 'waste exchange register' has been prepared to link 'waste producers' with potential 'waste users' and diverse waste items like discarded aluminum cans, paper and card-boards, wooden crates and off-cuts, steel plate off-cuts, plastic products, saw dust, egg-shells, caustic soda and chemicals have been listed in this register. The OECD countries have established a central system for moving the non-hazardous 'recyclable wastes' across international borders under the rules of normal trade goods listed in the 'green list' of Basle Convention (1989). In these countries several C and F agents have come up with list of 'waste available' and 'waste wanted'. The buyers benefit by the reduced cost of raw materials, while the sellers benefit by the reduced cost of treatment and disposal of wastes.

Trade in waste between two countries is economically and politically justified if it is based on ethics. Faced with rising cost of safe waste disposal and recycling at home, many industrialized nations prefer to pass their hazardous wastes along with the 'recyclable wastes' on to the poor Third World countries where there are facilities, cheaper manpower and infrastructure for waste recycling. This has happened greatly in case of hazardous electronics wastes. U.S. has dumped huge pile of e-waste in China and India for recycling.

Trade-in Program for Recycling Electronic Waste

Recycling is a good option for the extremely old generation computers such as the Pre-Pentium generation, or the computers (specially the monitors) which are broken. According to the International Association of Electronics Recyclers (IAER) more than 1.5 billion pounds of electronics equipment are recycled annually and is likely to grow by a factor of 4 or 5 by the end of this decade. Eleven countries currently have 'mandatory' electronics recovery laws on the books. These are Denmark, The Netherlands, Norway, Sweden, Switzerland, Japan, Belgium, Taiwan, Portugal and South Korea. Some EU nations have very strong system for e-waste collection, such as the SWICO system in Switzerland and the Netherlands Association for Disposal of Metalectro Products (NVMP). NVMP collect 80 % of e-waste. About 77 % of TVs and 64 % of other small brown goods are recovered for reuse and recycling. (Cui and Forssberg, 2003)

Most major computer manufacturers in world e.g. Dell, Hewlett-Packard (HP), Compaq, Gateway have begun to address e-waste problems with their own end-of-life management programs which offers a combination of trade-in, take-back and recycling programs. Dell and Gateway lease out their products thereby ensuring they get them back to further upgrade and lease out again. Dell offers both reuse and recycling programs. Dell purchases it computers for a nominal $15 fee. They will recycle both Dell and non-Dell computers, but for corporate customers only. Dell Europe, however, recycles individual consumer's computers. Gateway provides $25-50 cash refund for new PC and donate the customer's used computers. HP and Compaq's trade-in program provides a refund cheque for the value of the used computer if it is traded-in on the purchase of a new HP/Compaq computer. HP has been very active in recycling programs. Since 1987, it has recycled over 500 million pounds of materials from the e-waste and pledge to achieve 1 billion pounds by 2007. HP entered into a joint venture with Micro Metallics in 1996 to recycle materials recovered internally and to recover parts from products returned by customers and reported US $ 72.3 billion as revenue from the recycling program. IBM accepts any type of PC (even other brands) but would charge $ 29.99 to take it back. (Cui and Forssberg, 2003).

10.2. Economics of Recycling : Value Addition When Garbage Becomes Gold

Any waste has negative economic and environmental value and is a big techno-economic problem for the local government and involves an economic and environmental cost in safe disposal. But if the same waste is converted into an useful 'new material' its economic and environmental value goes to the positive. (Sinha, 1994).The Brisbane City Council in Queensland, Australia process over 60,000 tones of recyclable materials every year and add $ 20 million to their economy. (BCC, 2002).

What was the value of flyash before technology founds its use to reconvert it into building material ? It was an environmental a hazard. What is the value of food scraps and the human excreta ? It is a human waste to be safely disposed off every day and involves cost. Composting technology can convert them into a high value end product i.e. compost (a nutritive organic fertilizer for the farms). Biogas technology can now retrieve 'methane'- a clean burning fuel for power generation. (Sinha, 1994; Goldstein, 1995). Recycling also reduces the cost of construction and siting of new 'landfills' and closing it after use. It reduces the economic and environmental cost of incineration of several categories of wastes.

Recycling economy is a closed loop in which consumers, manufacturers and waste collectors and haulers, all have a critical sustaining role to play. Many waste articles in the society are 'potentially recyclable', but they may not actually be recycled unless there is a practical way to do so and there is a demand / market for the 'recycled goods'. The waste haulers would be encouraged to collect the recyclable wastes if there is a demand by the recycling industries, and the recycling industries will buy these wastes (as secondary raw materials for processing) only if it is less expensive (economically cheaper) than the primary (virgin) raw material. The consumers will buy recycled items only if it is as good as the product made from virgin materials and still less expensive. None of them are bothered about the high 'environmental cost' of the procurement of the primary raw materials from earth or the products made from them.

When recycled materials have a high 'social and economic value' despite the cost of collecting and processing, they find a ready market. Much of the gold, silver and other precious metals that were ever mined and extracted from their primary ores centuries ago is still circulating (recycling) in our economy (human ecosystem). Materials with low social and economic value relative to the cost of collecting and processing do not find a ready market.

The grocery and kitchen wastes, agriculture, dairy and slaughter house wastes and the sewage sludge, with greater organic contents can be biologically recycled to get 'fuel (biogas) and fertilizer' (compost). Even the 'human hair' which are protein materials can be recycled for getting 'amino acids' and making newer and cheaper proteins. It is like getting 'gold from the garbage' and 'silver from the sewage'.

Recycling of hazardous industrial wastes also minimizes the cost and risk of transporting, storing, treating and disposing of hazardous wastes to distant places. US and Japan recycles a great part of its hazardous wastes. Several recyclable hazardous wastes are 'exchanged' among nations under strict rules of Basel Convention (1989). The recycling potential of wastes from the pharmaceutical industries is 95 %, paints and allied products 40 %, organic chemicals 25 %, petroleum refinery 10 % and small industrial machinery 20 %. Used and discarded products from the automobiles e.g. the lead-acid batteries (LABs), the waste oil and the auto tires are also recycled.

In some cases the waste may have to undergo some modifications, such as 'dewatering', in order to become recyclable and salable product. An aluminum die-casting firm developed a market for a by-product of their production process- the 'fumed amorphous silica'. After much researches into uses for the product it was found to be a valuable additive to concrete. The firm marketed the waste and now sells all the fumed amorphous silica it generates to cement plants. This is bringing an income of US $ 1 million every year for the company and also saves the enormous cost of disposal. (Noll et. al., 1985).

An x-ray film manufacturer in U.S. generates a salable waste product. The company installed equipment that flakes and bales waste polyester –coated film stock which is sold as raw material input to another firm. Over 9 million kg of film stock is exchanged each year. This saves US $ 200,000 annually which would have incurred in collection, transport, and disposal cost. Above that, there is annual profit of US $ 150,000 to the x-ray film manufacturing firm from the sale of the recyclable materials. (Noll et. al., 1985).

10.3. The Environmental Significance of Recycling

Nature possess tremendous capacity of recycling of several categories of wastes by 'biodegradation' (biological recycling) aided by the decomposer organisms on earth. The earth provides all the necessary 'resources' for development of mankind and also 'assimilate' all the wastes generated by them in the process of those developmental activities. This is defined as the 'carrying capacity' of Earth. Unfortunately, due to the growing consumerism of resources and the consequent increase in the quantity and concentration of human wastes on earth, this carrying capacity is threatened to be jeopardized with dangerous consequences for the global ecological balance and grave risk of poisoning of the life support systems on earth. The addition of 'non-biodegradable technological wastes' has aggravated the problem. They can remain in the human environment for centuries as nature has not evolved the mechanism to degrade and recycle these new man-made materials.

Table 10. Environmental Benefits of Recycling of Papers, Metals and Glasses

Waste Recyled	Energy Savings	Pollution Control	Reduction in Solid Waste	Water Savings	Forest Protection
1. Iron & Steel Scraps	60-70 %	30 %	95 %	40 %	100 %
2. Aluminum Cans	90-95 %	95 %	100 %	46 %	100 %
3. Papers Wastes	60-65 %	95 %	100 %	58 %	100 %
4. Glass Wastes	30-32 %	20 %	60 %	50 %	-

Source: WWI (1984) 'State of the World'.

By resorting to 'recycling technologies' we can actually 'renew and sustain' the natural 'carrying capacity' of earth ecosystems and not only the natural human wastes can be reconverted into a resource, but also the ' man-made synthetic and hazardous wastes'. Recycling of some municipal and industrial wastes such as papers, metals, glasses can accrue several environmental benefits by way of water and energy saving (consequent reduction of greenhouse gas emission), control of air pollution and forest protection.

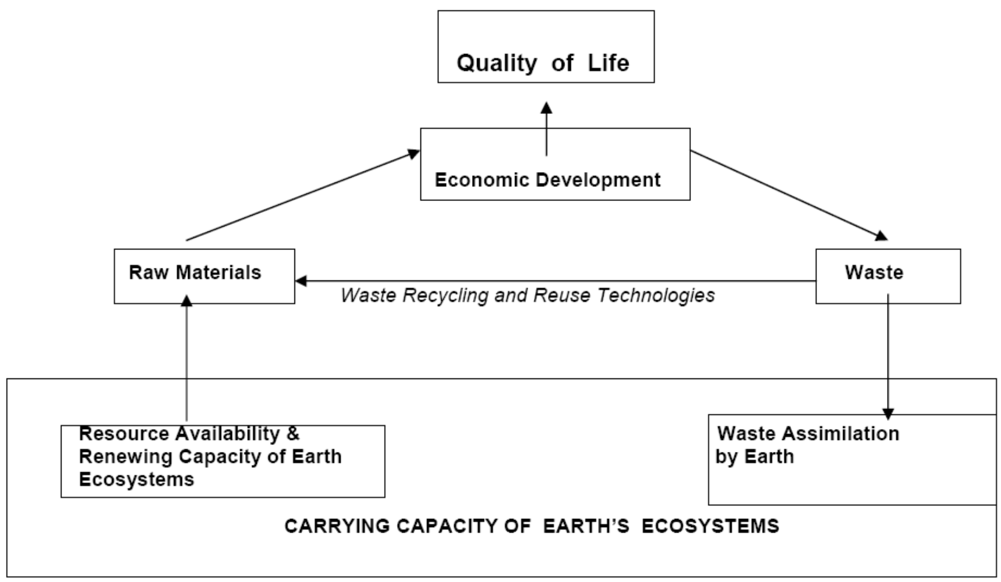

Figure 2. Explaining the Economic and Environmental Significance of Recycling.

10.4. Need for Appropriate Recycling Technologies

Several municipal as well as industrial solid wastes have potential to be recycled. They only need appropriate technologies for recycling. New recycling techniques are being developed constantly to maximize recovery of useful materials and minimize the amount of waste going to the landfills. Essentially two types of recycling technologies are being developed for waste processing to get valuable end products – mechanical and biological. Mechanical technology involves thermal and chemical processing of waste (both organic and inorganic fractions), while biological technology involves biological processing of waste (organic fraction only) by microbes and earthworms. While mechanical technologies incur expenditure of energy, the biological technologies may generate energy.

10.5. Biological Recycling of Wet Organic Wastes into Fertilizer and Fuel : Diverting the Major Part (70- 80 %) of MSW from Landfills

Biological recycling involves processing of wet and dry organics such as the food waste from homes and commercial institutions, green garden and farm wastes, cattle and farmyard wastes and the waste organics from the food processing industries). The traditional composting methods are essentially a biological recycling technology which is being revived and improved with new knowledge in microbiology and environmental biotechnology. Other biological recycling methods developed are technology to retrieve 'biogas' and 'bio-alcohol' (cleaner energy sources) from organic wastes.

MSW contain 70-80 % by weight of organic materials and the waste biomass is rich in carbon (C) and nitrogen (N) with other valuable minerals like phosphorus (P) and potassium (K) and have potential to be biologically recycled to recover fertilizer and fuel (energy). However, waste with high organic components should preferably be recycled to produce fertilizers (composts) and not fuel. (White, 1996).

Table 11. Useful Materials Recovered from Waste by Recycling Technologies

Recyclable Materials from MSW	Useful Materials Recovered / Typical Uses
WET RECYCLABLES	
Organic Fraction of MSW (70-80 %) Food waste, yard & garden waste etc.	Recovery of fertilizer (compost) and fuel (methane and ethanol) ;
DRY RECYCLABLES	
Paper	
Old Newspaper	Newsstand and home-delivered newspaper
Corrugated Cardboard	Bulk packaging, fiberboard & roofing material
High-grade Paper	Computer paper, white ledger paper
Plastics	
Polyethylene Terephthalate (PET)	Soft drink bottles, salad dressing and vegetable oil Bottles; photographic film
High-density Polyethylene (HDPE)	Milk jugs, water containers, detergent and cooking oil bottles.
Polyvinyl Chloride (PVC)	Home landscaping, irrigation pipes, some food packaging, and bottles
Low-density Polyethylene (LDPE)	Thin-film packaging and wraps; dry cleaning film bags; other film material
Polypropylene (PP)	Closures and labels for bottles and containers, battery casings, bread and cheese wraps, cereal box liners
Polystyrene (PS)	Packaging for electronic and electrical component,

Table 11 – Continued

	foam cups, fast-food containers, tableware and microwave plates;
Multilayer and other mixed plastics	Packaging, ketchup and mustard bottles
Glass	Clear, green and brown glass bottles & containers;
Metals	
Ferrous Metals (Iron & Steel)	Tin cans, white goods, reinforcing bars
Non-ferrous Metals	Aluminum cans, copper and lead products
Textiles	Wiping rags
Construction & Demolition Wastes	Soil, asphalt, concrete, wood, drywall, shingles
HAZARDOUS WASTES	
Auto Tires	Road building materials, paving and tire-derived fuel;
Household Batteries	Recovery of zinc, mercury and silver
Automobile Batteries	Recovery of acid, plastic and lead
Incinerator Residues	Concrete, road construction material
Engine Oil and Lubricants	Refined Oil

Fertilizer Production : Retrieving Nutrients from Organic Wastes

i) Compost from Waste (Getting Gold from Garbage)

There is always greater economic as well as ecological wisdom in converting as much ‘waste into compost’ (a nutritive fertilizer for farms), so that less and less waste (the non-compostable and non-recyclable residues) finally go to the landfills. The organic fraction of MSW (70-80 %) is rich in nitrogen, potash and phosphorus (NKP) and all macro and micronutrients. This can be easily recycled through microbial biodegradation – process called composting, to retrieve the nutrients from them. If residents all over the world, practice ‘home composting’ and ‘backyard composting’ of their ‘kitchen and garden wastes’, this will significantly reduce burden on the councils and very little MSW will be left for the landfills. Even councils should practice composting of waste on commercial scale instead of sending them to the landfills, earn money by selling them to the farmers, rather than spending money on their landfill disposal.

The components that constitute the organic fraction of MSW are food wastes, paper, cardboard, plastics, textiles, rubber, leather, yard wastes, and wood. Yard waste may contain even higher percentage of organic matter. All of these waste materials can be recycled, either separately or as a commingled waste. Certain industrial wastes such as those from the ‘food processing’, ‘agricultural’ and ‘paper-pulp industries’ are mostly organic in composition and can also be composted. Controlling the environmental conditions i.e. the biological, physical and the chemical factors can significantly improve and enhance the composting process without the emission of foul odor and pollution of the environment and without the loss of essential nutrients from the compost. (Epstein, 1997).

The conventional composting technology has now been significantly improved with our modern scientific knowledge in ‘microbiology’ and ‘biotechnology’ to ‘biodegrade’ all kinds of organic wastes including the ‘municipal solid wastes (MSW)’containing sufficient organic components under a completely controlled environmental conditions. We have innovated some new, cost-effective and more efficient methods of converting organic waste into compost which besides providing the macro and micronutrients also provide ‘beneficial soil microorganisms’ to the soil and work as ‘soil conditioner’ to prevent soil erosion. (Haug, 1993; Epstein, 1997).

The relative ease with which an organic material is biodegraded (composted) depends on the ‘genetic makeup’ of the microorganisms present and the ‘chemical makeup’ of the organic molecules. Carbons in sugars, lipids and proteins are easily decomposed than the carbon in lignin. A small portion of the carbon is converted to new microbial cells, while a significant portion is converted to carbon dioxide and lost to the atmosphere. The new cells that are produced become part of the active biomass (decomposer microbes), to further enhance and multiply the biodegradation and composting process and on death ultimately become part of the compost.

European cities and societies are developing and adopting ambitious technologies for recycling and composting of wastes to divert them from landfills. Some cities have installed sophisticated equipments for composting and resource recovery. Austrian, French and Swiss cities have taken the lead in installing waste recycling and composting systems. Twenty seven (27) composting plants with a combined annual capacity of 60,000 tones of compost from city trashes are currently under construction in German towns and cities (UNEP, 2004).

Vermicomposting: Using Waste Eater Earthworms for Rapid and Odorless Composting of Municipal and Industrial Organic Wastes

Vermicomposting is rapid and odorless process triggered by earthworms through enzymatic breakdown of waste organics and also enhancing the microbial degradation by proliferating the microbial population in the waste biomass. Vermicompost is completely free of pathogens but rich in beneficial decomposer microbes including nitrogen fixing bacteria, mycorrhizal fungi and actinomycetes. It is rich in NKP, trace elements, enzymes, growth promoting hormones (gibberlins and auxins) and readily works as ‘soil conditioner’.

Long-term researches into vermiculture have indicated that the Tiger Worm *(Elsenia fetida),* Red Tiger Worm (*E. andrei*), the Indian Blue Worm *(Perionyx excavatus),*the African Night Crawler *(Eudrilus euginae),*and the Red Worm *(Lumbricus rubellus)* are best suited for vermi-composting of variety of organic wastes including some of the hazardous wastes like the ‘sewage sludge’ (biosolids) from the sewage treatment plants and the ‘fly-ash’ from the coal power plants.

Vermiculture was started in the middle of 20^{th} century for management of municipal / industrial organic wastes in Holland in 1970, and subsequently in England, and Canada. Later vermiculture were followed in USA, Italy, Philippines, Thailand, China, Korea, Japan, Brazil, France, Australia and Israel. However, the farmers all over the world have been using worms for composting their farm waste and improving farm soil fertility since long time. In UK, large 1000 mt vermi-composting plants have been erected in Wales. The American Earthworm Technology Company started a 'vermi-composting farm' in 1978-79 with 500 t /month of vermicompost production. Japan imported 3000 mt of earthworms from the USA during the period 1985-87 for cellulose waste degradation. The Aoka Sangyo Co. Ltd., has three 1000 t /month plants processing waste from paper pulp and the food industry. This produces 400 ton of vermicompost and 10 ton of live earthworms per month.

The Toyhira Seiden Kogyo Co. of Japan is using rice straw, municipal sludge, sawdust and paper waste for vermicomposting involving 20 plants which in total produces 2-3 thousands tons of vermicompost per month. In Italy, vermiculture is used to biodegrade municipal and paper mill sludge. Aerobic and anaerobic sludge are mixed and aerated for more than 15 days and in 5000 cum of sludge 5 kg of earthworms are added. In about 8 months the hazardous sludge is converted into nutritive vermicompost. In France, 20 tons of mixed household wastes are being vermi-composted everyday using 1000 to 2000 million red tiger worms (*Elsenia andrei*) in earthworm tanks. Rideau Regional Hospital in Ontario, Canada, vermi-compost 375 - 400 kg of wet organics mainly food waste everyday. In Wilson, North Carolina, U.S., more than 5 tons of pig manure (excreta) is being vermi-composted every week. (Edward, 1998; Frederickson, 2000; Fraser-Quick, 2002; Sinha et. al., 2005 b).

ii) Fertilizer Pellets from Sludge Cake (Getting Silver from Sewage)

A technology has been developed in U.S. by Massachusetts Water Resources Authority to recycle the dewatered 'sewage sludge' into 'fertilizer pellets'. The sludge is shipped from sewage treatment plant and pumped directly from barges into the storage tank and then transferred to belt-filter press where water is mechanically squeezed out. The sludge cake is moved through the conveyer belts to rotating heat dryers and heated to convert into small hard pellets. This also destroys the foul smell and harmful bacteria. The pellets are low-grade fertilizers, but if blended with other synthetic nutrients can form a complete fertilizer. Cities all over the US is operating sludge processing plant like MWRA.

Fuel Production : Retrieving Cleaner Sources of Energy from Organic Waste

The organic municipal solid wastes enriched with biomass and materials with high calorific value (combustible) can be recycled to yield either gaseous fuel 'methane' (biogas) or liquid fuel 'ethanol' by fermentation. The wastes can be directly incinerated and the heat liberated is used for steam generation and electricity production. The new idea is to use the wastes a source of fuel in 'cement kilns' in cement industries to replace the costly fossil fuels. The emission problems accompanying incineration is also minimized to a great extent. But only wastes with high calorific value is useful for energy recovery. (Parker and Roberts, 1985; Porter and Roberts, 1985).

i) Biogas

There is always greater ecological wisdom in generating 'biofuel' (biogas and bioethanol) from the MSW rather than generating 'thermal energy' from them by combustion technology, with accompanying release of toxic gases especially 'dioxins' and residual 'ashes' which needs landfill disposal.

The biogas technology by the use of anaerobic 'metanobacteria' utilizes the organic wastes rich in cellulosic materials with high carbon and nitrogen (C/N) ratio. It produces both fuel and fertilizer. Each ton of organic waste by dry weight yields about 36 cum of biogas and 350 kg of biomanure. Methane is a clean burning substance and on combustion yields 550 BTU of heat per cft of its volume. Even the sewage sludge rich in organic matter and high C/N ratio is efficiently recycled to yield methane.

ii) Bio-diesel

Bio-diesel is emerging as an alternative cleaner fuel for diesel engines brewed from waste organic feed-stocks, such as animals waste fats (tallows), lard and waste cooking oils. This is being produced in Australia and other countries on commercial scales. Bio-diesel is also being produced from offal at a turkey-processing plant in the U.S. Any vegetable oil can form the feedstock to produce bio-diesel. It can produced by recycling the waste oil from fast-food restaurants and the deep friers of French fries which generate huge amount of waste vegetable oils.It can now be produced from household waste and used auto tires.

Bio-diesel is completely non-toxic and biodegradable, almost free of sulfur and aromatics, and have lower CO_2 emissions than the mineral oil derived diesel. It can be used in existing fuel engines without any modifications. The emissions from bio-diesel are 100 % lower in sulfur, 96 % lower in total hydrocarbons (HC), 80 % lower in polycyclic hydrocarbon (PAH), 45 % lower in carbon monoxide (CO) and 28 % lower in suspended particulate matters (SPM). (UNEP, 2006).

iii) Bio-alcohol (Ethanol)

Waste biomass rich in starch and cellulosic materials provides good raw material for ethanol production by enzymatic fermentation carried out by organisms ‘yeast’ and some bacteria. Bagasse, the waste from sugarcane industry is most appropriate raw material. 6000 kg of bagasse upon fermentation yields 1000 litres of ethanol of 95 % strength. It is a cleaner auto-fuel and Brazil is already using it as an ‘auto-fuel’ since 1975.

New bioconversion technologies could open the gate to the cost-effective use of a wide variety of feed-stocks including agricultural waste products like corn stalks, rice and wheat straws and perennial grasses to produce bio-fuel ethanol

iv) Coal Briquetts

Technology to recycle the agricultural wastes into a non-polluting fuel has been developed. The dried biomass is crushed and pre-heated to a temperature of 100-120 °C and then compacted.

v) Fuel Pellets

A technology has been developed for converting garbage into non-polluting fuel pellets. The garbage is first shredded and blown dry in rotary kiln. It is then blended with combustible wastes like saw dust and is then pelletized. The pellets have calorific value around 4,000 kcal /kg and there is no harmful emission upon combustion.

10.6. Mechanical Recycling of Dry Recyclables into Original or New Products

Mechanical recycling involves processing of dry organic and inorganic recyclables such as papers and cardboards, plastic cans and bottles, metal cans, glass jars and bottles. Mechanical methods include thermal and chemical processing of waste materials and also consumes considerable amounts of water and energy. Now new mechanical technologies is being developed to recycle even hazardous industrial wastes.

Metals, glasses, papers and plastics, wood and rubbers are some common domestic and commercial wastes which have high recycling potential to recover goods of mass consumption through mechanical technologies. (WWI, 1984).

Recycling Potential of Metallic Wastes

Iron, aluminum, lead, tin and copper are metals of mass consumption by the society. Their production from their virgin ores by mining activities requires huge amount of energy and water and also cause blatant environmental pollution, solid waste generation (as tailings) and deforestation. Metals like iron and aluminum can be effectively recycled for ever with least impact on environment while conserving huge amount of energy. (AEN, 2000).

a) Ferrous Metals (Iron and Steel)

The ferrous scraps include autos, household appliances, equipment, bridges, cans and other iron and steel products. The largest amount of recycled steel has traditionally come from large items like road unworthy cars and appliances. It can be reclaimed from the automobile bodies and engines, disused household or industrial equipment and building materials. The shipyards, railyards and the automobile junkyards offer vast amount of waste metallic products to be recycled. They can alone meet more than 50 % of the world's metal requirements. Marine ship break is a continuous process throughout the world as the ships lose sea worthiness in 25 to 30 years.

Recycling of steel cans is also becoming very popular. They can easily be separated from the mixed recyclables or MSW using large magnets. To protect them from corrosion, all steel cans are coated with a thin layer of 'tin' that must be removed in the recycling process. Immersing the sheets of steel in alkaline bath and transmitting an electric current completes the 'detinning' process.

Iron and steel has high recycling potential and can be recycled again and again without reducing the quality of the end products. Nearly half of the iron and steel which has already entered into the human ecosystem is now being used through recycling. World steel production alone consumes as much energy annually as Saudi Arabia produces. Making steel from recycled materials uses only a quarter of the energy needed to make steel from iron ores. (AEN, 2000). Iron scraps costs little more than iron ore but can be converted into steel with much lower economic and environmental cost. Using coke for iron ore reduction produce copious particulate matters including carcinogenic benzopyrene. Recycling of iron reduces this emission by 11 kg/metric tons of steel produced and also cuts iron ore waste and coal mining wastes by 1100 kg/metric tons recycled. Iron and steel scraps are baled into bricks at the material recycling facility (MRF) and melted at 1700 °C in the smelters to produce ingots.

b) Non-ferrous Metals

Non-ferrous scrap metals include aluminum, copper, lead, tin, and precious metals**.** Recyclable nonferrous metals are recovered from common household items (outdoor furniture, kitchen cookware and appliances, aluminum cans, ladders, tools, hardware); from construction and demolition projects (copper wire, pipe and plumbing supplies, light fixtures, aluminum siding, gutters and downspouts, doors, windows); and from large consumer, commercial and industrial products (appliances, automobiles, boats, trucks, aircraft, machinery)

Aluminum: It has high recycling potential. The amount of aluminum which has already entered into the human ecosystem is sufficient to cater the needs of the society through recycling and there is no need to process it from the virgin ores. Aluminum cans are baled into bricks and melted at 700 °C in rotary furnaces. The molten aluminum is cast into ingots and remade into cans or processed into other aluminum products like saucepans and home-wares.

Copper: It can be recycled from the boilers of hot water systems, old car radiators and copper pipes. Electric cabling and wiring contains copper and aluminum which can be recycled.

Lead: Lead can be recycled from old car batteries and old lead pipes. Lead is recycled in high rate because it is highly toxic and processing from its ore is highly damaging to both man and environment.

Silver can also be recovered from silver-plating industries through recycling. A 'silver-plating plant' in the US spends about US $ 120,000 a year on waste treatment, of which US $ 60,000 is returned as credit for 'silver' recovered from the waste. Silver and even gold is recovered from electrical industries.

Table 12. Metal Consumption Procured through Recycling in USA

(1). Lead	73 %	(2). Copper	60 %	(3). Iron & Steel	56 %
(4). Aluminum	45 %	(5). Zinc	43 %	(6.) Tin	38 %
(7). Tungsten	29 %	(8). Nickel	26 %	(9). Chromium	21 %

Source : WWI, Washington D.C. '*State of the World'* (1989).

Environmental and Economic Benefits of Recycling Metallic Wastes

World steel production alone consumes as much energy annually as Saudi Arabia produces. Making steel from recycled materials uses only a quarter of the energy needed to make steel from iron ores. Iron scraps costs little more than iron ore but can be converted into steel with much lower economic and environmental cost. Using coke for iron ore reduction produce copious particulate matters including carcinogenic benzopyrene. Recycling of iron reduces this emission by 11 kg/metric tons of steel produced and also cuts iron ore waste and coal mining wastes by 1100 kg/metric tons recycled.

Recycling aluminum uses only 5 % of the energy needed to produce new aluminum from its ore 'bauxite'. Recycling one aluminum beverage can, saves energy enough to run TV for 3 hours. The energy needed to make 1 ton of virgin aluminum from bauxite could be sufficient to recycle 20 tons of aluminum from its scrap. It takes about 4 tons of bauxite to produce 1 ton of finished aluminum. Recycling aluminum reduces air pollution including the toxic 'fluoride' by 95 %, and cut millions of tones of greenhouse gases (mainly CO_2). (AEN, 2000).

Recycling Potential of Paper and Cardboard Wastes

About 30 % of the paper products which we use today are made from recycled papers and cardboards. Three common grades of paper recycled are corrugated cardboard, high grade office paper and old newsprint. Waste papers and card boards make excellent pulp for making different grades of paper to be used for stationary, magazine and newspapers, game boards, ticket stubbs, cereal and cake mix boxes, grocery bags, tissue papers, paper towels, egg boxes, cards and packaging materials. If cotton rags are mixed with them they make excellent pulp for making other kinds of papers too. Office papers are recycled to manufacture computer papers, writing and printing papers.

However, infinite recycling of paper is not possible because the fibers become shorter and shorter and the quality of papers declines. Also the tissue papers and the wax coated papers cannot be recycled. The printed papers also need to be de-inked before recycling as it may contaminate the entire fibre stock.

Environmental and Economic Benefits of Recycling Paper Wastes

Recycling of waste papers saves green trees, large amount of energy and water and prevent the use of chemicals. Recycling 1 ton of waste paper saves 13 trees, 2.5 barrels of oil, 4100 kWh of electricity and 31,780 litres of water. About 64 % less energy and 58 % less water is needed to make papers from recycled fibers than to make from virgin pulp obtained from the plants. Recycling half of the papers used in the world today would meet almost 75 % of the demand for the new paper and would liberate 8 mha of forest from clear-felling for plantation for paper production. According to one estimate the energy required to produce one ton of paper from the virgin wood pulp is 16, 320 kWh, while only 6000 kWh is needed to obtain the same amount of paper through recycling from paper waste. Reduction in energy use (oil or electricity generated from fossil fuels) proportionately reduce the emissions of greenhouse gas CO_2 and other pollutants which would have occurred otherwise. (UNEP, 2004).

Recycling of Paper Industry Waste

All paper mills recycle and recover their intermediate and untreated effluents called 'white water' (water passing through a wire screen upon which paper is formed) and thus reduces the volume of spray and wash water it uses. Other wastes like 'sulfite waste-liquor' by-product have been found to have multiple uses. Their complete evaporation produces fuel and other salable by-product used in making core binder, road-binder, road bank stabilizer, cattle fodder, fertilizer, insecticides and fungicides, linoleum cement, ceramic hardener, insulating compounds, boiler-water additives, flotation agents, and in the production of alcohol and artificial 'vanillin'. The liquor may be 'fermented' to produce ethyl alcohol. About 40 liters of alcohol can be produced per ton of dry solids. Acetone and butyl alcohol can also be produced from the liquor waste. Another product of fermenting the liquor is yeast for cattle feed.

The 'spent cooking liquor' produced in the sulfate process (kraft mills) contain recoverable quantities of sodium salts, resins and fatty acids. Caustic soda (Na_2CO_3) is recovered from them. The resin and fatty acids are further refined and have a variety of applications in industry. In chemical precipitation with lime as coagulant, 'lignin' is precipitated which is used both as a fuel and in the manufacture of plastics, production of tannins, as an anti-scale or antifoam agent in boilers. Wastewater from the paper mills have also been found to be good for 'irrigation' of number of crops.

Recycling Potential of Glasses

Glasses are 100 % recyclable and can be effectively recycled for ever. The recyclable glasses in MSW are container glass (the clear, green and brown bottles and jars for food and beverages), flat glass (e.g. window panes), and pressed amber or green glass. Glasses to be recycled is often separated by color into categories of clear, green and amber. Broken glasses are known as 'cullet' which are valuable raw material in the production of new glasses. Manufacturer adds about 40 tons of cullet to every 100 tons of raw materials silica sand to produce glass.

However, several vitreous materials may look and shatter like glasses, but are NOT recyclable. They do not melt like glass. Even a minute amount of these materials can contaminate the whole load of recyclable glasses and render them useless. These are ceramic mugs and plates, cups and crockery such as pyrex and corning ware, mirror, broken drinking glass and flower vase, light globes and laboratory glass. Contamination as little as 5 grams per ton is harmful. One tiny fragment of ceramic material in a load of glass 'cullet' can cause a weakness in the new glass which may crack or even explode when the bottle is filled or opened.

Recycled glasses are being used as raw material in cement production. (Wong, 2000). A British firm is building an industry to recycle the used wine bottles into 'green sand' to be used for filtering drinking water and purify sewage. When the recycling plant is fully developed it can save the quarrying of high quality sand and use all the waste wine bottles. The European Union and the UK Department of Environment, Food and Rural Affairs are funding the project. (www.drydenaqua.com).

Environmental and Economic Benefits of Recycling Glass Wastes

The cullet (broken glass materials) melt at low temperature than the primary raw materials and hence require 25-30 % less energy on addition and also extends the life of melting furnaces. Every ton of cullet used saves the equivalent of 30 gallons of oil and replaces 1.2 tons of virgin raw materials and proportionately reduce the emissions of greenhouse gas CO_2 and other pollutants which would have occurred upon use of oil and other energy sources in the extraction of virgin materials from nature.

Recycling Potential of Plastic Wastes

Recycling of plastic wastes is not really a good option and is rather a hazard for the human health and the environment. It gives out 'toxic' fumes like 'dioxins' during melting. Technologies are not available for recycling of all categories of plastics. Plastics are recycled by codes. Currently only plastic bottles made of PET (Code 1: soft drink, juice and water bottles and some plastic jars); HDPE (Code 2: milk bottles, cream containers and juice bottles); PVC (Code 3: detergent, shampoo and cordial bottles); PP (Code 5: ice cream containers, takeaway food containers flower pots etc.); PS (Code 6: polystyrene cups, glasses and meat trays), and bottles with 'R' or 'please recycle' symbols are accepted for recycling.

Two types of plastics most commonly recycled in world are PET (Polyethylene Terephthalate) and HDPE (High Density Polyethylene). PET is recycled to make soft drink bottles, deli and bakery trays, carpets, fibrefill and geotextile liners for the waste landfills. HDPE is recycled to manufacture plastic milk, disinfectant and detergent bottles, recycling bins, sleeping bags and pillow stuffing, roadside guide posts, irrigation pipes, eskies, water meter boxes, air-conditioning and recycled layer in new PET plastic bottles, agricultural water pipes, bags and motor oil bottles. LDPE (Low Density Polyethylene) is recycled to make new plastic bags and films. PVC (Poly Vinyl Chloride) is recycled to manufacture drainage pipes, non-food bottles and fencing posts. Recycled polypropylene (PP) is used in auto-parts, carpets and geo-textiles. Recycled polystyrene (PS) is used to manufacture wide range of office accessories, video-cassettes and cases.

Plastic grocery bags made of LDPE or very thin HDPE cannot be recycled as they clog the system. Some supermarkets take back plastic shopping bags, recycling them into bin liners, and hospital waste bags. Other plastics like motor oil containers, plastic takeaway food containers and disposable nappies also cannot be recycled. Also different plastics cannot always be recycled together. The recycled plastic is often hard and brittle. To overcome this problem a 'compatibilser' molecule that sticks together the different plastic molecules have been developed. Such commingled plastic with much gloss and sturdiness as the originals can be used to make 'car bumpers' and fence posts.

Environmental and Economic Benefits of Recycling Plastic Wastes

Recycling of plastics at least diverts thousands of tons of plastic materials from ending up in landfills every year and besides saving landfill space also arrest emissions of some very toxic gases and leachate discharge from the landfills.

Recycling Potential of Waste Wood

It is a waste from the timber industries, forestry and agricultural activities and from building construction and demolitions. Technology found its use in the manufacture of 'plywood' and 'medium density fiber board' (MDF). They have properties like natural wood with additional advantage of not being flammable and absorbing moisture, resistant to pest attack and low cost. They are also shredded and processed as wood chips for fuel or landscaping cover.

Recycling Potential of Construction and Demolition (CD) Wastes

CD wastes results from construction, renovation, and demolition of buildings; road repaving; bridge repairs; and the cleanup after natural disasters. Typically they are made of about 40-50 % rubbish (concrete, asphalt, bricks, blocks, and dirt), 20-30 % wood and related products (pallets, stumps, branches, forming and framing lumber, treated lumber, and shingles), and 20-30 % miscellaneous wastes (painted or contaminated lumber, metals, tar-based products, plaster, glass, white goods, asbestos and other insulation materials, plumbing, heating and electrical parts).

The principal materials that are now recovered from the CD wastes are asphalt, concrete, wood, drywall, asphalt shingles, and ferrous and non-ferrous metals. Reinforcing steel used in foundations, slabs, and pavements are usually recovered and sold as scraps for recycling. Concrete and asphalt are processed for road base, aggregate in asphalt pavement, and as substitute for gravel aggregate in new concrete. Many landfills use the rubbles for road building and as 'daily cover' material for the compacted waste in the landfill. (Hamilton, 2000).

10.7. Recycling Potentials of Some Hazardous Industrial Wastes (IHW)

Technologies have been developed to recycle several categories of hazardous industrial wastes. Several hazardous industrial wastes are now finding new use and applications in construction industries through recycling. (Noll et. al., 1985).

New Use of Phosphogypsum from Phosphatic Fertilizer Industry

Radioactively contaminated calcium sulphate slurry called 'phosphogypsum' ($CaSO_4.2H_2O$) is a waste byproduct of these industries. For every ton of phosphoric acid produced, 5 tons of phosphogypsum (PG) must be removed. It is now being recovered and reused to manufacture partition panel, ceiling tiles/boards, walling blocks etc. They save cement and steel and minimize the use of timber. Direct reuse of PG, however, presents the potential problem of incorporating radioactivity into building or road products.

Several firms in the US and UK is processing the PG into useful cement or plaster. The quality of cement compares favourably with limestone-based cement and is used in all classes of building construction and civil engineering. It possess a 'compressive strength' 3 to 4 times that of Portland cement (1100 kg / cm^2 as compared to 300-400 for Portland cement). Moreover the cost of cement production from PG was US $10 / ton as compared to $ 30- $ 40 / ton for Portland cement. The PG is chemically processed into 'hemihydrate powder' to use in cement manufacture. Some South African fertilizer plants disposes about 25 % of its PG as soil conditioner, cement clinker and as cement retarder. (Noll et. al., 1985).

Any recovery and reuse of phosphogypsum (PG) would also free up reclaimable land resources for productive purposes by the industry or privately.

New Use of Fly-ash from Waste Slurry in Coal-fired Power Plants

Fly-ash is a waste byproduct of coal combustion in coal-fired power plants generally consisting of very fine particles. It pollutes water bodies. The wastewater usually contain 6750 gm / liter of fly-ash. A common method of fly-ash removal from the steam power-plant flue gases is by the use of 'wet scrubbers', 'electrostatic precipitators', or 'cyclone separators'. Major chemical component of fly-ash are silica (30-50 % by weight as SiO2) and alumina (20-30 % by weight as Al_2O). Other materials are sulfur trioxide (SO_3), carbon (C) and boron (B). It is now being reused to manufacture clay bonded bricks / blocks, fly-ash ceramics, aerated light weight cellular blocks and slabs, precast blocks for footpath, butiminous concrete for road surfacing and cement concrete etc. Fly-ash bricks have replaced baked earthen bricks and have saved million tones of fertile soil from getting eroded. Technology has found several new uses for fly-ash:

1) As a pozzolana ingredient in Portland cement;
2) As a pozzolana in soil stabilization;
3) As a soil conditioner in agriculture;
4) As a grout in oil wells;
5) In asphalt roofing and siding materials;
6) As a cement replacement in concrete;
7) As a mineral filler in asphalt pavement;
8) As a coagulant in sewage treatment.

New Use of Red Mud from Aluminum Industry

'Red Mud' is a waste from the aluminum industry being generated in million tones every year. It is a bauxite residue and clay like silt consisting of undissolved minerological components. It is being reused in cement industries both as component of cement raw mix as well as additives. Red mud light roofing sheets has been developed as an alternative to the dangerous 'asbestos' roofs.

New Use of Metallic Slag from Iron and Steel Industries It is a waste from the Iron and Steel industries and an excellent secondary raw material for cement production.

10.8. Thermal Recycling of Hazardous Wastes to Retrieve Thermal Energy

Several hazardous industrial wastes such as paint thinners, degreasing solvents, solvents from ink and printing industries, dry-cleaning fluids, chemical by-products from pharmaceutical industries, waste papers, waste oils and waste auto tires, sewage sludge and municipal solid waste can be used as fuel in industries.

Cement Kiln Using Hazardous Industrial Wastes as Fuel and Replacing Fossil Fuels The manufacture of cement from limestone require high kiln temperatures (about 1500 º C) and long residency times. This create an excellent opportunity for hazardous waste to be used as fuel and also get destroyed in the process. As much as 40 % of the fuel requirement of a well operated cement kiln is saved by the use of hazardous wastes.. It is like 'killing two birds in one shot'. Further, as the environment inside the kiln is alkaline due to the presence of lime, the acidic gases and the hydrogen chloride generated from the chlorinated wastes (which is poses problem in conventional incinerators) are neutralized. Combustion of wastes in a commercial incinerator also produces 'ash' which needs to be disposed off. Here there is no ash and the only by-product is the 'dust' which is recycled. Any incombustible material such as metals in the waste, becomes vaporized and incorporated in the product. Up to 95-99 % of the chloride and over 99 % of the lead entering the kiln are retained by the process solids. When the kilns are operating properly 'dioxins' and 'furans' and the particulate matters (which are emitted in the conventional incinerators) are significantly cut down and there is no risk to human health and the environment. U.S. uses about 1 million tons of hazardous wastes as a fuel in cement kilns every year. Reduction in use of fossil fuels as the source of energy in cement plants proportionately reduce the emissions of greenhouse gas CO_2 and other pollutants which would have occurred otherwise. (Jones and Herat, 1984).

10.9. Recycling Potential of Some Hazardous Consumer Wastes (CHW)

Appropriate technologies are now available to recycle several categories of hazardous wastes including the hazardous electronics wastes (e-waste) generated by society.

Recycling of E-Waste – A Hazardous and Costly Process : Reuse – A Better Option

Millions of tones of e-waste all over the world are ending up in landfills. According to the Silicon Valley Toxics Coalition in the U.S. cost of recycling obsolete and discarded computers is estimated to be at US $ 10 to $ 60 per unit. And if poorly handled during the clean-up cost of toxic materials from the e-waste, it could go higher. SVTC estimates the minimum costs for recycling and proper disposal of the remaining non-recyclable e-waste in US will reach US $ 10.8 billion by 2015 (Schneiderman, 2004). This could be the approximate cost of recycling of e-waste in all developed nations including the European Union, Canada and Australia where labor cost is high. Local governments and councils in these nations have neither the technical ability nor the financial resources to tackle this gigantic techno-economic problem at their own.

'Reuse' is a better option for several categories of e-waste. The term 'reuse' would mean using any old and obsolete electronic product or equipment with or without minor repair and reasonable upgrading, if possible. The best way of reuse is that computers can be sold to the employees of the organizations or the students of institutions at very reasonable price or donated to charitable organizations, schools, orphanage centers, old people homes, women asylums etc. Institutions and organizations in the rich developed nations (where computer models are changing fast) should develop a system based on ethics for donating their old computers to the needy organizations in the developing countries.

The term 'recycling' of e-waste would mean to dismantle the equipment or a product and retrieve the valuable components / materials from it for their reuse in other equipment or re-manufacture a new equipment / product. The difficulty with electronic waste and many other end of life electronic products is that they are made from a huge range of component materials that are useless for further manufacture until the product is dismantled and the component materials are separated – often a very difficult and expensive process.

Recycling may be a good option for the extremely old generation computers such as the Pre-Pentium generation, or the computers (specially the monitors) which are broken. According to the International Association of Electronics Recyclers (IAER) more than 1.5 billion pounds of electronics equipment are recycled annually and is likely to grow by a factor of 4 or 5 by the end of this decade. Eleven countries currently have 'mandatory' electronics recovery laws on the books. These are Denmark, The Netherlands, Norway, Sweden, Switzerland, Japan, Belgium, Taiwan, Portugal and South Korea. Some EU nations have very strong system for e-waste collection, such as the SWICO system in Switzerland and the Netherlands Association for Disposal of Metalectro Products (NVMP). NVMP collect 80 % of e-waste. About 77 % of TVs and 64 % of other small brown goods are recovered for reuse and recycling. (Monchamp, 2000; Cui and Forssberg, 2003; Mathew et. al., 2004)

Recycling Potential of Lead-Acid Car Batteries

Billions of lead-acid car batteries are used and replaced every year across the world, 70 to 80 millions in US alone. The average battery contains about 18 pounds of recoverable lead and the worldwide recycling rate is now 90 %. Batteries are crushed and then the lead, plastic, and sulfuric acid are separated. In an innovative recycling process developed in Italy in the 1980s, batteries are crushed in a hammer mill and the components are separated on a vibrating screen. The acid / lead – paste slurry is neutralized, the lead oxide is separated, and the reusable sodium hydroxide and sulfuric acid are recovered from the solution by electrodialysis. Lead oxides are reduced by electrolysis and combined with metallic components, then melted at 400-500 °C and cast into ingots. (Vaysgant, et. al., 1995).

Recycling Potential of Household Batteries

Billions of household dry-cell batteries are used and discarded worldwide, 2.5 billion in the US alone. These batteries are discarded with the general household waste. These batteries contain mercury, cadmium, lead, and other metals, which become toxic contaminants in the landfill leachate or in the air emissions if MSW are incinerated. Study reveals that household batteries are the source of more than 50 % of the mercury and cadmium in the MSW. Recycling of these batteries are difficult. Cylindrical 6-volt and 9-volt alkaline and carbon-zinc batteries are not recyclable. Only nickel-cadmium cylindrical cells or mercuric oxide and silver oxide button cells can be recycled. Mixed button batteries are difficult to sort out and may present a storage hazard in the MSW waste bin due to mercury vapor emissions.

Recycling Potential of Auto Tires

Several millions of auto tires are rejected every year all over the world which turn as hazardous wastes. Earlier they were reused after 'retreading', but with the advent of steel-belted radials and cheaper new tires most are discarded as waste. They cannot be landfilled as they occupy large volume and tend to come to the surface.

Auto tires present problem for safe recycling as they are made of 'hazardous materials'. The best option is to reuse them as 'fuel' resource in cement kilns. About 70 % of the waste auto tires in the US is being used as source of energy in cement kilns thus also reducing use of coal and emission of greenhouse gases. Power plants, paper and pulp mills and the cement kilns commonly use the shredded tires as fuel. Whole tires are also used to create 'artificial reefs' for erosion control and as highway crash barriers. Split and punched tires are used to make muffler hangers, belts, gaskets, and floor mats.

Recycling Potential of Waste Oils and Lubricants from Automobiles Industries

Billions of gallons of petroleum-derived waste oil are produced worldwide mostly from the automobiles and some from the industries. Automotive oils include crancase oil, diesel engine oil, transmission, brake and power steering fluids. Waste oil often contains metals like arsenic, cadmium, barium, chromium, and zinc; chlorinated solvents and organic compounds like benzene and naphthalene.

Used lubricants can be recycled in two ways- by reprocessing and by re-refining. Reprocessing is done by water and bottom sediment removal of suspended material and ash by gravity settling or chemical treatment to produce partially cleaned fuel oil. Heat is sometimes used to decrease viscosity and improve gravity settling. Distillation is also done to evaporate light fuel fractions. Re-refining produces a clean oil but it is very expensive affair. This is done by solvent treatment / vacuum distillation / hydrotreatment; by acid clay, chemical cleaning / demetalling etc.

Recycled lubricating oils are used as transformer oil, equipment oil, motor oil, cutting oil, soluble oil, diesel oil, gasoline, antifreeze, brake fluids and hydraulic oils. Waste oils are mainly recycled to be used as fuel in cement kilns, in commercial, industrial, and marine boilers, and for space heating. Waste oils can also be used as fuel in cement kilns, in commercial, industrial, and marine boilers, and for space heating.

11. Some Policy Measures on Waste Management by Global Society

Considerations of environmental sanitation, health and hygiene, contributing to safety and security of society are key factors which has prompted to enact suitable legislation for management of all kinds of waste by the global society. Safe waste management is not only a technological pursuit, but also require legal and administrative, economic and ecological planning.

Governments can develop policies to encourage and support the manufacture of ‘durable’ and ‘recyclable’ goods as well as ‘take-back programs’ by producers to recycle their products. If required to ‘take-back’ and recycle their products, manufactures will be compelled to produce durable and recyclable items, thus reducing waste for consumers.

11.1. The European Union’s Packaging and Packaging Waste (PPW) Directive (1994)

On average each EU citizen is currently responsible, directly or indirectly, for the generation of some 172 kg of ‘packaging waste’ every year. (UNEP, 2006). As early as in 1994 it issued this directive to ‘prevent’ packaging waste. Yet, the packaging waste (PW) generation increased by 10 % in the EU-15 between 1997 and 2002, in close line with the 12.6 % growth in GDP. Per capita consumption of plastics increased by almost 50 % from 64 kg / year in 1990 to 95 kg / year in 2002. Only UK managed to actually reduce, and Austria stabilize the generation of PW since 1997.

The review of the EU-15 PPW in 2005 however, showed that the both the producers (companies) and the consumers (society) made good progress in recycling PW. The EU target of recycling 25 % of packaging waste in 2001 significantly increased to 54 % in 2002 in the 15 member countries then. (UNEP, 2006).

11.2. EU Directives on ‘Extended Producer / Manufacturer Responsibility’ (EPR) for Reducing Electronic Waste (2001)

In Europe, e-waste is projected to reach 12 million metric tones by 2010 (Schneiderman, 2004). In 2001, the European Union adopted a system called ‘Extended Producer / Manufacturer Responsibility’ that requires the electronics manufacturers to ‘take-back’ their used products and assume full responsibility for the production of cleaner electronics items, phasing out of hazardous materials in production process, and also dismantling the e-waste products more easily for recycling at the end of their useful life by trading-in the products for recycling.

In January 2003, the EU parliament enacted two directives. The first - ‘Waste Electrical and Electronics Equipment’ (WEE) is based on the concept of Extended Producer Responsibility (EPR) which requires the industries to ‘*take-back*’ all their used and obsolete electronic products for safe recycling. The second directive ‘Restriction on Hazardous Substances’ (RoHS), called for phasing out of heavy metals Hg, Cd, Pb and Cr VI in all electronics items by July 2006 (with a number of exemptions) to reduce hazardous waste when they are discarded. This has now come into effect. (Adam, 2005).

11.3. The International Legal Instruments for Combating the Problem of Hazardous Wastes at Global Level

The United Nations General Assembly initiated to review the international environmental laws in 1981 at Montevideo. The laws were to cover among other things, the transport, handling and disposal of toxic and hazardous wastes. Real negotiations to impose curb on the production, storage and transport of hazardous chemicals and wastes began soon after the Basel Disaster (Switzerland) in 1986 which resulted into the adoption of 'Basel Convention' in 1989.

The Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and Their Safe Disposal (1989)

The Convention was adopted in 1989 unanimously by 116 States in the Swiss city of Basel, to reduce the global generation of hazardous wastes and chemicals to a minimum and to prohibit / regularize the illegal traffic in hazardous wastes and to fix the responsibilities of the parties involved. It entered into force on 5 May, 1992 and now have 131 Parties to the Convention except the U.S. It outlines the general obligations of the hazardous waste generating nations for moving their wastes across their boundaries either for disposal or for exchange for recycling. It also outlines the principles of international co-operation to improve and achieve environmentally sound management of all kinds of hazardous wastes.

Trade in hazardous waste that does not comply with the terms of the Basel Convention or its control system is illegal, and considered to be criminal. Parties are obliged to enact stringent national laws to prevent and punish the illegal trafficators in hazardous waste. The Convention also cooperates with the Interpol over illegal traffic. The first 10 years of the Convention (1989 – 1999) concentrated on consolidating its control system, legal framework and operation through improving the classification of wastes and refining the work on their hazard characterization.

Cooperation to Developing Countries

Under the Convention international cooperation is to be extended to developing countries in:

1. Transferring technology and management systems for hazardous waste;
2. Developing and implementing new environmentally sound low-waste technologies, and improving existing ones to eliminate the generation of waste, as far as practicable, and studying the economic, social and environmental effects of adopting the new technologies;
3. Developing and promoting environmentally sound management of hazardous and other wastes;
4. Promoting public awareness about hazardous waste.

12. Some Innovative Ideas towards Sustainable Waste Management

12.1. The Australian Innovations on Landfill Gas Utilization for Energy Generation While Reducing Emission of Greenhouse Gases

An innovative technology to convert the MSW landfills into a bioreactor is being experimented in Australia. In the traditional landfills the 'anaerobic decomposition' of waste is highly retarded and rather inhibited, as the waste has very little moisture. Daily covering and heavy compaction of waste exclude the moisture content. Normal waste typically contains 10-30 % moisture. The rate of waste biodegradation is a function of moisture content. Bioreactor technology significantly reduces the decomposition time and the production of gas begins soon.

Bioreactor is a large 'anaerobic digester', in a specially designed void in landfills which receives municipal solid wastes and the also the biosolid (sludge) from the sewage treatment plants. In the landfill bioreactor, the waste is not heavily compacted and sufficient moisture content (45 – 60 %) is maintained through extensive networks of pipes that re-circulate the nutrient rich leachate and inject additional water such as the stormwater and the run-off. Additional microbial inoculum is added to promote rapid anaerobic microbial decomposition and biogas (60 % methane and 40 % carbon dioxide) production is augmented with 98 % collection efficiency and conversion to energy. Each kilogram of waste can generate up to 220 liters of methane. In case there is more paper content in the waste, the methane production is 365 litre / kg. A typical 4000,000 tones per year 'landfill bioreactor' will produce about 7,500 cum of methane per hour, with a generating capacity of 25 MW. This will also save greenhouse gas equivalent to taking 175,000 cars off the road.

When biogas generation in the bio-cell declines, the residual partially degraded organic materials can be excavated and used as a 'soil conditioner' or feedstock for composting. Besides, generating biofuel and biofertilizer, the recycling technology will reduce the emission of greenhouse gas (methane) from the landfills. Fugitive emissions of VOCs is decreased to as low as 0.7 %. It would also reduce the environmental risk period of landfills to 5-10 years from 30-50 years.

Power Generation from Landfill Gas

The ReOrganic Energy Swanbank in Ipswich, Brisbane, Australia is generating electricity from the landfill biogas. Natural biodegradation processes in the landfills are enhanced in a special configuration to accelerate the production of biogas (methane). This is supplied to the Swanbank Power Plant for electricity generation displacing coal. By end of April 2002, some 20,000 cubic meters per day of biogas was produced and utilized and over 2,300 MWh of electricity generated. It is envisaged that over this period beginning from 2002 to 2016, some 90,000 cubic meters of biogas per day will be utilized, 500,000 MWh of electricity will be generated, while some 250,000 tones of coal will be displaced and approximately 3 million tones of carbon dioxide equivalent greenhouse gas (methane and carbon dioxide) will be arrested from going to the atmosphere. The $ 4 million project took some 20 months to complete.

After successful utilization of landfill gases for power generation at Ipswich, another $ 5 million landfill gas power generating facility was launched at Rochedale Landfill site in Brisbane in 2004, generating 3 MW of power. This is expected to reduce greenhouse gases by 20,000 tones a year and also supply electricity to 5000 homes. Since the closure of the landfill at Roghan Road, Fitzgibbon in March 2000, BCC has also started generating 2 MW electricity from the methane produced in the old landfill. New waste landfills in Brisbane are now purpose designed to be used as ‘bioreactors’ for biogas generation and electricity production, killing two birds in one shot (www.thiess-services.com.au).

12.2. Molok Waste Bins: Odor Free, Less Space, Holds More Waste and Emptied Less Often : An Australian Innovation

The Molok Pty. Ltd. Of NSW in Australia has invented a new waste collection bin (40 x 120 L size) 60 % of which lies underground and only 40 % is visible. It is installed to a depth of 1.5 meter in ground and takes 80 % less surface area than the conventional waste bins. It comes in 300 L, 1300 L, 3000 L and 5000 L sizes suiting to all locations in residential and commercial areas. The containers are water tight and the waste drop hole opening is approximately 1.1 m above ground level. Within the PVC container is suspended the lifting waste bag made of double layered textile material. While emptying the bag is simply lifted by the hydraulic lifting arm and hoisted into the truck container. Emptying 5000 L Molok bin takes about 3 mins and is one man job.

The key advantage of the vertical bin is that gravity forces the old waste to compact as the new waste is added, and the oldest waste materials at the bottom of the container is kept cool because the earth underground is naturally cool due to evaporation. The lowering of temperature at the bottom reduces microbial activity arresting any odor problem. It is also likely that there will be lesser emission of greenhouse gas methane.(www.molok.com.au).

12.3. The Innovative ‘Bio-Bin’ System of Cleanway for Kerbside Composting of Green Waste

Cleanaway’ is an enterprise of Brambles Industries Limited established in 1970. It operates across Australia and around the world. It provides services in waste recycling, safe hazardous waste disposal, site remediation, and landfill operations. It operates 8 waste recycling plants in four Australian states. It’s co-mingled bin recycling system services over 770,000 Australian households and has participation rate over 85 %. ‘Cleanaway’ has introduced a new and innovative concept of ‘Bio-insert’ system. The ‘Bio-Bins’ break down ‘green organic waste’ on the kerbside and reduces the weight of the waste. It promotes oxygen-flow around and through the organic waste, triggering the aerobic decomposition process. Problems like odor, leachate production and greenwaste sticking to the bottom of the bin are eliminated because of oxygenation. The contents of the bio-bins are less compacted, drier, lighter and more uniform than those in the standard bins. It forms good feed-stock material for the ‘compost facility operators’. A collection frequency of 4 weeks is recommended for green organics, while 2 weeks for the food organics. It is also inexpensive to integrate the bio-bin system into the existing waste management services and would save the city councils considerable expenses in collection and landfill costs. Bio-Bins are widely in use in Europe and North America for the past ten years. A trial of bio-bins is being conducted in the City of Mooney Valley, Melbourne, Victoria with very encouraging results.

12.4. The Innovative DiCOM 'Aerobic-Anaerobic-Aerobic' Hybrid System of Bioconversion of MSW into Clean Biofuel and Biofertilizer

A new and innovative hybrid biological system for composting of MSW was developed in Australia in 2000 by AnaeCo which process the MSW and produces a finished product in less than half the time required for normal aerobic process of microbial composting without any odor problem. The end products are 'green energy' (biogas methane) and 'compost'. This has been termed as DiCOM bioconversion process.

The facility was installed at the cost of $ 5 million and is situated in Perth, Western Australia. It receives commingled municipal solid wastes (MSW) from the local councils, removes the non-compostable inert materials (the dry recyclable) such as the metals, glasses and plastics from the waste and then subject the organic materials to a 'Three (3) Stage Processing' that involves an 'Anaerobic Digestion Phase' in between the initial and final 'Aerobic Composting' period. The methane (CH_4) gas generated from the anaerobic digestion phase is captured and used as biogas fuel for electricity generation at the facility. The separated recyclable materials are sent to MRF. (www.anaeco.com).

The company has patented this technology. The initial bioconversion capacity was 17,000 tons of MSW per annum which increased to 55,000 tons per annum by 2005. The whole plant has small 'ecological foot print' requiring small operational area and with potential for decentralization of waste treatment to multiple sites close to the sources of community waste generation, thus significantly reducing the cost of waste transportation and pollution.

12.5. The Innovative Total Waste Management System' (TWMS) in Australia: No Waste to Landfills

Berrybank Piggery in Victoria Shows the Way Charles Integrated Farming Enterprises Private Limited company in Victoria developed an innovative concept of 'Total Waste Management System' (TWMS) for its Berrybank Piggery. in Victoria, Australia. The piggery produces on an average 275,000 L of effluents (sewage) a day with 'solid contents' approximately 2 %. The company found that the 'traditional farming philosophy' of 'wasting nothing' and 'waste from one part of a farm is the input in another' makes a good business sense. On regular inventory program the management of piggery found that half of the feed consumed by the animals is actually utilized, and the remaining half goes as waste. The company considered this generation of waste as 'poor return on investment'.

The TWMS is a seven-stage process which salvages all the waste byproducts in the form of fuel, fertilizer and flush water. Since the introduction of TWMS, the Berrybank Piggery now daily produces –

- Seven (7) tones of waste solids which are utilized as 'fertilizer' for farms;
- 100,000 L of flush water (recycled water) to be used for flushing toilets;
- 100,000 L of mineralized water rich in essential micro and macro-nutrients which is utilized as 'liquid fertilizer' for farm irrigation; and
- 1,700 cum of biogas fuel (methane) which is used for power generation on farm with daily output of 2,900 kW of electricity.

The capital cost of the Berrybank Farm project was approximately AU $ 2 million which was paid back in about 6 years by way of fuel, fertilizer and usable water. From a $ 2 m investment made in the TWMS for the Berrybank Piggery, the Charles IFE brings in AU $ 435,000 return every year. Other environmental benefits was that the odor problem and the risk of groundwater contamination (due to sewage) was completely eliminated and it dramatically reduced the consumption of freshwater

(www.environment.gov.au/settlement/industry/corporate/eecp/case-studies/charlesife.html)

12.6. The Indian Innovation on Dumpsite Composting of Commingled MSW: A Cheaper and Safer Alternative to Costly Landfills?

An innovative technology to compost the un-segregated municipal solid waste (MSW) biomass on ordinary waste dump-site was developed in India in the 1990's and is giving excellent results for managing the solid wastes. No prior segregation of commingled waste is required. Segregation of commingled wastes at source or before composting imposes the biggest obstacle in any composting technology because it is highly labour intensive job to segregate the often sticky and wet biodegradable (compostable) matters from the dry non-biodegradable ones. It becomes much easier after composting.

The technology was developed by Ms. Excel Industries, Mumbai, India and can suit to all countries and is also flexible for 150-700 MT of waste per day. The largest plant with an installed capacity to bioprocess 500 tones /day of MSW is operating in Mumbai. The process can recycle all organic wastes from the households, restaurants and hotels, dairy, agriculture and agro-processing industries, brewing industries and slaughter houses. (Ranjwani, 1996;.Sinha and Herat, 2002 b).

The Bioconversion Process and the Composting Mechanism

The dump site is leveled and either cemented or paved with bricks on the bottom to prevent leachate and for easy movement of waste carrying vehicles. Long windrows, about 5 meters wide and 2-3 meters high (deep) are erected and the MSW is then stacked and heaped in the windrows. A 'microbial consortium' slurry containing active decomposer bacteria and enzymes are then added to the windrows to initiate rapid aerobic decomposition of the waste biomass. The slurry is spread on the surface of the garbage and inside the heaps in the windrows with help of probes, so that it reaches deep and in every pocket of the heap. Microbial culture of active decomposer bacteria is prepared from the 'sewage sludge' which contains active decomposer bacteria in millions/gram of the sludge. (Ranjwani, 1996).

The microbial culture is known as ‘Celrich Substrate DF BC-01. It is prepared after analyzing the composition of the waste and identifying the predominant materials such as celluloses, hemicelluloses, lignins, proteins and fats etc. The microbes produce enzymes such as cellulase, lipase, amylase, protease, pectinase and phospholipase to breakdown the long chain complexes of the substrates. About 1 kg of the consortium in the colloidal emulsion form is mixed with 20 litres of water to be used for spraying on about 3 cubic meter of solid waste and for one ton of waste 200 litres of water is needed. Recycled water can also be used. The waste heaps are turned around once in 7 to 10 days for proper aeration and the inoculant slurry is sprayed in each turning to enhance decomposition and maintain the proper moisture level which is usually 45 - 55 %. The process is ‘exothermic’ and the windrows reach a temperature of 70°-75 °C within 24-36 hours, killing the harmful pathogens and repelling all birds, stray animals, flies and mosquitoes from the dump site. (Ranjwani, 1996).

Recovery of Compost

The entire process of aerobic decomposition of garbage is completed within 4-6 weeks and as the decomposition is complete the temperature comes down to normal. It recovers over 90 % of the organic matter in the form of compost which may be 25-30 % of the raw waste on dry weight basis. Recovery of compost depends upon the presence of organic matter in the garbage. There will be greater recovery of compost in developed countries as much higher amount of organic wastes reaches the dump-sites (tips) in every city.

Retrieving the Dry Recyclables

The decomposed waste biomass is passed through rotary and vibratory screens to sieve out the compost. The soft decomposed powdery materials gets easily separated from the plastics, metals, stones and pebbles. About 20-25 % are dry recyclable materials and the rest about 20-25 % are inert materials which are disposed in ordinary land-fills.

Same Land for Dumpsite Can be Reused and No Need of Engineered Landfill

The same dump-sites can be used again and again after excavating the biodegraded mass (compost) and there is no need of additional land for making more dump-sites. Also the need for ‘engineered land-fills’ are greatly reduced because very little is left to be disposed off after retrieving the compost and the recyclable materials.

Low Emission of Greenhouse Gas Methane

The problem of emission of landfill gas methane (CH_4) is significantly minimized as the waste is turned constantly and the waste biomass is thoroughly aerated throughout the composting period.

Foul Odor at Waste Dumpsite Disappear Soon Giving Relief to Waste Workers

Emission of ammonia and hydrogen sulfide which are mainly responsible for foul odor at the waste dump-site (tips), and the leachate discharge is also greatly reduced. The foul odor at the waste dump-site disappear within 2-3 days of sanitization by the microbial culture giving great relief to the waste workers and the local residents.

13. Conclusion and Recommendations

An assessment of waste generation not only involves the production and distribution of commodities and services but also its actual history of use/reuse/recycling. How people act as consumers, re-users and recyclers is as important as how a thing is made and sold to consumers.

Any government policy, any waste reducing and recycling technology and strategy cannot succeed unless every member of society is aware and behave responsibly. Sometimes policing becomes essential to change societal behavior. Random check of waste bins by councils and 'refusal' to pick up waste not disposed according to council directives, can force people to behave. The strategy has worked well in some Canadian cities. Economic instruments also seem to affect human behavior. 'Landfill taxes' in Denmark, Austria, Ireland, Italy and the UK, and charging people for plastic bags in supermarkets in Denmark and Ireland (and in France from late 2005 onward) have changed the human behavior in these nations. Manufacturers of consumer goods hold great responsibility in reducing waste in modern consumerist society. Governments of nations need to come out with a policy of 'durable and recyclable goods' by manufacturers, and also 'take back policy' of their products for recycling. It will also be a 'disincentive' for them to change their product versions too frequently to lure people.

Society has to play very critical role in all waste management programs. The traditional societies were basically 'recycling societies'. They made best use and reuse of all materials several times before discarding them. The modern society is basically a 'throwaway society' which discard most materials after short use. Modern human societies have to revive some of the 'traditional cultures' of resource conservation, resource recycling and their ethical use. Waste recycling is essential for economic stability, ecological sustainability, environmental safety and survival of the global human society.

Human society has to begin the process of recycling at the source – the home, office, or factory- so that fewer materials will become part of the disposable solid wastes of a community. A 'consumer education' program is needed to educate the society about the hidden 'environmental value' (the energy and water it has saved, the pollution and deforestation it has prevented) of the recycled goods. All recycled goods should have 'recycled tag' telling about the origin and life history of the goods (from which waste it was produced) and how it has saved the environment. It would develop a sense of 'civic pride' among the consumers that he / she is helping the environment. There is always greater economic and ecological wisdom in reducing waste at source, and diverting more and more of the waste to the 'mechanical recycling, 'biological recycling' (composting) and 'thermal recycling' (combustion) processes to recover some useful materials and energy from them and reduce their volume, so that less and less waste is left for final disposal in landfills.

Government, industries, science and society all have to join hands in fighting the menace of mounting wastes. Industries producing consumer goods have to play more responsible role in waste management program because they have potential to generate waste twice in the life-cycle of the goods produced. First at the 'production level' when they process the virgin raw materials and generate 'industrial wastes'. Second at the 'consumption level' when the goods produced by them are used and discarded by the society as 'municipal solid waste' (MSW). Policy makers have carrot and stick options to encourage or enforce industry to contribute to reduce waste. Industrialists also owe moral obligation to provide necessary information to its prospective buyers on the matter of using, handling, conservation, disposal and recycling potentialities of its products. In designing new products, the industry must assess its potential and even suspected adverse impact on its consumers health and the environment.

We need more and more waste to be converted into resource (by recycling) to sustain our growing population as the several natural resources are either on decline or becoming scarce or are unavailable and beyond our capability to exploit them sustainabily with present technology and within the ecological limits. Government must encourage and promote the recycling industries using waste as raw materials by way of reduced taxation, reduced cost of water and electricity supply etc. Given current technology, not all the municipal or industrial wastes can be readily recycled. Nor do all the waste materials have qualities that currently make them a valuable commodity in the recycling marketplace.

Hazardous waste is growing in U.S. industries and very little is being done to reduce or recycle them at source. Most hazardous wastes are being exported to poor developing countries either for dumping or for recycling. (Duke, 1994). Wrong policy decisions of the U.S. government has aggravated the problem. Study made by an environmental organization in the U.S. indicates that subsidies given to the timber, mining, oil, energy, and waste disposal industries undermine and discourage waste recycling industries. These subsidies lower the cost of products made from new and virgin materials, giving them a competitive advantage over those made from recyclable materials. Fifteen government subsidies given to these industries in the U.S. amounted to as much as US $ 13 billion over the next 5 years. It was a great setback for the waste recycling industries in the U.S. They include indirect subsidies such as cheap water and energy supply to these industries.(UNEP, 2006).

Life-cycle assessments is also important to determine the recycling potential of a waste product. A number of life-cycle assessments have found that fully recycled paper is not always the most environmentally friendly choice. In some countries paper produced from local agricultural wastes, such as rice straw, may be environmentally more sustainable than that produced from recyclable paper wastes shipped from overseas or transported from distant locations in the same country. One study in Australia found that if the recyclable paper waste is transported more than about 20 km by road, the energy balance (fuel used and pollution generated during transport) is not in favor of recycling.

Safe disposal of the radioactive wastes which are accumulating exponentially in the human environment cannot be guaranteed at all even after huge expenditure. A huge pile of radioactive wastes (most in the U.S., France and Japan) remains to be disposed safely. It was just 84,000 tones in 1990 and must have crossed 100,000 tones limit by now. According to the celebrated geologist Konrad – ‘No scientist or engineer can give an absolute guarantee that radioactive waste will not some day leak in dangerous quantities from even the best of repositories’. The word ‘safe’ seems to be incompatible with radioactive wastes.

However, ‘waste prevention’ through ‘cleaner production’ is considered to be even more wiser and sustainable idea of waste management so that any treatment or recycling is not at all needed and tremendous cost can be saved. Waste prevention would also reduce the cost of construction and maintenance of secured landfills because some residual wastes are always left after treatment or recycling which has to be safely dumped in the landfills.

Educating the ‘environmentally illiterate’ society is a big challenge. People need to understand the importance of their activities in the context of global consequences, for instance, the ‘links between waste generation, greenhouse gas emission and climate change’.

Waste education needs to take place in a continuous way through schools and universities, through mass and diffuse media and community education programs run by governments at all levels as well as non-government organizations, businesses and industries.

Waste education of society should become an integral part of all waste management programs. We have to mend our ways, change our behavior and attitude of life, re-order our priorities, simplify our life-style, and then only the gigantic problem of mounting solid waste, which literally threatens to bury the mankind alive, can be overcome. Only a 'resource conserving, waste reducing and waste recycling' society would be the 'sustainable human societies' of the future and the 'throwaway wasteful societies' would perish.

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EFFECTIVE REMOVAL OF LOW CONCENTRATIONS OF ARSENIC AND LEAD AND THE MONITORING OF MOLECULAR REMOVAL MECHANISM AT SURFACE

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ABSTRACT

New sorbents were investigated for the effective removal of low concentrations of arsenic and lead to adjust to modern worldwide environmental regulation of drinking water (10 ppb). Mesoporous Fe oxyhydroxide synthesized using dodecylsulfate was most effective for initial 200 ppb of As removal, especially for more hazardous arsenite for human's health. Hydrotalcite-like layered double hydroxide consisted of Fe and Mg was most effective for initial 55 ppb of Pb removal.

The molecular removal mechanism is critical for environmental problem and protection because valence state change upon removal of *e.g.* As on sorbent surface from environmental water may detoxify arsenite to less harmful arsenate. It is also because the evaluation of desorption rates is important to judge the efficiency of reuse of sorbents. To monitor the low concentrations of arsenic and lead on sorbent surface, selective X-ray absorption fine structure (XAFS) spectroscopy was applied for arsenic and lead species adsorbed, free from the interference of high concentrations of Fe sites contained in the sorbents and to selectively detect toxic As^{III} among the mixture of As^{III} and As^{V} species in sample.

Oxidative adsorption mechanism was demonstrated on Fe-montmorillonite and mesoporous Fe oxyhydroxide starting from As^{III} species in aqueous solution to As^{V} by making complex with unsaturated $FeO_x(OH)_y$ sites at sorbent surface. Coagulation mechanism was demonstrated on double hydroxide consisted of Fe and Mg from the initial 1 ppm of Pb^{2+} aqueous solution whereas the mechanism was simple ion exchange reaction when the initial Pb^{2+} concentrations were as low as 100 ppb.

INTRODUCTION

Recently, global environment induces even serious debate, *e.g.* the Novel Prize 2007 for Piece to "*An Inconvenient Truth*" by Al Gore [1]. The environmental problem is not only the

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global warming as the major claim in this movie/book by Gore. Contamination of water and soil is one of traditional, major environmental problems and directly affects the human health, *e.g.* carcinogenic risk via drinking water [2 – 4]. Cadmium contaminated in rice [5], copper contaminated in environmental water from mine, mercury contaminated in fish [6 – 8], and arsenic contaminated in powdered milk are most notorious environmental tragedies occurred in Japan between 1890 and 1960. These accidents are all related to contamination of water derived from human activity (industry) [2].

The health risk of poisonous elements in water has been studied and is becoming clear. Recent environmental regulation sets the minimum level of Mn, Cu, Cd, Pb, Cr, As, and Hg to 400, 125, 5, 10, 50, 10, and 0.5 ppb, respectively. Among these elements, lead is less focused and less intensively studied to adjust to the regulation. Arsenic can be contaminated in ground water not only anthropogenically but from the earth naturally [2 – 4]. Unfortunately, mines containing As mainly distribute in contact with the ground water in developing countries, *e.g.* Bangladesh, East Bengal, Argentina, Chile, and Vietnam [9]. Especially in Bangladesh, the shallow ground water with arsenic concentrations up to 1 ppm is often used pumped from tube wells without adequate treatment for drinking and thus leading to serious health problem. The arsenic release into ground water is related to microbial metabolism of organic matter [10]. The high capital and maintenance costs of piped water supply are still not acceptable in Bangladesh, especially most affluent villages compared to present individual tube wells [10]. Lead was used as gasoline additive and automobile tail pipes and may be included in drinking water from water supply pipes made of lead, soil contamination, and toys/tools made in developing countries [11, 12].

This chapter reviews recent development of sorbents for low concentrations of Pb and As to adjust to modern environmental regulation for drinking water and monitoring of the molecular removal process by selective spectroscopy in water [13]. The monitoring of surface uptake of Pb [14] and As includes local coordination structure and electronic structure changes in the inner sphere reaction.

METHODS

This chapter focuses on the removal of Pb and As by sorption because sorption is economic process to be applicable in developing countries and the reuse is possible by desorption. The concentrations of Pb and As in test aqueous solutions were set between 55 ppb and 32 ppm in this chapter. Various sorbents were evaluated to maintain the concentrations of Pb or As less than 10 ppb or not.

Fe-montmorillonite was prepared by mixing 0.43 M ferric nitrate solution with Na-montmorillonite (Kunipia F; $Na_{1.5}Ca_{0.096}Al_{5.1}Mg_{1.0}Fe_{0.33}Si_{12}O_{27.6}(OH)_{6.4}$) [15]. A 0.75 M sodium hydroxide solution was added dropwise to the mixture until the molar ratio Fe^{3+} added and hydroxide reached 1:2. Iron cations and/or $FeO_x(OH)_y$ nanoparticles were inserted between negatively-charged montmorillonite clay layers. Recently, some chemical forms of Fe^{III} species formed between montomorillonite layers were spectroscopically analyzed [16]. Monomeric and/or dimeric Fe^{III} species was active in oxidative dehydrogenation of propane. In contrast, polymeric $FeO_x(OH)_y$ nanoparticles were effective for arsenic sorption and unselective propane combustion.

$FeO_x(OH)_y$ porous material was prepared by mixing 0.10 M ferrous chloride with 0.070 M sodium dodecylsulfate followed by the addition of 0.25 M H_2O_2 [17]. Obtained $FeO_x(OH)_y$ material was mixed with 0.050 M sodium acetate in ethanol for anion exchange or with pure ethanol for washing. The micro/mesoporous $FeO_x(OH)_y$ material was characterized by X ray diffraction (XRD), specific surface area measurements and pore volume determination by N_2 adsorption/desorption, high-resolution transmission electron microscope (TEM), Fourier-transformed infrared absorption (FT-IR), inductively coupled plasma (ICP) combined with optical emission spectroscopy (OES), electron probe microanalysis (EPMA), thermo-gravimetric differential thermal analysis (TG-DTA), and Fe K-edge X-ray absorption fine structure (XAFS). Based on these analyses, detailed structural transformation was clarified for the sorbents as depicted in Figure 8 of Ref [17].

Hydrotalcite-like (pyroaurite) layered double hydroxide $Mg_6Fe_2(OH)_{16}(CO_3)•3H_2O$ was synthesized via the procedure described in Ref 18. The carbonate anions are sandwiched between positively-charged $[Mg_3Fe(OH)_8]^+$ layers.

To monitor low concentrations of Pb and As, XAFS spectroscopy is most appropriate technique. For several spectroscopic techniques of structural analysis in the application to nanotechnology, the advantage and drawback were summarized in Table 1 [19]. For non-crystalline or hybrid samples, EXAFS (extended X-ray absorption fine structure) gives direct structural information for X-ray absorbing local element sites. XANES (X-ray absorption near-edge structure) is a part of EXAFS spectrum near the X-ray absorption edge region ranging up to 100 eV and gives electronic and (indirectly) structural information [20].

Table 1. Various Analytical Methods for Nano Structure Classified Based on Directness of the Information and the Target to Be Analyzed

Method	Directness	Target
TEM (Transmission electron microscope)	Direct	Local
XRD (X-ray diffraction)	Direct	Local
EXAFS (Extended X-ray absorption fine structure)	Direct	Bulk
XANES (X-ray absorption near-edge structure)	Indirect	Bulk
Raman	Indirect	Bulk
Small angle scattering	Indirect	Bulk
NMR (Nuclear magnetic resonance)	Indirect	Local
Mössbauer	Indirect	Local
SPM (Scanning probe microscope)	Indirect	Local (surface)
Reflectivity	Indirect	Local (surface)

Thus, XAFS spectroscopy (EXAFS, XANES) is essentially single technique for local structure analysis accompanied with valence and coordination symmetry information of nanoparticles and micro/mesoporous materials. The Pb and As adsorbed from low concentrations of aqueous solutions in this chapter are typical examples of nanoparticles and micro/mesoporous material samples.

Further, this chapter combines X-ray fluorescence (XRF) spectrometry with the XAFS spectroscopy [21 – 24]. Simply, XRF spectra support valence state information deduced from XAFS. Essentially, high-energy-resolution XRF spectrometry is able to discriminate valence state of Pb and As. In this chapter, the XRF signals originating from Pb^{II}, As^{III}, and As^{V} were monitored independently in the XAFS measurements to obtain each coordination structure of Pb^{II}, As^{III}, and As^{V} (*state-selective XAFS*). The experimental setup and measurement conditions for state-selective XAFS were depicted and described in Refs 21, 23, and 24. In brief, XRF spectra and state-selective XAFS spectra measurements were performed at Undulator beamline 10XU of SPring-8 (Sayo, Japan) by utilizing a homemade high-energy-resolution Rowland-type fluorescence spectrometer equipped with a Johansson-type Ge(555) crystal (Saint-Gobain) and NaI(Tl) scintillation counter (Oken). The monochromator of beamline used Si(111) double crystal and the X-ray beam intensity in front of sample was monitored using ion chamber (Oken) purged with N_2 gas.

RESULTS AND DISCUSSION

Arsenic Problem. Adsorption isotherms of arsenite and arsenate at 290 K for 12 h on Fe-montmorillonite in batch setup are depicted in Figure 1. The Fe-montmorillonite was superior to α-FeO(OH) (göthite > 95%) both for arsenite and arsenate sorptions. Fe-montmorillonite consisted of 2-dimensionally distributed Fe^{3+} ions and $FeO_x(OH)_y$ nanoparticles between clay layers [16].

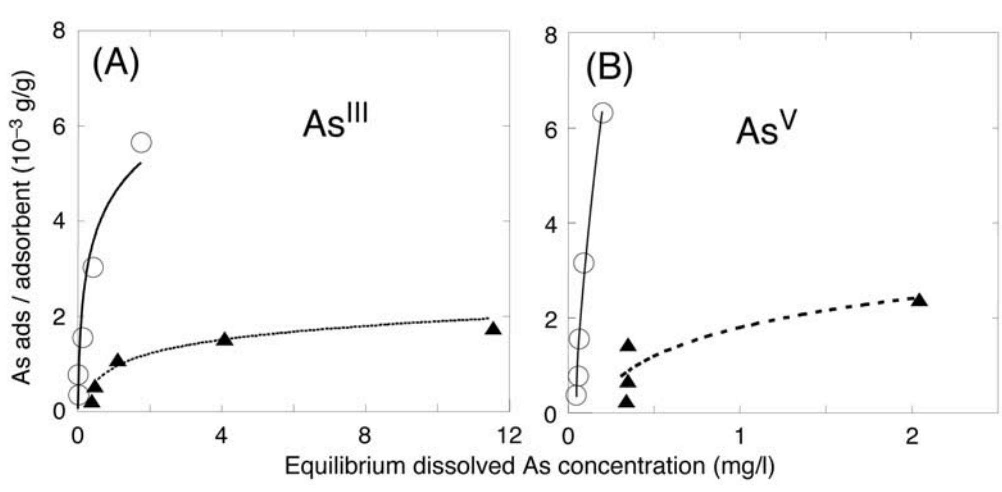

Figure 1. Adsorption isotherms of arsenite (A) and arsenate (B) at 290 K on Fe-montmorillonite (14.0 wt% Fe) (circles) and α-FeO(OH) (triangles). Batch tests for 12h. Observed data were plotted as points and the fits to first-order Langmuir equations were drawn as lines.

The saturated amount of As adsorbed was evaluated to 8.0 and 76 $mg_{As}\ g_{sorbent}^{-1}$ for arsenite and arsenate, respectively, on Fe-montmorillonite. The equilibrium adsorption constant was 1.4×10^6 ml g_{As}^{-1} for arsenite on Fe-montmorillonite. Even better adsorption capacity was found on acetate-exchanged microporous $FeO_x(OH)_y$ as depicted in Figure 2 for arsenite. The saturated amount and the equilibrium adsorption constant of As adsorbed were evaluated to 21 $mg_{As}\ g_{sorbent}^{-1}$ and 1.0×10^7 ml g_{As}^{-1}, respectively. The high specific surface area of microporous $FeO_x(OH)_y$ (230 $m^2\ g^{-1}$) was advantageous compared to Fe-montmorillonite (100 $m^2\ g^{-1}$) with as much as 14 wt% of Fe. Utilizing template synthesis technique for microporous and mesoporous materials, lower coordination FeO_x sites were effectively exposed to surface to complex with $As^{III}(OH)_3$ [17, 26]. The acetate-exchanged and ethanol-washed $FeO_x(OH)_y$ consist of 3-dimensionally distributed wormholes exposed with coordinatively unsaturated FeO(OH) sites.

The surface uptake mechanism of most toxic arsenite was monitored by XRF and XAFS spectroscopy. Arsenic was adsorbed on Fe-montmorillonite from 200 ppb test aqueous solution of arsenite. The As $K\alpha_1$ emission spectrum was depicted in Figure 3. The peak energy position suggested that the adsorbed As state changed to V, not remained at III, compared to the data for $KH_2As^VO_4$ and $As^{III}{}_2O_3$ [15].

As K-edge XANES spectra for standard inorganic compounds of As^0, As^{III}, and As^V consist of broad peak feature (Figure 4a – c) and it is complicating to evaluate each valence contribution to a spectrum for sample of mixed valence. In order to demonstrate directly the oxidative adsorption of arsenite suggested above, the author of this chapter observed the uptake of low concentrations of arsenite on Fe-montmorillonite by means of state-selective XAFS. Note that the energy resolution of fluorescence spectrometer (1.3 eV; Figure 3) was smaller than the core-hole lifetime width of As K level (2.14 eV) [27].

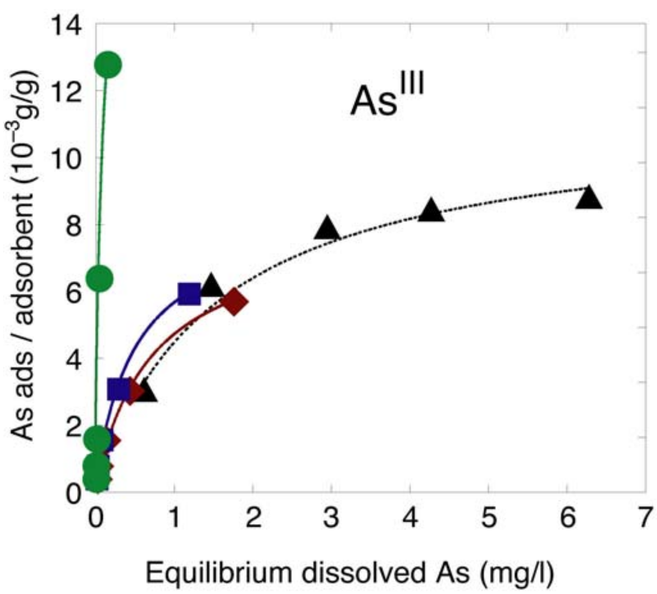

Figure 2. Adsorption isotherms of arsenite at 290 K on acetate-exchanged $FeO_x(OH)_y$ previously heated at 423 K (circles), ethanol-washed $FeO_x(OH)_y$ previously heated at 423 K (squares), Fe-montmorillonite

(14.0 wt% Fe; diamonds), and α-FeO(OH) (triangles) [25]. Batch tests for 12h. Observed data were plotted as points and the fits to first-order Langmuir equations were drawn as lines.

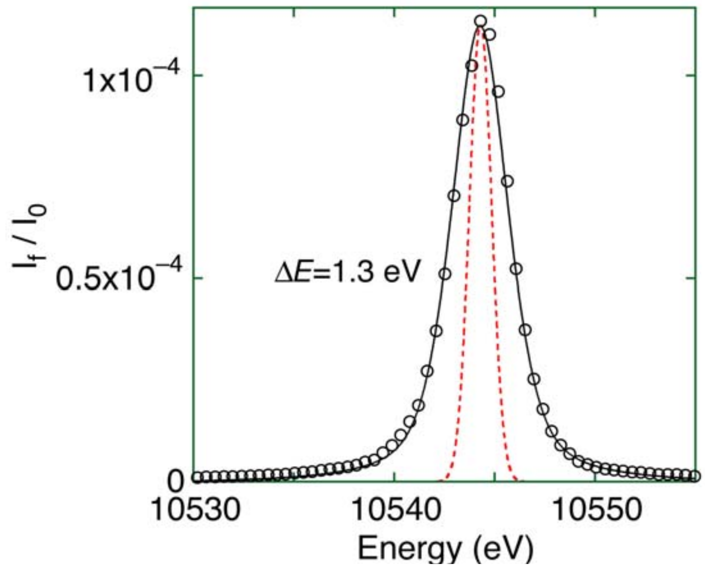

Figure 3. Arsenic Kα_1 emission spectrum for As adsorbed on Fe-montmorillonite (14.0 wt% Fe) from 200 ppb test solution of arsenite (points). A fit to data with pseudo-Voigt function (solid line) and the energy resolution of fluorescence spectrometer (dotted line) were also drawn. The intensity ratio of the Lorentzian and Gaussian components was fixed to 1:1 for the pseudo-Voigt function.

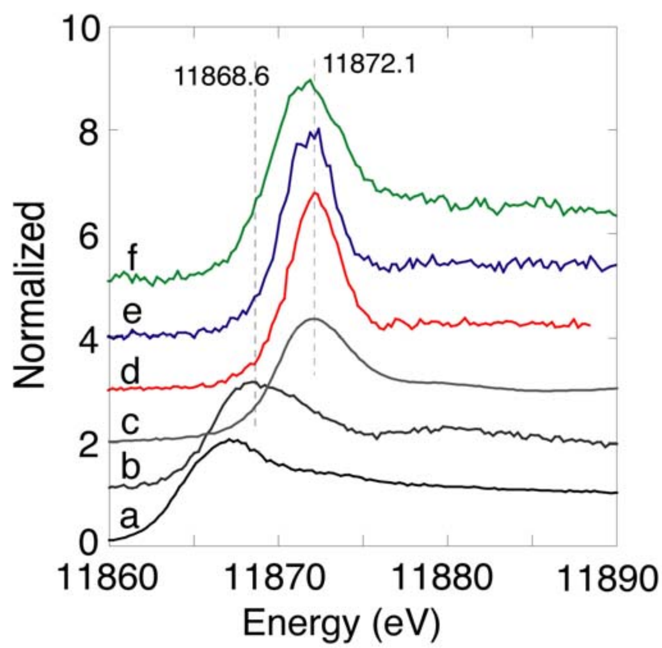

Figure 4. XANES spectra measured at 290 K in transmission mode for As metal (a), $As^{III}{}_2O_3$ (b), and $KH_2As^VO_4$ (c). Arsenic Kα_1-selecting As K-edge XANES spectra measured at 290 K for As adsorbed on Fe-montmorillonite (14.0 wt% Fe) (d – f) from aqueous test solutions of 16 ppm of $KH_2As^VO_4$ (d),

16 ppm of $As^{III}_2O_3$ (e), and 200 ppb of $As^{III}_2O_3$ (f). Tune energy of fluorescence spectrometer was 10544.3 eV for spectra d – f.

Based on the theory discussed in the Appendix section of Ref 24, the As $K\alpha_1$-selecting As K-edge XANES spectrum with the energy resolution of 1.3 eV would be shaper and more resolved. The energy values of K absorption edge and first strong peak after the edge were essentially identical for As adsorbed on Fe-montmorillonite from 200 ppb – 16 ppm of As^{III} solutions (Figure 4e, f) and from 16 ppm of As^{V} solution (d). Thus, oxidative adsorption of 200 ppb – 16 ppm of arsenite on Fe-montmorillonite was confirmed based on As $K\alpha_1$-selecting XANES and As $K\alpha_1$ emission spectrum. Proposed molecular surface uptake mechanism was illustrated in Figure 5 over acetate-exchanged microporous $FeO_x(OH)_y$. The reaction formula was $As^{III}(OH)_3 + FeO(OH) \rightarrow (FeO)_2As^{V}(OH)_2 + H_2O$.

In summary, oxidative adsorption of low concentrations (200 ppb – 16 ppm) of arsenite was found on coordinatively unsaturated $FeO_x(OH)_y$ nanoparticles or micro/mesoporous $FeO_x(OH)_y$ partially covered with acetate anions. The oxidation to arsenate seems to be due to lower coordination of surface $FeO_x(OH)_y$ species. The lower coordination was also the reason to make the equilibrium sorption constant greater for acetate-exchanged $FeO_x(OH)_y$ and Fe-montmorillonite [15, 17].

Lead Problem. Sorption tests for low concentrations (55 ppb) of lead in flow setup were depicted in Figure 6 [18]. The superiority of $Mg_6Fe_2(OH)_{16}(CO_3)\cdot 3H_2O$ was clearly demonstrated to maintain the Pb^{2+} concentration less than modern environmental regulation (10 ppb) compared to commercially available activated carbon.

Lead $L\alpha_1$ emission spectrum for Pb adsorbed on $Mg_6Fe_2(OH)_{16}(CO_3)\cdot 3H_2O$ from 100 ppb Pb^{2+} test solution was depicted in Figure 7. The peak energy was identical to that for standard Pb^{II} compounds. The energy resolution of fluorescence spectrometer in this measurement condition was 5.0 – 10.1 eV dependent on the measurement conditions of fluorescence spectrometer (Figure 7) [24, 28]. Because the core-hole lifetime widths are 5.81 and 2.48 eV for Pb L_3 and M_5 levels, respectively [27], the width for $L\alpha_1$ is 8.29 eV comparable to the energy resolution of fluorescence spectrometer. Thus, sharper, more resolved spectral feature was expected in Pb $L\alpha_1$-selecting Pb L_3-edge XANES spectrum if the energy resolution of fluorescence spectrometer was smaller than 5.81 eV, similar to the case of As $K\alpha_1$-selecting XANES in previous section.

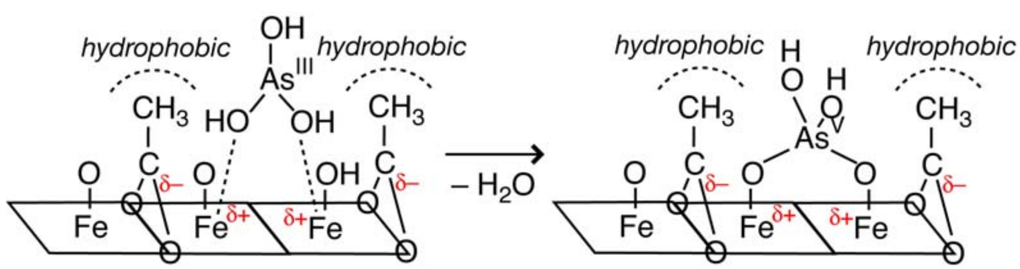

Figure 5. Proposed adsorption mechanism of low concentrations of arsenite on acetate-exchanged $FeO_x(OH)_y$ previously heated at 423 K.

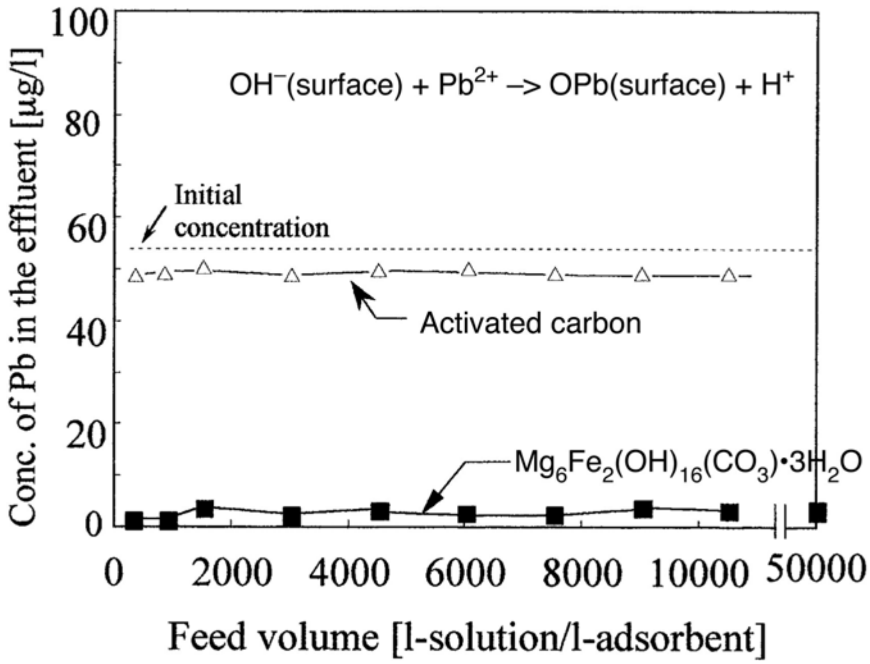

Figure 6. Results of sorption on $Mg_6Fe_2(OH)_{16}(CO_3){\bullet}3H_2O$ and on activated carbon from 55 ppb of Pb^{2+} aqueous test solution. The space velocity was 150 min^{-1}.

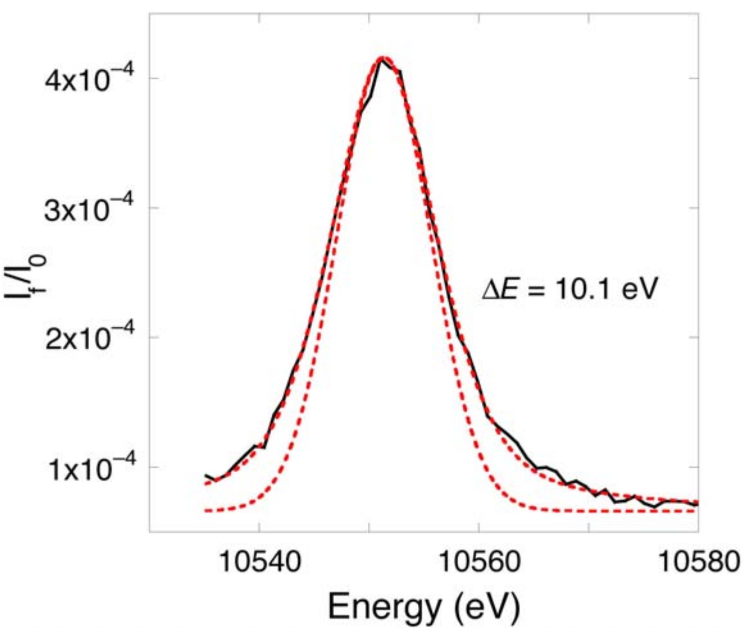

Figure 7. Lead $L\alpha_1$ emission spectrum for 0.12 wt% of Pb adsorbed on $Mg_6Fe_2(OH)_{16}(CO_3){\bullet}3H_2O$. The solid line is the experimental data, and (wider) dotted line is a fit with a pseudo-Voigt function. The intensity of the Lorentzian and Gaussian components was fixed to 1:1. The narrower dotted line is the energy resolution of fluorescence spectrometer (10.1 eV).

Pb $L\alpha_1$-selecting XANES spectra are shown in Figure 8a – c. The spectral pattern of b and c resembled each other. The two samples contained 0.30 – 0.12 wt% of lead adsorbed from 100 ppb test aqueous Pb^{2+} solution. The Pb contents in samples were determined by ICP. Compared to XANES spectra for standard inorganic Pb compounds (Figure 8d – i) and supported Pb species on zeolite [29] or on Fe_2O_3 [30], the spectra b and c resembled most spectrum d measured for ion-exchanged PbY zeolite (d). Thus, surface uptake mechanism via ion exchange reaction was proposed on $Mg_6Fe_2(OH)_{16}(CO_3)•3H_2O$ from relatively low concentration of 100 ppb divalent lead solutions (Figure 9). The reaction formula is $[Mg_3Fe(OH)_8]^+ + Pb^{2+} \rightarrow [Mg_3Fe(OH)_7(OPb)]^{2+} + H^+$.

Pb $L\alpha_1$-selecting XANES spectrum for Pb adsorbed from 1.0 ppm test Pb^{2+} solution is depicted in Figure 8a. Compared to XANES spectra for standard inorganic Pb compounds (Figure 8d – i), the spectrum a resembled most spectrum g measured for $2PbCO_3•Pb(OH)_2$. Thus, coagulation uptake mechanism was proposed on $Mg_6Fe_2(OH)_{16}(CO_3)•3H_2O$ from relatively high concentration of 1 ppm Pb^{2+} test solution. Thus-identified reaction formula was $Pb^{2+} + nCO_3^{2-} + 2(1-n)OH^- \rightleftarrows nPbCO_3•(1-n)Pb(OH)_2$.

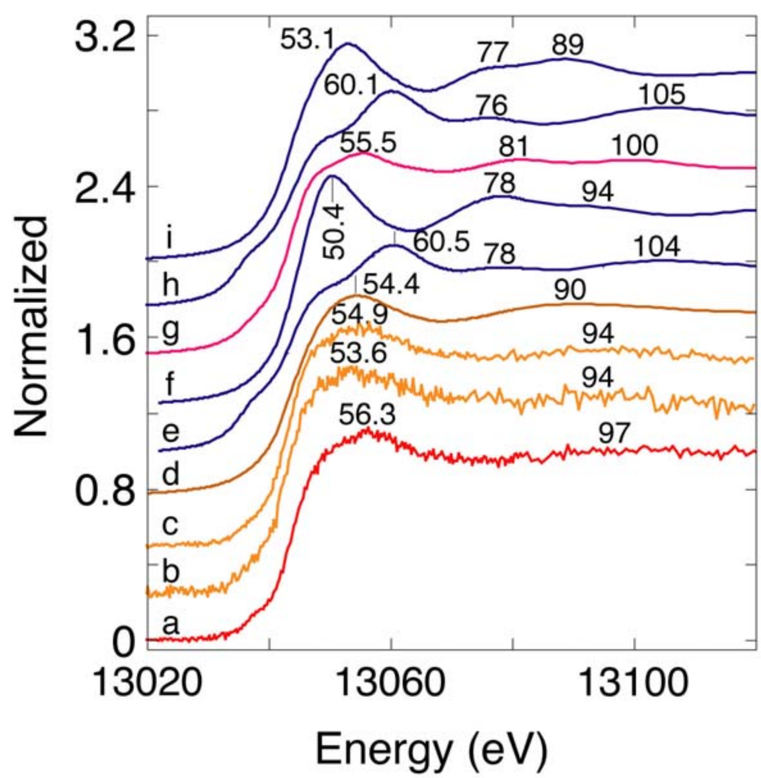

Figure 8. Lead $L\alpha_1$-selecting Pb L_3-edge XANES spectra measured at 290 K for Pb adsorbed on $Mg_6Fe_2(OH)_{16}(CO_3)•3H_2O$ (a – c). Tune energy of fluorescence spectrometer was 10551.5 eV. The Pb content was 1.0 wt% adsorbed from 1.0 ppm Pb^{2+} aqueous test solution (a) and 0.30 (b) and 0.12 wt% (c) from 100 ppb Pb^{2+} test solution. XANES spectra measured in transmission mode (d – i) for PbY zeolite (d), PbO (e), $Pb(NO_3)_2$ (f), $2PbCO_3•Pb(OH)_2$ (g), $Pb_6O_4(OH)_4$ (h), and $PbCO_3$ (i).

With closer look of Figure 8a – c, a shoulder feature appeared at 13049 eV. Similar shoulder feature can be found in spectra for PbO, $2PbCO_3•Pb(OH)_2$, and $Pb_6O_4(OH)_4$ (spectra e, g, and h, respectively). However, intense peak at 13060.1 – 13060.5 eV for PbO or $Pb_6O_4(OH)_4$ did not appear in spectra a – c. Thus, minor coagulation uptake mechanism was suggested from 100 ppb Pb^{2+} solutions in addition to major ion exchange process (Figure 9).

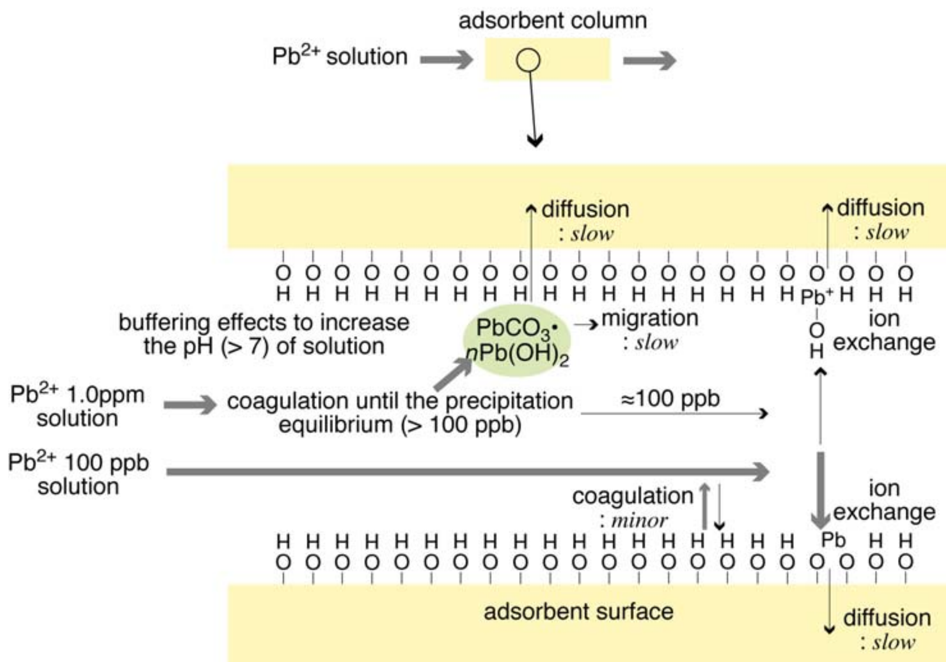

Figure 9. Pb^{2+} adsorption mechanism on $Mg_6Fe_2(OH)_{16}(CO_3)\bullet 3H_2O$ from Pb^{2+} 1.0 ppm and 100 ppb aqueous solutions.

In summary, Pb^{2+} uptake mechanism on $Mg_6Fe_2(OH)_{16}(CO_3)\bullet 3H_2O$ exhibited a switch-over from coagulation to (major) ion exchange reactions as the Pb^{2+} concentration decreased from 1.0 ppm to more environmentally plausible 100 ppb [28].

CONCLUDING REMARKS AND FUTURE PROSPECTS

This chapter focused on the removal of low concentrations (55 – 200 ppb) of arsenite and lead by utilizing Fe-montmorillonite, micro/mesoporous $FeO_x(OH)_y$ effectively porous due to carboxyl-exchange method, and layered double hydroxide consisted of Fe and Mg (pyroaurite). It is still open to discuss the systematic survey of the removal process of other dilute toxic elements, *e.g.* Cr, Cu, Zn, Cd, or Hg. It is important to formulate the efficiency of surface uptake with respect to critical factors, *i.e.* pH, chemical species of toxic elements (naked cations, oxyanions, or oxyhydroxyl anions), initial concentrations (10 – 100 ppb) and space velocity of aqueous solutions to be processed, and chemical combination of surface *versus* chemical species (*e.g.* $Fe^{III}O(OH)$ *versus* $As(OH)_3$ and OH^-(clay surface)/CO_3^{2-} (between layers) *versus* Pb^{2+}).

In the analytical point of view to monitor the destiny of low concentrations of toxic elements, selective XAFS technique, with which the author of this chapter has also investigated surface catalytic sites of gold, platinum, tin, and vanadium [31 – 35], needs to be combined with other technique with nanoscale spacial resolution. Spectroscopy with nanoscale spacial resolution is under investigation, but not established to be applicable to nanotechnology (Table 2).

At present, spacial resolution of X-ray microscopy is 1 μm [36]. Several types of X-ray microscopy/imaging are under investigation, *e.g.* microbeam XAFS, photoemission electron microscope (PEEM), or phase contrast imaging [37, 38]. The spacial resolution of TEM is already smaller than 1 nm if the sample nanoscopic condition matches to the high-resolution measurement. To monitor the sorption between 2-dimensinal layers (*e.g.* montmorillonite, hematite), in 2-dimensional mesopores (*e.g.* FSM-16, MCM-41), and in 3-dimensional micro/mesopores (*e.g.* ZSM-5, acetate-exchanged $FeO_x(OH)_y$ [17]), 3-dimensional TEM images would be very helpful by taking series of TEM snapshots from various angles to sample and organizing 3-dimensional image on computer [39].

Scanning probe microscope (SPM), especially scanning tunneling microscopy (STM) and atomic force microscope (AFM), has an advantage of atomic resolution for well-defined surface [40]. To utilize SPM technique to monitor the sorption from low concentrations of toxic elements, the combination with element specific spectroscopy, *e.g.* XPS, XAFS, is essential to describe the surface chemical mechanism. The author of this chapter is developing this combination (AFM and XPS) based on temporal electron trap phenomena in the metal nano-dots in the front of the AFM tip [41, 42].

Table 2. Spectroscopy Needed to Be Developed to Give Direct Spacial Information of Surface Uptake Mechanism from Low Concentrations (10 – 100 ppb) of Toxic Metal Elements

Probe Method	Factor to be developed for this application	Refs
X-ray Microscope	Smaller X-ray beam (< 10 nm)	[36 – 38]
Electron Microscope	3-dimensional information	[39]
Tip Microscope	Scanning probe microscope to discriminate the kind of element	[41, 42]
X-ray Diffraction	Surface-sensitivity between nano-layers or in micro/mesospace	[43]
X-ray XAFS/XRF	On-site analysis in the field	[44, 45]

Surface-sensitive XRD may be applicable to monitor the application of water purification [43]. The breakthrough is selectivity to internal surface of layered and micro/mesoporous materials used as sorbents. Portable XRF/XAFS apparatus that has been investigated for space science [44, 45] will be applicable to environmental on-site monitoring of the fate of toxic elements in the field.

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AEROBICALLY BIODEGRADED FISH-MEAL WASTEWATER AS A FERTILIZER

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ABSTRACT

Reutilization of fish-meal wastewater (FMW) as a fertilizer was attempted, and aerobic biodegradation of the FMW were successfully achieved by microbial consortium in a 1-ton bioreactor. During the large-scale biodegradation of FMW, the level of DO was maintained over 1.25 mg·l^{-1}, and a strong unpleasant smell remarkably disappeared in the end. Although the level of total amino acids and the concentrations of N, P and K in the biodegraded FMW were relatively lower than those in two commercial fertilizers, the concentrations of noxious components in the biodegraded FMW were much lower than the standard concentrations. The phytotoxicity of the biodegraded FMW was almost equal to that of the commercial fertilizers. The fastest growth in hydroponic cultures of red bean and barley was achieved at 100-fold and 500-fold dilution, respectively, the growth of which was comparable to those of 1,000-fold diluted commercial-fertilizers. From all above results, it was concluded that a large-scale biodegradation of FMW was successful and the properties of FMW were acceptable. This is the first study to demonstrate aerobic production of liquid-fertilizer from FMW.

Keywords: fish-meal wastewater, fertilizer, microbial consortium, large-scale biodegradation, phytotoxicity, hydroponic culture.

INTRODUCTION

The amount of fisheries waste generated in Korea is expected to increase with a steady increase in population to enjoy taste of slices of raw fish. The fisheries waste is reduced and reutilized through the fish meal production. The process, which uses fish wastes such as heads, bones or other residues, is the commonest used in the Korean industries. The first step of the fish-meal manufacturing processes is the compression and crushing of the raw material, which is then cooked with steam, and the liquid effluent is filtered off in a filter press. The liquid stream contains oils and a high content of organic suspended solids. After oil separation, the fish-meal wastewater (FMW) is generated and shipped to wastewater treatment place. FMW has been customarily disposed of by dumping into the sea, since direct discharge of FMW can cause serious environmental problems. Besides, bad smell, which is produced during fish-meal manufacturing processes, causes civil petition. Stricter regulations for this problem also come into force every year in Korea. Therefore, there is an urge to seek for an effective treatment to remove the organic load from the FMW; otherwise the fish meal factories will be forced to shut down.

Biological treatment technologies of fish-processing wastewater have been studied to improve effluent quality (Battistoni and Fava, 1995; Park et al., 2001). The common feature of the wastewaters from fish processing is their diluted protein content, which after concentration by a suitable method would enable the recovery and reuse of this valuable raw material, either by direct recycling to the process or subsequent use in animal feed, human food, seasoning, etc. (Afonso and Borquez, 2002). It has been also reported that the organic wastes contain compounds, which are capable of promoting plant growth (Day and Katterman, 1992), and seafood processing wastewaters do not contain known toxic or carcinogenic materials unlike other types of municipal and industrial effluents (Afonso and Borquez, 2002). Although these studies imply that FMW could be a valuable resource for agriculture, potential utilization of this fish wastes has been limited because of its bad smell (Martin, 1999). There is an increasing need to find ecologically acceptable alternatives to overcome this problem.

Aerobic biodegradation has been widely used in treatment of wastewaters, and recently references to the use of meso- and thermophilic microorganisms have become increasingly frequent (Cibis et al., 2006). During the biodegradation, the organic matter is biodegraded mainly through exothermic aerobic reactions, producing carbon dioxide, water, mineral salts, and a stable and humified organic material (Ferrer et al., 2001). There have been few reports that presented the reutilization of biodegraded waste products as liquid-fertilizer: a waste product of alcoholic fermentation of sugar beet (Agaur and Kadioglu, 1992), diluted manure streams after biological treatment (Kalyuzhnyi et al., 1999), and biodegraded fish-meal wastewater in our previous studies (Kim et al, 2007; Kim and Lee, 2008). Therefore, aerobic biodegradation is considered to be the most suitable alternative to treat FMW and realize a market for such a waste as a fertilizer.

The growth of plants and their quality are mainly a function of the quantity of fertilizer and water. So it is very important to improve the utilization of water resources and fertilizer nutrients. The influence of organic matter on soil biological and physical fertility is well known. Organic matter affects crop growth and yield either directly by supplying nutrients or indirectly by modifying soil physical properties such as stability of aggregates and porosity that can improve the root environment and stimulate plant growth (Darwish et al., 1995). Incorporation of organic matter has been shown to improve soil properties such as aggregation, water-holding capacity, hydraulic conductivity, bulk density, the degree of compaction, fertility and resistance to water and wind erosion (Carter and Stewart, 1996; Franzluebbers, 2002; Zebarth et al., 1999). Combined use of organic and inorganic sources of nutrients is essential to maintain soil health and to augment the efficiency of nutrients (Lian, 1994).

Three primary nutrients in fertilizers are nitrogen, phosphate, and potassium. According to Perrenoud's report (1990), most authors agree that N generally increases crop susceptibility to pests and diseases, and P and K tend to improve plant health. It has been reported that tomato is a heavy feeder of NPK (Hebbar et al., 2004) and total nitrogen content is high in leaves in plants having a high occurrence of bitter fruits (Kano et al., 2001). Phosphorus is one of the most essential macronutrients (N, P, K, Ca, Mg, S) required for the growth of plants, and the deficiency of phosphorus will restrict plant growth in soil (Son et al., 2006). However, the excessive fertilization with chemically synthesized phosphate fertilizers has caused severe accumulation of insoluble phosphate compounds in farming soil (Omar, 1998), which gradually deteriorates the quality as well as the pH of soil. Different fertilization treatments of a long-term field experiment can cause soil macronutrients and their available concentrations to change, which in turn affects soil micronutrient (Cu, Fe, Mn, Zn) levels. Application of appropriate rates of N, P and K fertilizers has been reported to be able to increase soil Cu, Zn and Mn availabilities and the concentrations of Cu, Zn, Fe and Mn in wheat (Li, et al., 2007).

It has been also reported that higher rates of fertilizers suppress microbial respiration (Thirukkumaran and Parkinson, 2000) and dehydrogenase activity (Simek et al., 1999). Recently, greater emphasis has been placed on the proper handling and application of agricultural fertilizers in order to increase crop yield, reduce costs and minimize environmental pollution (Allaire and Parent, 2004; Tomaszewska and Jarosiewicz, 2006).

Hydroponics is a plant culture technique, which enables plant growth in a nutrient solution with the mechanical support of inert substrata (Nhut et al., 2006). Hydroponic culture systems provide a convenient means of studying plant uptake of nutrients free of confounding and uncontrollable changes in soil nutrient supply to the roots. Thus, it is fit for test of fertilizing ability of liquid fertilizers. The technique was developed from experiments carried out to determine what substances make plants grow and plant composition (Howard, 1993). Water culture was one of the earliest methods of hydroponics used both in laboratory experiments and in commercial crop production. Nowadays, hydroponics is considered as a promising technique not only for plant physiology experiments but also for commercial production (Nhut et al., 2004; Resh, 1993). The technique has been also adapted to many situations, from field and indoor greenhouse culture to highly specialized culture in atomic submarines to grow fresh vegetables for the crew (Nhut et al., 2004). Hydroponics provides numerous advantages: no need for soil sterilization, high yields, good quality, precise and complete control of nutrition and diseases, shorter length of cultivation time, safety for the environment and special utility in non-arable regions. Application of this culture technique can be considered as an alternative approach for large-scale production of some desired and valuable crops.

In this study, a large-scale biodegradation was successfully carried out for three days in a 1-ton reactor using the FMW generated from fish-meal manufacturing processes, and the properties of the biodegraded FMW, such as phytotoxicity, amino-acid composition, concentrations of major and noxious components, and fertilizing ability on hydroponic culture plants were determined to examine the suitability of the biodegraded FMW as a fertilizer.

MATERIALS AND METHODS

Microorganisms and Media

The mixed microorganisms used in this study comprised seven microorganisms: *Bacillus subtilis*, *Bacillus licheniformis*, *Brevibacillus agri*, *Bacillus coagulans*, *Bacillus circulans*, *Bacillus anthracis* and *Bacillus fusiformis*. They were potential aerobically-degrading bacteria, which were isolated from commercial good-quality humus and from compost and leachate collected at three different sites of composting plants (Kim et al., 2007). There was no potential bacterial antagonist among them. Each pure culture was maintained on 1.5% Nutrient agar plate at 4□ until used, and transferred to a fresh agar plate every month. At the same time, the potential degrading ability of each pure culture was also checked on 1% skim milk agar, 3.215% spirit blue agar, starch hydrolysis agar (5 $g \cdot l^{-1}$ of beef extract, 20 $g \cdot l^{-1}$ of soluble starch, 10 $g \cdot l^{-1}$ of tryptose, 5 $g \cdot l^{-1}$ of NaCl, and 15 $g \cdot l^{-1}$ of agar, pH 7.4) and cellulose agar (10 $g \cdot l^{-1}$ of cellulose powder, 1 $g \cdot l^{-1}$ of yeast extract, 0.1 $g \cdot l^{-1}$ of NaCl, 2.5 $g \cdot l^{-1}$ of $(NH_4)_2SO_4$, 0.25 $g \cdot l^{-1}$ of K_2HPO_4, 0.125 $g \cdot l^{-1}$ of $MgSO_4 \cdot 7H_2O$, 0.0025 $g \cdot l^{-1}$ of $FeSO_4 \cdot 7H_2O$, 0.025 $g \cdot l^{-1}$ of $MnSO_4 \cdot 4H_2O$, and 15 $g \cdot l^{-1}$ of agar, pH 7.2), respectively. All agar plates were incubated at 45^0C until change of color or a clear zone around each colony appeared.

Liquid-Fertilization of FMW

A large-scale biodegradation of the original FMW was carried out in a 1-ton reactor for its liquid-fertilization. The inside of the reactor was sterilized by hot steam for 30 min, and then 600 l of the FMW obtained from a fish-meal factory was added into the reactor by a peristaltic pump under the steaming. The FMW was characterized as: 115,000±13,000 $mg \cdot l^{-1}$ of chemical oxygen demand- dichromate (COD_{Cr}), 15,400±1,300 $mg \cdot l^{-1}$ of total nitrogen (TN), 68,900±7,600 $mg \cdot l^{-1}$ of five days biological oxygen demand (BOD_5), 2,800±600 $mg \cdot l^{-1}$ of NH_4^+-N, 0 $mg \cdot l^{-1}$ of NO_3^--N and 0 $mg \cdot l^{-1}$ of NO_2^--N. The salt concentration and pH of the FMW were 0.6±0.1% and 6.5±0.2, respectively. After the steaming was quit, the reactor was placed until temperature dropped down to 45^0C. Then, 30-l liquid broth of seven microorganisms (on the same ratio of cell mass) grown in exponential phase of growth were seeded into the reactor. For faster biodegradation, the inoculated cells were previously acclimated for two days in the original FMW under an aerobic condition. The bioreactor was operated at 42 ± 4^0C, and air was supplied from two blowers (6.4 $m^3 \cdot min^{-1}$ of capacity) into the reactor through ceramic disk-typed diffusers. The aeration rate was 1,280 $l \cdot min^{-1}$. Ten-fold diluted 'Antifoam 204' was used when severe foams occurred during biodegradation. Samples from the reactor were collected periodically. The concentrations of dissolved oxygen (DO), COD_{Cr} and TN were measured with oxidation-reduction potential (ORP) and pH.

Seed Germination Test

According to the method of Wong et al.(2001), seed germination tests for 50-, 100-, 250-, 500-, and 1,000-fold diluted final broths, which were taken from the biodegradation of original FMW in a 1-ton reactor, were carried out against control in order to evaluate the phytotoxicity of the biodegraded FMW. Two commercial fertilizers, C-1 (A-company, Incheon, Korea) and C-2 (N-company, Kimhae, Korea), frequently used in Korea were also tested for the comparison of their phytotoxicity. Five milliliters of each sample were pipetted into a sterile petri dish lined with Whatman #1 filter paper. Ten cress (*Lepidium sativum*) seeds were evenly placed in each dish. The plates were incubated at 25 ºC in the dark at 75% of humidity. Distilled water was used as a control. Seed germination and root length in each plate were measured at 72 h. The percentages of relative seed germination (RSG), relative root growth (RRG) and germination index (GI) after expose to the sample were calculated as the following formula (Zucconi et al., 1981; Hoekstra et al., 2002):

$$RSG\ (\%) = \frac{\text{Number of seeds germinated in the biodegraded FMW}}{\text{Number of seeds germinated in control}} \times 100$$

$$RRG\ (\%) = \frac{\text{Mean root length in the biodegraded FMW}}{\text{Mean root length in control}} \times 100$$

$$GI\ (\%) = \frac{RSG \times RRG}{100}$$

Hydroponic Culture

To test the fertilizing ability of the biodegraded FMW produced in a 1-ton reactor, a hydroponic culture system was applied to cultivate red bean and barley in a mini-hydroponic culture pot ($5 \times 12 \times 8\ cm^3$) against control. Tests were carried out on the biodegraded FMW at various dilutions (50, 100, 250, 500 and 1,000-fold). The tests were also carried out on 1,000-fold diluted commercial-fertilizers in order to compare with the fertilizing ability of the biodegraded FMW. The hydroponic culture pot was composed of a glass vessel and a plastic screen inside. In each pot, ten seeds of red bean or twenty-five seeds of barley were put on top of the plastic screen, respectively, and approximately 300-ml solution of the biodegraded FMW at various dilution ratios was filled underneath the plastic screen. After set-up of the hydroponic culture system, each pot was initially covered with aluminum foil to keep seeds in dark before seed germination. After seed germination, the pot placed by the window all day long to provide the necessary sunlight for plant's growth. Day and night temperatures of air were maintained at 22 ± 2^0C and 18±2℃ by natural ventilation and heating. Water temperature was 15 ± 3^0C, and the relative humidity in the room was 60% on the average. The fertilizer solution was refreshed every four days, and the seeds were soaked all the time. After seed germination, roots grew through the pore of the plastic screen. The growth of plants was observed periodically, and height, thickness of stem, number of leaf, and length of leaf of each plant were measured.

Analyses

The concentrations of cations (NH_4^+) and anions (NO_2^- and NO_3^-) were estimated by IC (Metrohm 792 Basic IC, Switzerland). The columns used in these analyses were Metrosep C2-150 and Metrosep Supp 5-150 for cation and anion, respectively. The concentrations of COD_{Cr} and TN concentrations were analyzed by the Water-quality Analyzer (Humas, Korea). The concentration of BOD_5 was analyzed by the OxiDirect BOD-System (Lovibond, Germany). The composition of amino acids, and concentrations of major and noxious components in biodegraded FMW and commercial liquid-fertilizers were analyzed at Science Lab Center Co., Ltd (Daejeon, Korea) by our request.

RESULTS AND DISCUSSION

Liquid-Fertilization of FMW

To industrialize the biodegraded FMW as liquid-fertilizer, data obtained in laboratory equipment should be transferred to industrial production. Problems of scale-up in a bioreactor are associated with the behavior of liquid in the bioreactor and the metabolic reactions of the organisms. Transport limitation is considered as one of the major factors responsible for phenomena observed at large-scale. For this reason, a large-scale FMW biodegradation were attempted in a 1-ton bioreactor, and the result is shown in Figure 1. As shown in Figure 1, DO level in the reactor started to decrease after 5 h. This implies that active biodegradation of FMW took placed after a lag phase by the mixed microorganisms used in this study, since oxygen consumption has been known to be a general index of microbial metabolism (Tomati et al., 1996). During two days biodegradation, the DO level was maintained over 2 $mg \cdot l^{-1}$, but it decreased further thereafter. The final DO level was 1.25 $mg \cdot l^{-1}$. In aerobic processes, oxygen is a key substrate and a continuous transfer of oxygen from the gas phase to the liquid phase is decisive for maintaining the oxidative metabolism of the cells because of its low solubility in aqueous solutions. Generally, it has known that DO level in a bioreactor should be maintained over 1 $mg \cdot l^{-1}$ for aerobic fermentation (Tohyama et al., 2000). Therefore, it would seem that the supply of oxygen into the 1-ton reactor met the demand of oxygen by the microorganisms during the biodegradation.

The pH was 6.99 at the beginning and decreased down to 6.15 after 20 h. Then the pH was recovered slowly and its final value was 6.86. In our previous study (Kim et al., 2008), pH had a tendency to increase during the biodegradation because of insufficient supply of oxygen. These results imply that microorganisms had different metabolism, which was dependent on the availability of dissolved oxygen. The value of ORP started at 18.2 mV. The value of ORP decreased rapidly after 45 h and the final value reached to 0.6 mV. The decrease in the ORP value resulted from the decrease in DO level. During the biodegradation, the values of ORP maintained positive, and a strong unpleasant smell (mainly a fishy smell) remarkably disappeared in the end. It seemed that a complete aerobic biodegradation might take place to a certain extent with maintenance of ORP in a positive range, since unpleasant odor can be easily produced under incomplete aerobic biodegradation (Zhang et al., 2004).

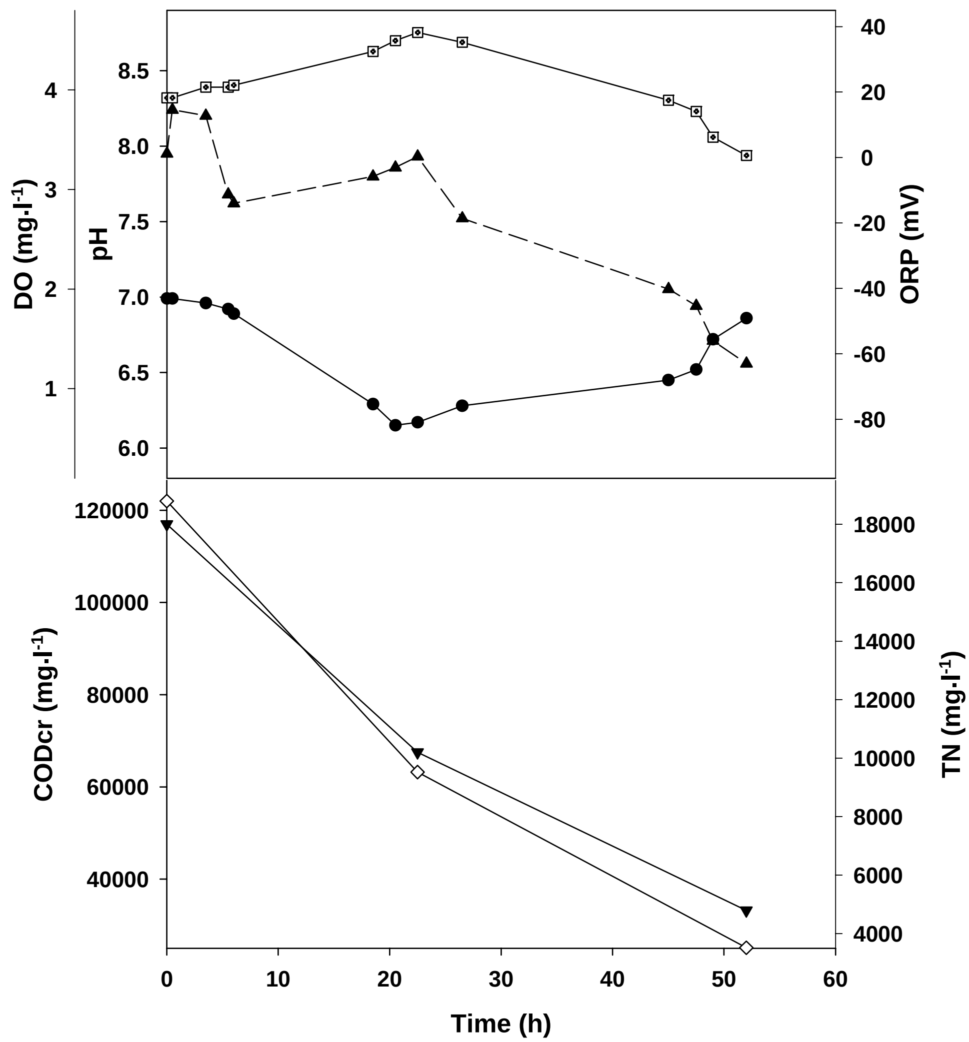

Figure 1. Changes of ORP(□), DO(▲), pH(●), CODcr(□) and TN(▼) during the biodegradation in a 1-ton reactor.

From all the results, maintenance of DO level during biodegradation was found to be very important and ORP could be a key parameter to operate biodegradation of FMW in a large-scale. The ORP was reported to be used as a controlling parameter for regulation of sulfide oxidation in anaerobic treatment of high-sulfate wastewater (Khanal and Huang, 2003), and on-line monitoring of ORP has been proved to be a practical and useful technique for process control of wastewater treatment systems (Guo et al., 2007; Yu et al., 1997). As a result, process optimization is required in a large-scale operation, especially aeration rate in this case. After 52 h of biodegradation, the concentrations of COD_{Cr} and TN in original FMW reduced to 25,100 and 4,790 mg·l^{-1}, respectively. The removal percentages of COD_{Cr} and TN were 79.4 and 73.4%, respectively, with slight decrease of COD_{Cr}/TN ratio from 6.8 to 5.2. It has been known that the COD/N ratio may influence biomass activity, and therefore on the metabolic pathways of organic matter utilization (Ruiz et al., 2006). Based on this information, the cell activity and metabolic pathways of the mixed microorganisms might be maintained somewhat with their mutualism during the biodegradation.

Properties of Biodegraded FMW as Fertilizer

Since the FMW contains various compounds potentially useful for diverse plants, an attractive application is its use as a fertilizer; however, this could have limitations due to some toxic characteristics of the waste. For this reason, it is necessary to prove the non-toxic properties and fertilizing ability of the final biodegraded FMW.

Phytotoxicity of Biodegraded FMW

Organic matters hold great promise due to their local availability as a source of multiple nutrients and ability to improve soil characteristics. Sufficient aeration promotes the conversion of the organic matters into nonobjectionable, stable end products such as CO_2, SO_4^{2-}, NO_3^-, etc. However, an incomplete aeration may result in accumulation of organic acid, thus giving trouble to plant growth if the fertilizer is incorporated into the soil (Jakobsen, 1995). The phytotoxicity of the biodegraded FMW produced in a 1-ton reactor was examined at various dilution ratios, and compared with those of two commercial fertilizers (Figure 2).

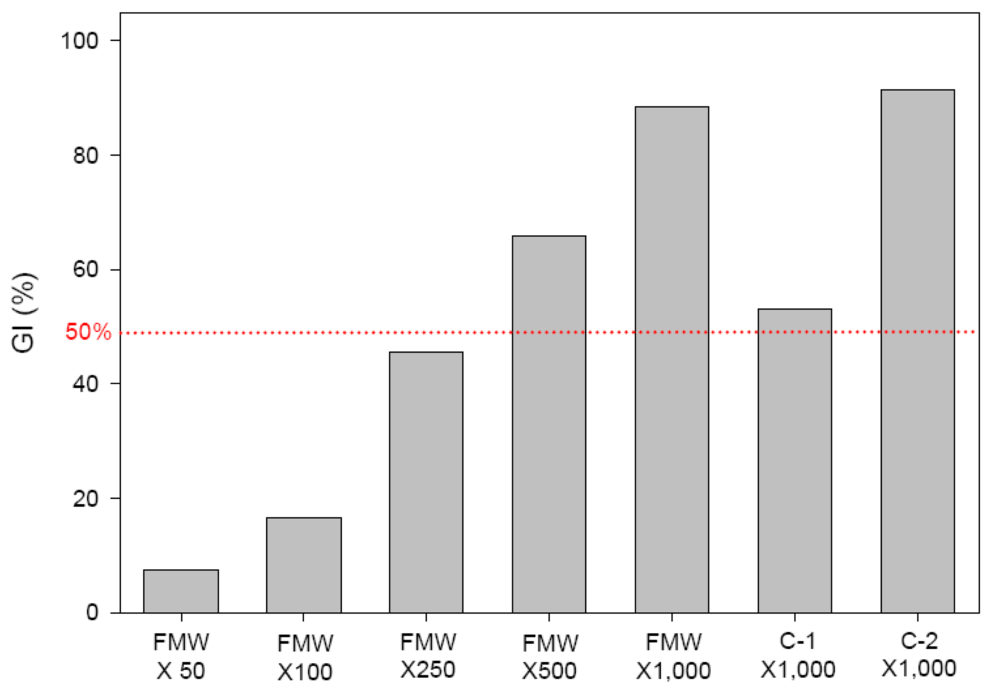

Figure 2. Percentages of germination index (GI) at various dilution ratios of the biodegraded FMW produced in a 1-ton reactor. The results are compared to those of 1,000-fold diluted commercial fertilizers, C-1 and C-2.

As shown in Figure 2, the values of GI had a tendency to increase with increase of dilution ratio of the biodegraded FMW. The GI values of the biodegraded FMW were less than 20% at 50- and 100-fold dilution with low root elongation. The reduction in values of GI indicates that some characteristics existed had an adverse effect on root growth. This may be attributed to the release of high concentrations of ammonia and low molecular weight organic acids (Fang and Wong, 1999; Wong, 1985), since cress (*Lepidium sativum*) used in this study is known to be sensitive to the toxic effect of these compounds (Fuentes et al., 2004). At 250-fold dilution, the GI value of the biodegraded FMW was close to 50%. A GI value of 50% has been used as an indication of phytotoxin-free compost (Zucconi et al., 1985). According to this GI criterion, the biodegraded FMW required more than 250-fold dilution to reach stabilization of the organic matter to maintain the long-term fertility in soil. At 1,000-fold dilution, the GI value was found to be close to 90%. This GI value was compared with those of two commercial fertilizers at the same dilution, since 1,000-fold diluted liquid fertilizer was used in horticulture for general purpose. The GI value of the biodegradative FMW was much better than that of C-1 and comparable to that of C-2. This result implies that the biodegradation of FMW in a 1-ton reactor was successfully carried out, and thus the development of a liquid-fertilizer from the FMW was feasible.

Composition of Amino Acids of Biodegraded FMW

Amino acids are an essential part of the active fraction of organic matter in a fertilizer. The growth of plants depends ultimately upon the availability of a suitable balance of amino acids, and their composition might also be used as a means of assessing biodegradation. The success of the scale-up process for the production of liquid fertilizer from the FMW can be verified by determining the composition of amino acids. From this point of view, it is necessary to analyze the amino-acid composition of the biodegraded FMW produced in a 1-ton bioreactor. The analytical result was tabulated in Table 1 with those of two commercial fertilizers. The level of total amino acids was 5.60 $g \cdot 100g\ sample^{-1}$, which was a little bit better than that produced in our previous study (Kim and Lee, 2008). The higher content of amino acids is probably due to the higher degree of mineralization of FMW, which indicates release of more nutrients available for plants. However, the level of total amino acids in the biodegraded FMW was lower, compared with those in two commercial fertilizers. This implies that mineralization of FMW in a 1-ton reactor was not as great as that in a lab-scale reactor (Bylund et al., 1998; Xu et al., 1999). Especially, the levels of aspartic acid, alanine and lysine were low, whereas those of proline and glycine were relatively high. The difference may be due to the composition of the original FMW, since it was found to be dependent on the nature of the raw material processed in the factory (Kim et al., 2007). Moreover, the composition of sulfur-containing amino acids, cysteine and methionine, was relatively high in the biodegraded FMW. It has been reported that the sulfur-containing amino acid, methionine is a nutritionally important essential amino acid and is the precursor of several metabolites that regulate plant growth (Amir et al., 2002).

Table 1. Comparison of amino-acids composition of the biodegraded FMW with those of commercial fertilizers[a]

Amino acid	Source of liquid fertilizer		
	Biodegraded FMW[b]	Commercial C-1	Commercial C-2
Aspartic acid	0.49	0.90	0.58
Threonine	0.18	0.23	0.21
Serine	0.21	0.21	0.23
Glutamic acid	0.78	2.96	0.89
Proline	0.50	0.09	0.61
Glycine	1.06	0.31	1.25
Alanine	0.60	1.00	0.98
Valine	0.15	0.39	0.24
Isoleucine	0.14	0.28	0.13
Leucine	0.24	0.42	0.26
Tyrosine	0.07	0.17	0.05
Phenylalanine	0.19	0.22	0.18
Histidine	0.20	0.28	0.25
Lysine	0.29	1.54	0.53
Arginine	0.31	0.23	0.35
Cystine	0.04	n.d.[c]	0.04
Metionine	0.13	n.d.	0.01
Tryptophan	0.02	n.d.	0.02
Total	5.60	9.23	6.81

[a]composition of amino acids was based on dry weight (g•100g sample^{-1}).
[b]produced in a 1-ton reactor.
[c]n.d. means 'not detected'.

Concentrations of Major and Noxious Components in Biodegraded FMW

It is very important to improve the utilization of fertilizer nutrients, since the growth of plants and their quality are mainly a function of the quantity of fertilizer. Organic matter affects crop growth and yield directly by supplying nutrients (Darwish et al., 1995). Combined use of organic and inorganic sources of nutrients is essential to augment the efficiency of nutrients (Lian, 1994). For this reason, concentrations of three primary nutrients (N, P, and K) in the biodegraded FMW were anaylized together with noxious components, and compared with those in commercial fertilizers. The results were tabulated in Table 2. The concentrations of N, P and K in the biodegraded FMW were 1.49, 0.28 and 0.41%, respectively, and were much lower than those in commercial fertilizers.

Table 2. Comparison of concentrations of major and noxious components present in the biodegraded FMW with those present in commercial fertilizers

Measurement		Source of liquid fertilizer		
		Biodegraded FMW[a]	Commercial C-1	Commercial C-2
N, P, K (%)	N	1.49	4.83	3.80
	P_2O_5	0.28	2.86	2.83
	K_2O	0.41	2.10	3.04
Noxious Compounds ($mg{\cdot}kg^{-1}$)	Pb	n.d.[b]	0.63	0.31
	As	n.d.	0.88	0.36
	Cd	n.d.	0.08	0.03
	Hg	0.01	n.d.	n.d.
	Cr	0.20	3.52	3.44
	Cu	n.d.	3.24	2.24
	Ni	n.d.	1.54	2.32
	Zn	1.61	4.39	3.51

[a]produced in a 1-ton reactor.
[b]n.d. means 'not detected'.

However, the concentrations of noxious components in the biodegraded FMW were much lower than those in commercial fertilizers. The noxious components, Pb, As, Cd, Cu and Ni were not detected, and the other components were much less than the standard concentrations provided by the law.

Hydroponic Culture on Biodegraded FMW

The fertilizing ability of the biodegraded FMW at various dilution ratios was tested in a hydroponic culture system, which was applied to cultivate red bean and barley. The tests were also carried out on 1,000-fold diluted commercial-fertilizers simultaneously. Results of hydroponic culture of red bean on diluted biodegraded-FMW and commercial fertilizers were tabulated in Table 3. As seen in Table 3, elongation of root was slow after seed germination in all diluted FMW. However, roots elongated soon after development of root. The fastest growth was achieved at 100-fold dilution, the growth of which was comparable to that of 1,000-fold diluted commercial-fertilizers. This result was somewhat surprising because the GI test on the 100-fold diluted FMW showed low root elongation (Figure 2). The toxic effect of the 100-fold diluted FMW might be not severe on red bean, although it was sensitive on cress.

Table 3. Results of hydroponic culture of red bean on diluted biodegraded-FMW and commercial fertilizers

Measurement	Control (Water)					Dilution of biodegraded FMW														
						50-fold					100-fold					250-fold				
	Time (day)					Time (day)					Time (day)					Time (day)				
	2	5	8	12	14	2	5	8	12	14	2	5	8	12	14	2	5	8	12	14
Height (cm)	-	-	1.5	3.0	6.0	-	-	-	1.0	2.0	-	2.0	4.0	6.0	9.0	-	-	1.0	3.0	4.5
Thickness of stem (cm)	-	-	0.2	0.3	0.5	-	-	-	0.2	0.2	-	0.2	0.3	0.4	0.5	-	-	0.2	0.3	0.3
Number of leaf	-	-	-	-	2	-	-	-	1	1	-	-	-	2	2	-	-	-	1	2
Length of leaf (cm)	-	-	-	-	3.0	-	-	-	1.0	2.0	-	-	-	1.5	4.0	-	-	-	1.0	1.5

Measurement	Dilution of biodegraded FMW										Commercial fertilizer									
	500-fold					1,000-fold					1,000-fold, C-1					1,000-fold, C-2				
	Time (day)					Time (day)					Time (day)					Time (day)				
	2	5	8	12	14	2	5	8	12	14	2	5	8	12	14	2	5	8	12	14
Height (cm)	-	-	1.0	3.0	4.0	-	1.0	2.0	4.0	5.5	1.0	4.0	4.5	5.0	8.0	-	2.0	3.0	4.0	6.0
Thickness of stem (cm)	-	-	0.2	0.3	0.4	-	0.2	0.2	0.3	0.4	0.2	0.3	0.3	0.4	0.5	-	0.2	0.3	0.4	0.5
Number of leaf	-	-	-	1	2	-	-	-	1	2	-	-	-	2	2	-	-	-	2	2
Length of leaf (cm)	-	-	-	1.0	1.5	-	-	-	1.0	2.0	-	-	-	1.5	4.5	-	-	-	1.0	3.0

Table 4. Results of hydroponic culture of barley on diluted biodegraded-FMW and commercial fertilizers

Measurement	Control (Water)					Dilution of biodegraded FMW														
						50-fold					100-fold					250-fold				
	Time (day)					Time (day)					Time (day)					Time (day)				
	2	5	8	12	14	2	5	8	12	14	2	5	8	12	14	2	5	8	12	14
Height (cm)	-	1.7	5.8	8.3	8.5	-	1.2	2.6	4.4	5.2	-	2.1	4.1	6.5	7.5	-	2.4	4.3	6.7	7.6
Thickness of stem (cm)	-	0.1	0.2	0.2	0.2	-	0.1	0.2	0.2	0.2	-	0.1	0.2	0.2	0.2	-	0.1	0.2	0.2	0.2
Number of leaf	-	1	2	2	2	-	1	2	2	2	-	1	2	2	2	-	1	2	2	2
Length of leaf (cm)	-	1.2	4.6	6.5	6.8	-	0.7	1.3	3.1	3.5	-	1.6	3.0	5.0	5.5	-	1.9	3.0	5.0	5.6

Measurement	Dilution of biodegraded FMW										Commercial fertilizer									
	500-fold					1,000-fold					1,000-fold, C-1					1,000-fold, C-2				
	Time (day)					Time (day)					Time (day)					Time (day)				
	2	5	8	12	14	2	5	8	12	14	2	5	8	12	14	2	5	8	12	14
Height (cm)	-	2.9	5.5	7.8	8.1	-	1.5	3.9	5.6	6.3	-	2.8	5.6	7.1	7.7	-	1.8	4.8	8.6	9.0
Thickness of stem (cm)	-	0.1	0.2	0.2	0.2	-	0.1	0.2	0.2	0.2	-	0.1	0.2	0.2	0.2	-	0.1	0.2	0.2	0.2
Number of leaf	-	1	2	2	2	-	1	2	2	2	-	1	2	2	2	-	1	2	2	2
Length of leaf (cm)	-	2.4	4.2	5.7	6.1	-	0.9	2.7	3.8	4.2	-	2	4.3	5.3	5.7	-	1.3	3.8	6.6	7.0

In Figure 3, the change of red bean's growth from the seed at 100-fold dilution is shown against control. Germination from the seed was observed at day 8 with the 100-fold diluted FMW, whereas the germination was observed at day 12 in control. After 14 days cultivation, much better growth of red bean was observed with the 100-fold diluted FMW, compared with that in control. At the same dilution of 1,000-fold, growth of red bean cultivated on the biodegraded FMW was not as good as that cultivated on commercial fertilizers. A decreasing order of growth in the culture of red bean was C-1 > C-2 > biodegraded FMW. According to Perrenoud's report (1990), N, P and K are primary nutrients and considered to improve plant health. The deficiency of phosphorus restricts plant growth in soil (Son et al., 2006), although the excessive fertilization with chemically synthesized phosphate fertilizers has caused severe accumulation of insoluble phosphate compounds (Omar, 1998). Therefore, relatively lower growth of red bean on the biodegraded FMW might be due to the shortage of NPK components (Table 2).

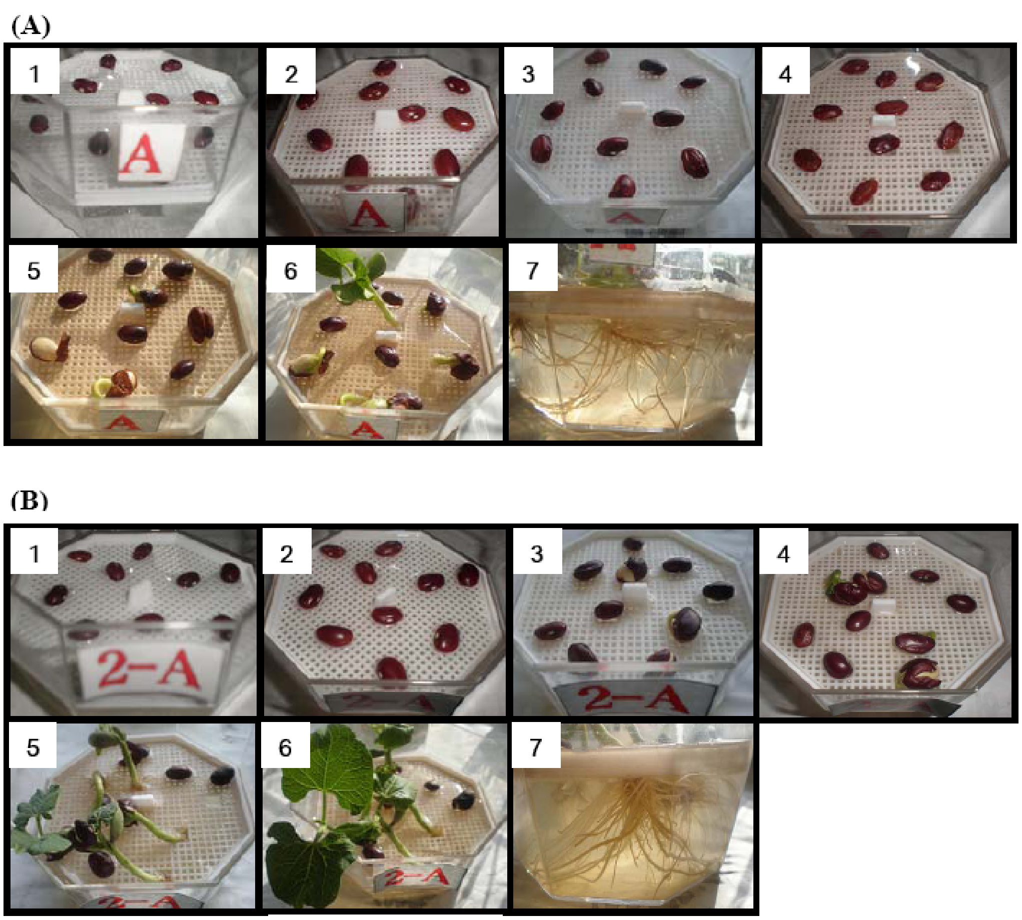

Figure 3. Results of hydroponic culture of red bean in control (A) and 100-fold diluted FMW (B). Each figure shows the growth of red bean from the seed along the cultivation time. (1) day 1; (2) day 2; (3) day 5; (4) day 8; (5) day 12; (6) day 14 and (7) roots on day 14.

Growth indexes of barley during hydroponic culture were measured on the biodegraded FMW at various dilution ratios, and the measurements were compared with those of commercial fertilizers (Table 4). Even though the growth in root and stem of barley at 50-fold dilution was lower than that of control, it had a tendency to improve with increase of dilution ratio of the biodegraded FMW. The best growth was achieved at 500-fold dilution in which the growth was seen evenly in root and stem of barley (Figure 4).

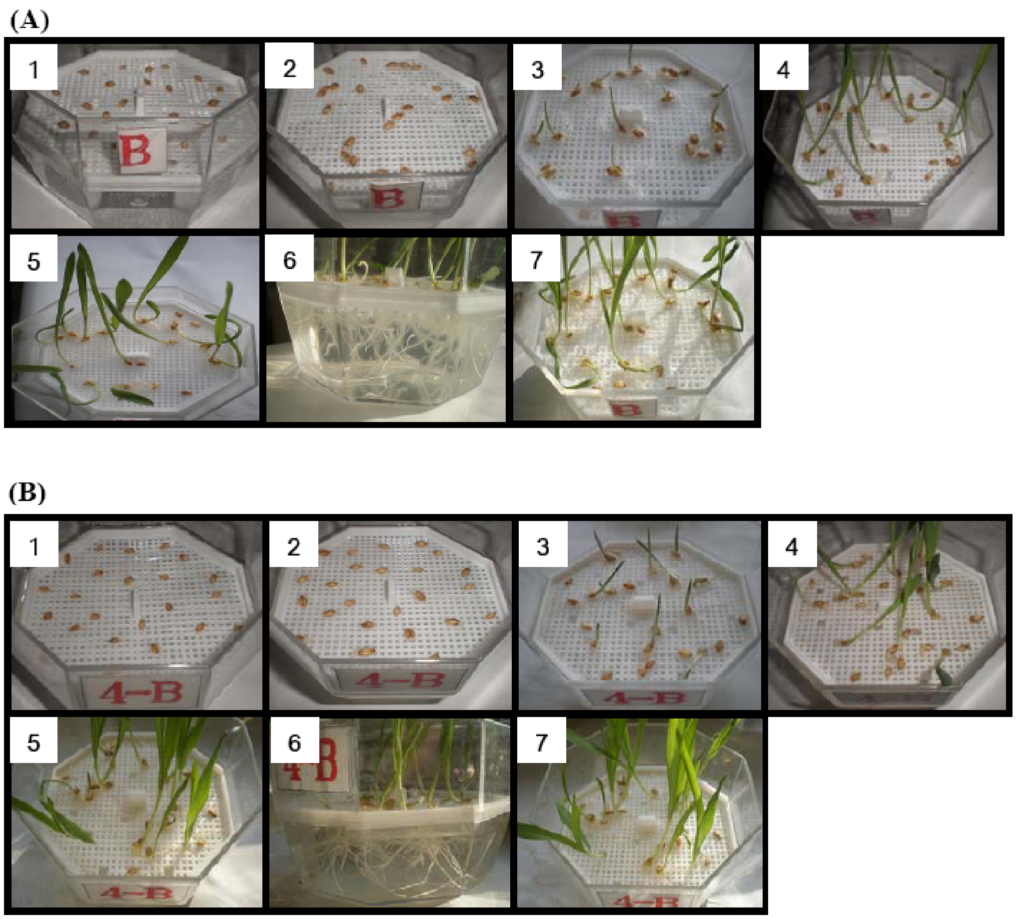

Figure 4. Results of hydroponic culture of barley in control (A) and 500-fold diluted FMW (B). Each figure shows the growth of barley from the seed along the cultivation time. (1) day 1; (2) day 2; (3) day 5; (4) day 8; (5) day 12; (6) roots on day 12 and (7) day 14.

From the GI test, the biodegraded FMW at 500-fold dilution was found to be phytotoxin-free (Figure 2). With the 500-fold diluted FMW, germination from the seed was observed at day 5, and the same result was observed in control. After 14 days cultivation, however, faster growth of barley was observed with the 500-fold diluted FMW, compared with that in control. This growth of barley with the 500-fold diluted FMW was comparable to that cultivated on 1,000-fold diluted commercial-fertilizers. However, the effect of dilution on barley was not as sensitive as that on red bean.

CONCLUSION

Seven thermophilic microorganisms, which had proteolytic, lipolytic and carbohydrate-degrading functions, were used in order to reutilize fish-meal wastewater (FMW). With coexistence of the seven microorganisms, a lab-scale aerobic biodegradation of FMW were successfully achieved, and its data were transferred to a 1-ton bioreactor. Although the level of DO was decreased during the large-scale biodegradation of FMW, it was maintained over 1.25 $mg \cdot l^{-1}$. The decrease in the level of DO resulted in decrease in ORP value. However, the ORP values were maintained positive, and a strong unpleasant smell remarkably disappeared in the end. After 52 h of biodegradation, the concentrations of COD_{Cr} and TN in original FMW reduced to 25,100 and 4,790 $mg \cdot l^{-1}$, respectively with slight decrease of COD_{Cr}/TN ratio.

Properties of the biodegraded FMW were determined to examine the suitability of the biodegraded FMW as a fertilizer. The result of the phytotoxicity test showed that the biodegraded FMW required more than 250-fold dilution to reach stabilization of the organic matter to maintain the long-term fertility in soil. At 1,000-fold dilution, the GI value was found to be close to 90%, which was comparable to those of commercial fertilizers. The level of total amino acids in the biodegraded FMW was 5.60 $g \cdot 100g\ sample^{-1}$, which was lower than those in two commercial fertilizers. Especially, the levels of aspartic acid, alanine and lysine were low, whereas those of proline and glycine were relatively high. Moreover, the composition of sulfur-containing amino acids, cysteine and methionine, were relatively high in the biodegraded FMW. The concentrations of N, P and K in the biodegraded FMW were 1.49, 0.28 and 0.41%, respectively, which were lower than those in commercial fertilizers. However, the concentrations of noxious components in the biodegraded FMW were much lower than the standard concentrations. The fertilizing ability of the biodegraded FMW at various dilution ratios was tested in a hydroponic culture system. The fastest growth in culture of red bean was achieved at 100-fold dilution, the growth of which was comparable to those of 1,000-fold diluted commercial-fertilizers.

In the hydroponic culture of barley, the best growth was achieved at 500-fold dilution in which its growth was seen evenly in root and stem. This growth of barley with the 500-fold diluted FMW was comparable to that cultivated on 1,000-fold diluted commercial-fertilizers. From all above results, it was concluded that a large-scale biodegradation of FMW was successful and the properties of FMW were acceptable as a fertilizer. Consequently, FMW could be a potential industrial resource for liquid-fertilizer production.

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EQUITY OF ACCESS TO PUBLIC PARKS IN BIRMINGHAM, ENGLAND

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ABSTRACT

Provision of public parks has long been advocated as an equalising measure between different elements of society. This study assesses equity of park provision for different ethnic and income-status populations in the urban area of Birmingham in central England. Parks in Birmingham were categorized into a two group typology of green areas suited for more solitary and passive activities (amenity parks) or open spaces designed more for informal sports or other physical and group activities (recreational parks). Using a geographical information system, measures of access to these green spaces were computed for populations of different ethnicities and levels of material deprivation, derived from data from the 2001 UK Census and the 2004 Index of Multiple Deprivation. Distance-weighted access scores were calculated and compared for five population groups ranked by relative deprivation, and for five ethnic groups; Bangladeshis, blacks, Indians, Pakistanis and whites. Statistical analysis found that there were strong disparities in access with respect to deprivation whereby the most income-deprived groups were also the most deprived with regard to access to public parks. There was little evidence of unequal access between ethnic groups. The implications of these findings are discussed.

Keywords: Environmental equity, accessibility, deprivation, ethnicity, urban parks.

INTRODUCTION

The establishment of urban public parks has its origins in the social ideal of providing pleasant open space that is free at the point of access, and as such these places have always been intended to be equally accessible for different social groups. Public urban parks were

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originally established, in part, to provide a place where rich and poor could meet on an equal footing (Young 1996). It is therefore somewhat surprising that relatively few studies concerned with environmental social justice have examined the provision and accessibility of open public space for different social groups.

The exact definition of 'equity of access' is difficult to make, and often context specific. Extended discussion of the general concept of equity is given by Harding and Holdren (1993). Crompton and Wicks (1988), Marsh and Schilling (1994) and Wicks and Backman (1994) discuss different approaches to defining or ensuring equity in a planning context. Crompton and Lue (1992) and Nicholls (2001) consider how equity may be defined with relation to urban park usage, and which definitions are likely to be practicable and preferred by the public. We define equity simply as equal opportunity between social groups.

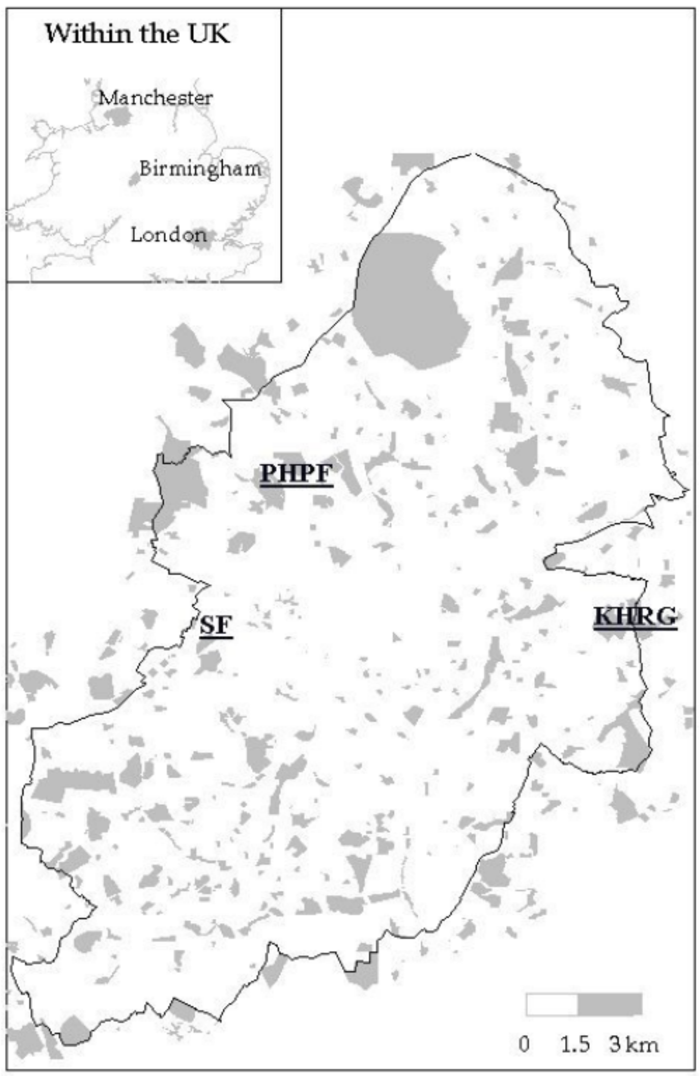

Figure 1. Amenity and recreational parks in the study area, with visitor survey parks marked (SF=Summerfield, PHPF=Perry Hall Playing Fields, KHRG=Kinghurst Recreation Grounds).

Previous research on equity of access to public parks is limited (see Wolch et al. 2005; Estabrooks *et al*. 2003; Nichols 2001; Talen 1997), and we are not aware of any studies for either a large city or for places outside the USA. Some research from the USA (Payne *et al.* 2002; Tinsley *et al*. 2002) reported that ethnic minorities tend to travel further to surveyed parks, but did not question why this might be. In the UK, DTLR (2001) note that ethnic minorities tend to visit urban parks less often than white people. The question arises as to whether this is partly because non-white communities find it more difficult to travel to urban parks. It is also important to consider whether access to parks is reduced for economically or socially deprived populations.

The Greater London Authority acknowledge that socially deprived areas in London often have relatively poor access to green spaces (GLA, 2001), and areas with less green space seemed to have more benefit claimants and overcrowded households (GLA, 2003).

The relative dearth of work in the UK on the issue of access to urban parks is perhaps surprising when it is considered how much they are a very visible and publicly-owned environmental good. The work reported here focuses on differential access between ethnic minorities and socio-economic groups with respect to urban parks. Our study area is the city of Birmingham, where we had detailed information on parks, demographic statistics and the transport network. Birmingham is located in central England (see Figure 1) and is the second largest city in the UK with just under 1 million residents in the 2001 Census. Approximately 28% of the city population are non-white. In this research we examine equity of access in terms of neighbourhood ethnicity and socio-economic deprivation.

MATERIALS AND METHODS

Data Sources

Our analysis focused on urban rather than regional parks provision, and hence the boundaries of the city of Birmingham in central England defined the study area. There were 977,087 residents in the city at the time of the 2001 Census.

The project benefited from data derived from a wide variety of sources. These included the 2001 UK Census, and an existing database of Ordnance Survey (OS) digital data encompassing the city of Birmingham and the areas immediately beyond the city boundaries. The Ordnance Survey dataset included property boundary features (OS Landline) and a detailed road network (OSCAR).

This was augmented with information on the location and type of parks and green spaces that we obtained from a number of sources. Social surveys were also undertaken to collect information on park usage. This information was used to model the relationship between frequency of visits and distance to park entrances.

Our analysis made use of the ArcGIS Geographical Information System (GIS) package. The application of these various data sources in the research is discussed below.

Birmingham Road Network

We presumed that people would travel to parks via the city road network, either on foot, by bicycle, or in a vehicle. The Ordnance Survey OSCAR digital map database was used to extract road centrelines for the entire city and immediately adjacent areas. The data were produced in early 2000, and hence coincide well with the 2001 Census.

Parks in Birmingham

What qualifies as a "park" is a subjective judgement. Examples of different typologies of green and public open spaces are found in Kit Campbell Associates (2001) and DTLR (2002a and 2002b). These typologies tend to include such open spaces as allotments, canal banks or public squares. In our analysis we have consider only spaces that would be used for a particular set of purposes, namely casual recreation. Parks and other green spaces within Birmingham and up to 500m outside of the city boundaries were located with the use of a city atlas (Geographers' A-Z Map Co., 2000). Precise boundaries for each park area were located and extracted from the Ordnance Survey digital Landline database. Following the labelling in the A-Z atlas, four categories of park or green space were distinguished:

- *Amenity parks* refers to leisure gardens, country parks, wildlife centres, woods, fish ponds, public greens and commons, areas labelled as simply as 'park', and green spaces not allocated for other specific undeveloped purposes (such as canal banks, paved public squares or allotments).
- *Recreational parks* are those designated as 'recreation grounds', 'playgrounds', 'sports grounds' and 'playing fields' not attached to any specific school or institution.
- *Specialist sports grounds* denotes areas labelled as used for a specific sport, such as tennis courts, hockey pitches, cricket grounds and golf courses.
- *Other* facilities included cemeteries, school grounds and college or university grounds.

We consulted both the Birmingham Open Spaces Forum and Birmingham City Council in devising this typology and both organisations agreed with the manner by which we had classified parks. Table 1 provides summary statistics for each type of park. Amenity and recreational parks provide the majority of park provision in the city. Specialist sports grounds and 'other' parks were found to not be generally of open access to nearby communities. We therefore focus the rest of our analysis on the former two types of green space. Figure 1 shows amenity and recreational parks in the study area.

The large scale of the OS data made it necessary to locate park entrances precisely, and hence the locations of access points were identified for each park included in our analysis, and these were digitised into the GIS. The A-Z map and the Landline database were jointly consulted for this purpose. These sources indicate where parks border roads and where breaks in surrounding buildings exist to apparently allow pedestrian access to the parks, but they do not depict the presence of fencing. Moreover, we had no easy way of detecting informal access routes and points (i.e., cut-throughs over rough ground, or holes in fencing).

Table 1. Main types of park included in each typological category

General Category	Including:	Number
Amenity	Public open space/commons/greens	59
	Ponds and reservoirs	50
	Nature reserves/woods	31
	Country parks	5
	Park farms	3
	Leisure gardens	2
	Public playgrounds	2
	School rough	1
	Other parks not labelled as sporting areas	89
Total area		2821 ha
General Recreation	Recreation grounds	105
	Playing fields	98
	Sports grounds	36
	Paddling pool	1
Total area		1308 ha
Specialist Recreation	Golf courses	24
	Bowling greens/pavilions	20
	Cricket grounds	13
	Stadia	8
	Tennis courts	7
	Football grounds	4
	Rugby grounds	3
	Hockey pitch	1
	Leisure centre	1
Total area		1175 ha

Census area boundaries and 2001 population.

The Office of National Statistics (ONS) supplied data on population totals, population-adjusted geographical centroids (centre points), and geographical boundaries of Output Areas (OAs). These are the smallest geographical units in the 2001 Census. There were 3127 OAs within Birmingham city boundaries, containing an average of 312 persons and 125 households each. Output Area centroids and population totals for them were input to the *SurfaceBuilder* computer programme (Martin 1996). *SurfaceBuilder* generates a surface depicting the estimated number of persons resident in regularly spaced square areas, or cells. A cell resolution of 20x20m was used. Because the resulting surface is partially a function of original centroid locations, the resultant cell values are an imperfect measure of actual population locations. Furthermore, the fine scale does not necessarily provide an accurate measure of the number of residents in each individual cell. However, the production of the surface enabled the easy estimation of accessibility measures that were weighted by relative population sizes, and it was employed here in the estimation of population accessibility to parks.

Deprivation and Ethnicity

Information on material deprivation and ethnicity was collected at the scale of Lower Layer Super Output Areas (LSOAs). These contain small groups (typically 4-6 in number) of contiguous OAs with similar social profiles. There are 641 LSOAs in Birmingham. The LSOA level is appealing because of the availability of the Index of Multiple Deprivation (IMD2004; ODPM 2004) for this geographical scale. The IMD2004 comprises of seven domains describing different types of deprivation including income, access to housing and services, education, employment, health and disability, skills and training, living environment, and crime. For this research only the income domain of the IMD2004 (subsequently abbreviated to Inc-IMD2004) was used. The income domain relates to data collected in 2001 and 2002 on the proportion of the population receiving various types of means-tested income support, including benefits and tax credits. Hence areas scoring more highly on Inc-IMD2004 are more materially deprived.

From 2001 Census data, statistics were derived on the percentage population composition of various ethnic groups. The ethnic categorisations that we used (white, Bangladeshi, Pakistani, Indian, and black,) were identical to those reported in the Census, and are based on self-report. For the latter category we combined persons of Caribbean and African heritage who identified themselves as “black” in the 2001 Census with persons of mixed white and black heritage.

Quantification of the Effect of Distance on Accessibility

A number of factors will impact upon the decision to visit a park. Purpose of visit is likely to shape decisions regarding which park a person might visit, and both seasonality and time of day can also influence visit patterns (DTLR, 2002a; Scott, 1997). However, the principal consideration for many is likely to be travel distance. Hence, in order to adequately measure accessibility, information on the relationship between distance and park usage was required.

We were unable to find previous research that provided information on distances that users in Britain travel to visit urban parks. We therefore conducted our own survey. Visitors to three parks in Birmingham were interviewed during the summer of 2001. Survey parks were chosen by considering deprivation levels in the area around each. Census wards were categorised according to their levels of deprivation into the 33% most deprived, 33% least deprived, and the remaining 33%. One medium-size park was selected for survey in an area dominated by each deprivation tercile: Summerfield Park (most deprived), Perry Hall Playing Fields (least deprived) and Kingshurst Recreation Grounds (middle).

In total, 117 individuals were interviewed (a minimum of 35 at each park) and asked for their mode of travel, the full postcode of their outset point, estimated one-way travel time to reach the park, the number of persons in their visitor party, and reasons for being in the park that day. Five respondents had to be excluded from subsequent analysis due to them providing incomplete information (such as an invalid postcode). The outset origin postcode supplied by each respondent was related to a 100m resolution reference (on the national grid system) using the Central Postcode Directory held at Manchester University. The road network distance between this origin and the nearest entrance to the park was then calculated within the GIS.

Table 2 summarises the characteristics of each park and its visitors. Included are socio-economic statistics for the origin areas from which visitors came. A trend is apparent where Summerfield visitors tend to come from the most deprived areas, and Perry Hall park users tend to originate from the least deprived areas. Otherwise, the most striking features are the much higher proportion of visitors from predominantly white neighbourhoods to Kinghurst Park, and an inverse association between the proportion of visitors travelling by car and the deprivation levels surrounding each park.

Table 2. Summary statistics for the visitor survey locations

	Summerfield	Kinghurst	Perry Hall
Deprivation tercile	*Most deprived*	*Middle*	*Least deprived*
Origin Inc-IMD2004 score, 10^{th}–90^{th} %ile (median)	0.23-0.45 (0.39)	0.14-0.40 (0.27)	0.08-0.47 (0.13)
Park size, ha	15.7	116	62.9
Median (mean) party size	2 (3.37)	1 (2.26)	2 (2.36)
Mode of travel:			
Number of motorists (%)	7 (20%)	11 (34%)	15 (38%)
Number of cyclists (%)	0 (0%)	2 (5%)	3 (8%)
Number of pedestrians (%)	28 (80%)	25 (66%)	21 (54%)
Travel distance:			
Median (mean) road distance in metres, all visitors	311 (705)	420 (1232)	1420 (2194)
Median (mean) road distance in metres, pedestrians only	225 (395)	288 (814)	717 (923)
Maximum stated travel time amongst non-motorists (mins)	22	150	53
Maximum modelled travel distance amongst non motorists (km)	1.1	9.6	3.1
Ethnic composition of neighbourhood			
% White, 10^{th}–90^{th} %ile (median)	17.9-51.7 (42.0)	83.2-97.4 (94.1)	11.5-95.7 (36.7)
% Bangladeshi, 10^{th}–90^{th} %ile (median)	0-2.3 (1.1)	0-0 (0)	0-10.2 (1.01)
% Indian, 10^{th}–90^{th} %ile (median)	9.9-32.2 (19.2)	0-2.2 (0)	0-39.5 (16.7)
% Pakistani, 10^{th}–90^{th} %ile (median)	2.7-35.0 (13.9)	0-3.12 (0.5)	0-42.3 (6.5)
% Black, 10^{th}–90^{th} %ile (median)	10.8-28.5 (18.6)	1.1-9.4 (4.5)	3.2-30.8 (12.1)

The survey data were used to model the relationship between travel distances and frequency of visits. A model of the decay relationship between proximity and visit frequency was developed for all parks. This was used to generate data indicating the level of park accessibility from any single origin point in Birmingham. There are many possible ways to derive an accessibility index for an environmental amenity and facility such as public parks. Haynes *et al*. (2003) argued the case for a function to measure relative accessibility taking the form:

P = C * exp (Decay_coefficient * Impedance) {1}

where

P=Potential or accessibility index
C=Constant
Decay_coefficient = the rate at which accessibility declines per unit of impedance
Impedance = difficulty, usually measured in terms of travel time or distance

A common way to calculate P would be to predict the number of visitor parties from origin zones as a per capita visitor rate. Unfortunately we did not know what percentage of the total number of visitors we surveyed at each park. In the absence of this information we used the number of visits reported by respondents during the preceding four weeks. This has the advantage of not requiring information about the total number of visitors to the park in any given period, yet visit frequency can be expected to decline with decreasing distance, and to reflect, in large part, ease of access.

A distance decay relationship between journey origins and parks in Birmingham was derived by comparing reported frequency with calculated travel distance in the GIS. The relationship was generalised by grouping visitors into seven distance bands: 0-250m, 251-500m, 501-750m, 751-1000m, 1001-1500m, 1500-2500m and 2500-3500m. Survey respondents who were only in a park because they were en-route to another location were excluded from this and further analysis. The average number of visits amongst respondents in each distance band is plotted against the average calculated travel distance in Figure 2. A strong and consistent decline is apparent in average visit frequency with increasing average distance.

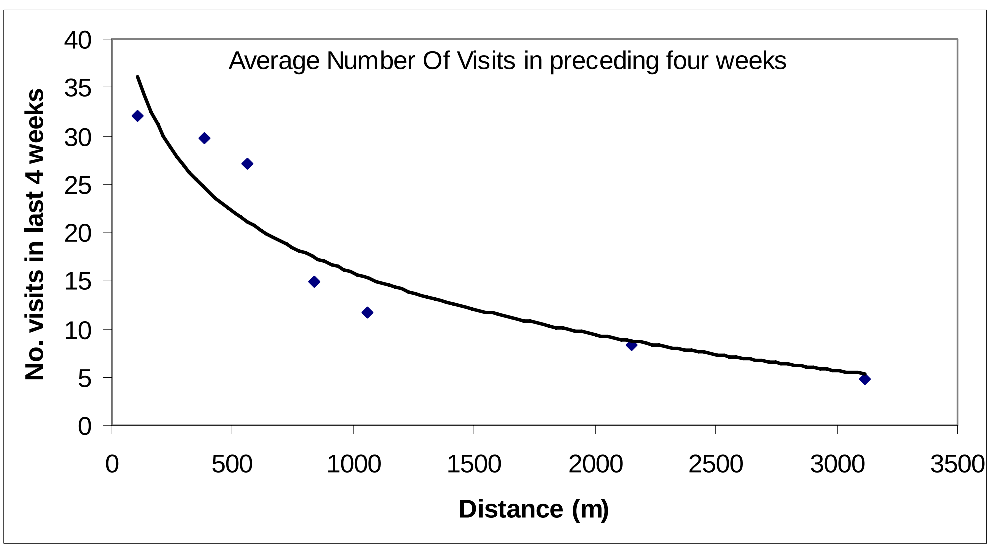

Figure 2. Average number of visits in preceding four weeks plotted against average distance bands.

Using the functional form depicted in Equation 1, the average number of visits was regressed against travel distance for Birmingham parks visitors, to produce;

$$P = 32.0085 * \exp(-0.0006398 * \text{distance}) \quad \{2\}$$

The high R^2 value obtained of 0.922 indicates a strong link between grouped visit frequency and distance between home origin and the nearest park entrance, and this relationship was used to model the way by which accessibility will decline with distance.

Based on the results of the above modelling, three accessibility 'potential' surfaces were generated for recreational, amenity, and combined park areas. This process required the identification of both designated outset and destination points. Potential population journey origins were generated at 1420 road junctions throughout Birmingham. Destination points were taken to be park entrances. Visits are known to increase with park size, but the relationship between visit frequency and park size may not be linear. In a study of 516 urban parks in Perth, Australia, Giles-Corti *et al.* (2005) found that visit frequency was best predicted when they weighted their distance decay function by the natural logarithm of park size (in ha) raised to the power of 0.85, or

$$\text{Attractiveness=Distance\_Decay\_Function} * \log(\text{size}^{0.85}) \quad \{3\}$$

"Attractiveness" as Giles-Corti *et al.* defined it equates to visit frequency in this work. We therefore allocated to each entrance a supply weighting equal to the area (in ha) of that park, raised to a power of 0.85 and then transformed by natural logarithm. For instance, Phoenix Park to the south of the city centre measures 1.58 hectares and is classified as entirely amenity park area. Phoenix has two entrances, each of which was given a supply weighting of 0.388811 (=$\log(1.58^{0.85})$). Very small parks less than 1 ha were given a supply weighting of 0.01 to prevent negative values being calculated. Only the nearest entrance for each origin was considered as an access point, and all of the supply weighting was applied to that.

Within the GIS the distance in metres between each pair of origin and destination points was calculated. Distances below 110 m were reset to a value of 110, to prevent spuriously high potential being predicted very close to parks. 110m was chosen because of a natural break in the original survey data at that point. Next, an interaction score between each origin and destination was generated using the formula;

$$\text{SCORE} = [32.0085 - \exp(-0.0006398 * \text{DISTANCE})] * \log(\text{HECTARES}^{0.85}) \quad \{4\}$$

Subsequently, scores were summed by origin, to yield a single value indicative of park accessibility for that origin.

A triangulated irregular network (TIN) (Peuker *et al.* 1976) was generated to estimate access scores for locations between origin points. The TIN data were sampled on a regular 20 x 20m grid to create potential surfaces. To facilitate interpretation, the potential values were converted to Z-scores with a mean of zero and a standard deviation of one. The greater the index value, the better the access to parks for persons travelling from that location. The resulting values are mapped in Figure 3 for amenity and recreational parks, and Figure 4 for both park types combined. Figure 3 shows that the northern-central area and the southwest of the city are well-endowed with amenity type parks. There is a ring of high provision of recreational type parks around the city centre, whilst the city centre itself and the furthest suburbs, especially in the north, are relatively poorly provided with this type of park.

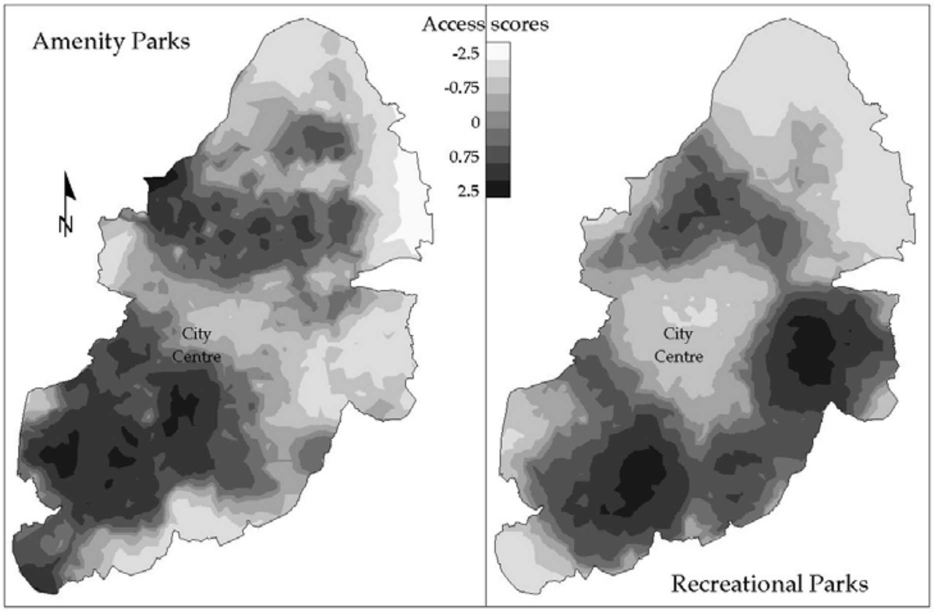

Figure 3. Calculated access scores for amenity (left) and recreational (right) parks in Birmingham.

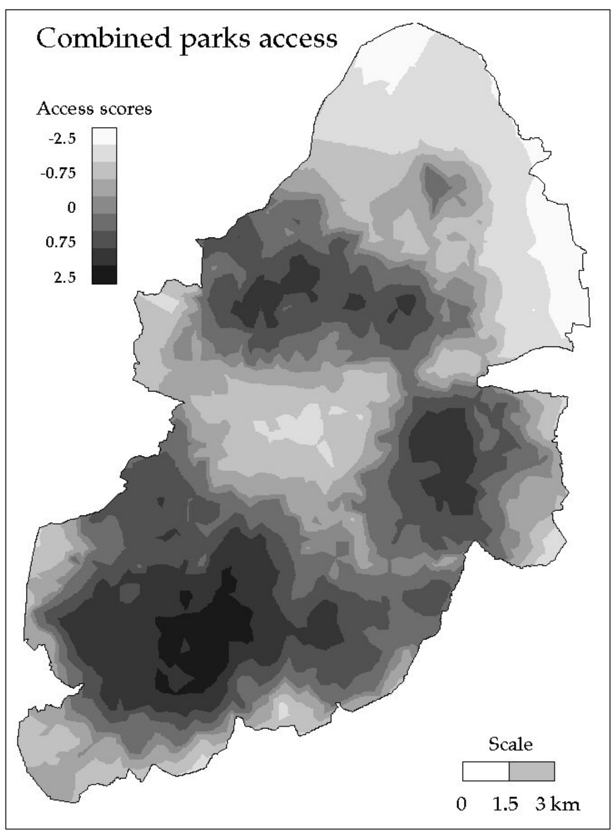

Figure 4. Calculated access scores for amenity and recreational parks combined.

Combing the two types of park (Figure 4) the north eastern suburbs and the city centre itself are most disadvantaged.

The next step was to overlay these surfaces with LSOA boundaries and the population surface. This enabled us to calculate a population-weighted park access score for each individual LSOA.

RESULTS

Equality of access to parks for different communities in Birmingham was examined with respect to both income deprivation and ethnic composition. In order to determine how the estimates of access were distributed across different populations, tests that compared the distributions of access scores were undertaken, as discussed below.

Ethnicity and Equity of Access to Public Parks

The population of Birmingham was 70.35% white, 20.16% Asian/mixed Asian and 7.87% black/mixed black in the 2001 Census. To compare park access between these populations, the percentage of the total Birmingham population in each ethnic group was determined for each LSOA. For example, the LSOA labelled E01009276 had 166 persons recorded as black. This equates to 0.216% of the total 76,930 black persons residing inside the Birmingham city boundaries in 2001. Calculating this percentage of the total for each LSOA allowed us to determine what proportion of each ethnic group had particular parks access scores.

Table 3 shows the median access scores for each ethnic group. There are no striking differences between ethnic groups for amenity parks access, although Pakistani populations have the best access.

Median scores differ little. However, with respect to recreational or combined parks access, whites seem to have more advantage over other groups, especially Bangladeshis.

The detailed distributions of park access scores for different ethnic groups were examined by plotting cumulative frequency distributions against access scores. The resulting plot for access to amenity parks is shown in Figure 5. The plots for access to recreational parks and both types combined were similar and are not reproduced here. Park access scores for LSOAs were divided into fifty categories. Each contains two percent of Birmingham's total population. The horizontal axis shows the upper limit of amenity or recreational access scores in each category.

Table 3. Median parks access indices for ethnic groups in Birmingham.

	Indian	*Pakistani*	*Black*	*Bangladeshi*	*White*
Amenity	-0.052	0.107	-0.071	-0.101	0.024
Recreational	0.069	0.109	0.131	-0.027	0.218
Combined	0.145	0.193	0.165	0.045	0.247

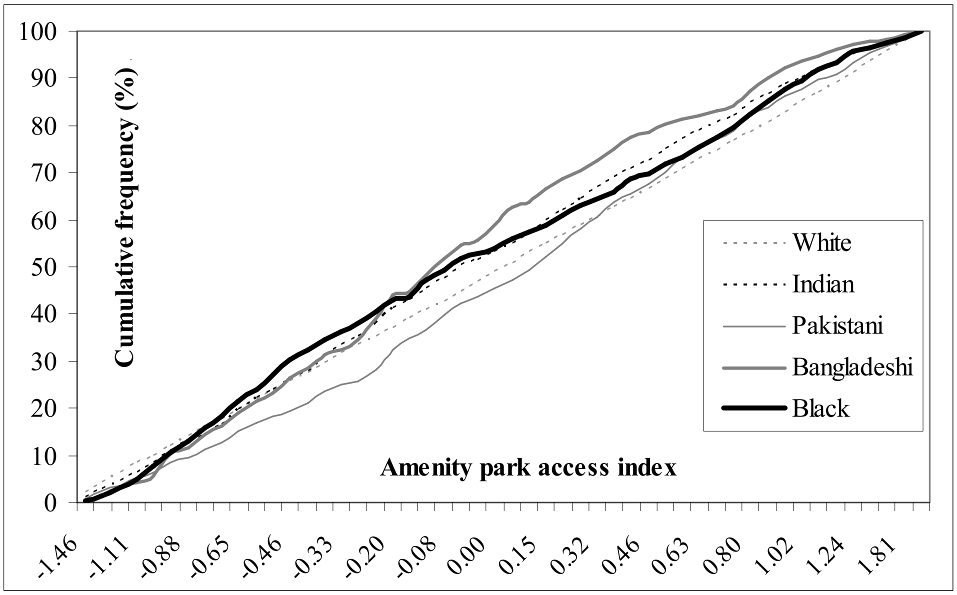

Figure 5. Cumulative probability distributions for specified ethnic groups and access to amenity parks.

The vertical axis plots cumulative percentages. A perfectly straight diagonal line on the plots would indicate that the given range of potential scores occurred equally often across that ethnic group. This is because each category contains an equal proportion of the city population and the horizontal axis is non-linear. Lines that deviate from a perfect diagonal suggest a population displacement towards higher or lower access scores. Percentile lines bulging to the left of a perfect diagonal indicate a population group with relatively lower than average access, whilst lines pushed to the right suggest superior access. The greater the vertical gaps between the cumulative percentile lines, the more likely it is that an inequality is occurring between groups.

A robust way to test for differences in the data in cumulative distribution plots is to use the Kolmogorov-Smirnov (KS) test (Connover, 1999). This test assesses the significance of the relative distance between the cumulative frequency lines. A two-sample KS test was used to examine the differences in population distribution between the various subgroups. Table 4 provides the resultant KS values, with the critical values at p=0.1, 0.05 and 0.01 levels.

Table 4. Kolmogorov-Smirnov statistics for two-sample tests comparing cumulative probability distributions for ethnic groups and parks access

Amenity				
	Indian	*Pakistani*	*Black*	*Bangladeshi*
White	0.0776	0.0776	0.0704	0.1296
Indian		0.0996	0.0448	0.0775
Pakistani			0.1230	0.1572
Black				0.0884

Table 4 – Continued

Recreational				
	Indian	*Pakistani*	*Black*	*Bangladeshi*
White	0.0701	0.0823	0.0870	0.1375
Indian		0.0353	0.0535	0.0949
Pakistani			0.0508	0.1153
Black				0.0986

Combined Amenity and Recreational				
	Indian	*Pakistani*	*Black*	*Bangladeshi*
White	0.0610	0.0514	0.0739	0.1381
Indian		0.0527	0.0694	0.0901
Pakistani			0.0334	0.1010
Black				0.1113

Critical KS values for p=0.1, 0.05 and 0.01 are 0.1725, 0.1923 and 0.2305 respectively.

The KS statistics confirmed the visual impression from the figures that there is no significant inequity between ethnic groups and their relative access to different categories of park type. The greatest differences occur between white and Bangladeshi populations, but these do not reach statistical significance.

Deprivation and Equity of Access to Public Parks

Table 5 gives the median park access score for five deprivation groups (Inc-IMD2004 quartile groups and the most deprived decile) and by type of park. Figures 6 to 8 plot the cumulative percentiles of population in each Inc-IMD2004 quartile (plus the top decile) against amenity/recreational/combined parks access scores. Table 6 presents KS statistics for the data in the figures.

The table and figures show that, for Amenity parks, there is some indication of disparities in access between the different deprivation groups, with the poorest population cohorts having worse access compared to other deprivation groups ($p<0.01$). For recreational parks, and both park types combined these disparities are much stronger with the most deprived population groups having significantly poorer access than the others. The middle two deprivation quartiles tended to have better accessibility than the other groups, with the most affluent quartile having comparatively average park access.

Table 5. Median access scores for each income deprivation group, by park type

	Quartile 1 (least deprived)	*Quartile 2*	*Quartile 3*	*Quartile 4 (most deprived)*	*Decile 10 (10% most deprived)*
Amenity	-0.030	0.268	0	-0.079	-0.148
Recreational	0.027	0.422	0.3	-0.220	-0.505
Combined	0.248	0.423	0.270	-0.043	-0.268

Table 6. Kolmogorov-Smirnov statistics for two-sample tests comparing cumulative probability distributions for Inc-IMD2004 and park access

Amenity	*Quartile 2*	*Quartile 3*	*Quartile 4*	*Decile 10 (10% most deprived)*
Quartile 1 (least deprived)	0.1509	0.1214	0.1778*	0.2037**
Quartile 2		0.1878*	0.2349***	0.2589***
Quartile 3			0.1086	0.1545
Quartile 4 (most deprived)				0.0568

Recreational	*Quartile 2*	*Quartile 3*	*Quartile 4*	*Decile 10 (10% most deprived)*
Quartile 1 (least deprived)	0.2573***	0.2261**	0.2111**	0.4101***
Quartile 2		0.0968	0.4073***	0.6574***
Quartile 3			0.3239***	0.5961***
Quartile 4 (most deprived)				0.2853***

Combined Amenity and Recreational	*Quartile 2*	*Quartile 3*	*Quartile 4*	*Decile 10 (10% most deprived)*
Quartile 1 (least deprived)	0.2416***	0.1960**	0.2347***	0.4302***
Quartile 2		0.1470	0.3478***	0.5806***
Quartile 3			0.2438***	0.5048***
Quartile 4 (most deprived)				0.2610***

Critical KS values for p=0.1, 0.05 and 0.01 are respectively 0.1725 (*), 0.1923 (**) and 0.2305 (***).

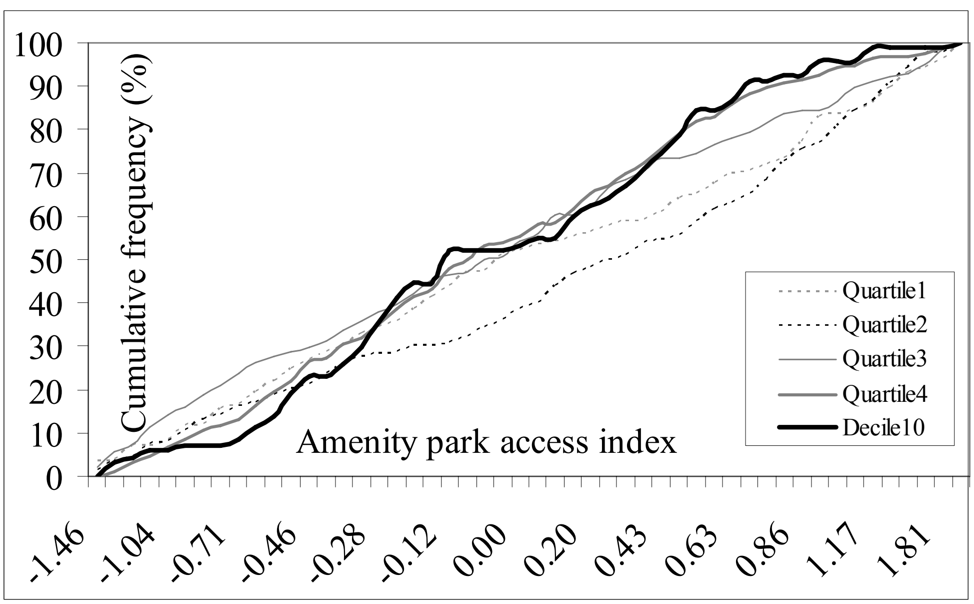

Figure 6. Cumulative probability distributions for specified deprivation groups and access to amenity parks.

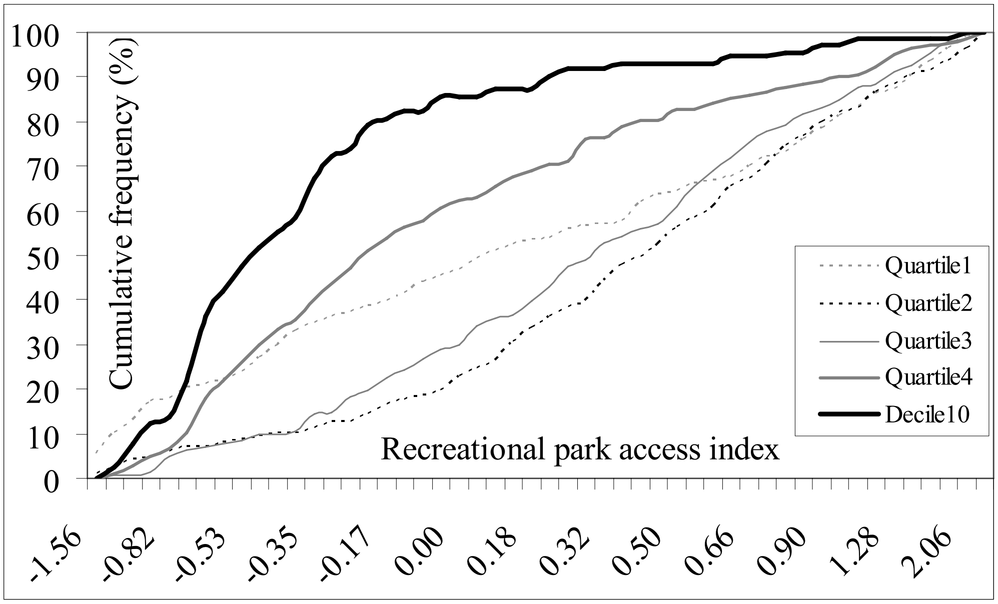

Figure 7. Cumulative probability distributions for specified deprivation groups and access to recreational parks.

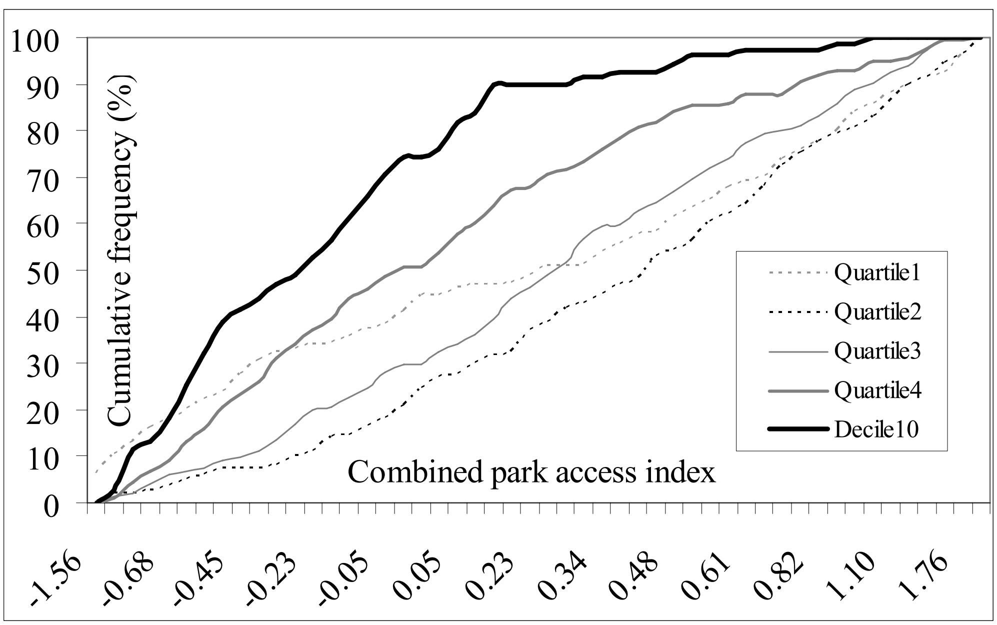

Figure 8. Cumulative probability distributions for specified deprivation groups and amenity and recreational parks combined.

DISCUSSION

Relatively little previous research has addressed the question of the differential access to green spaces amongst diverse communities residing in urban areas. Using a case study of the city of Birmingham England, this study has sought to go some way to rectify this deficiency by assessing the distribution of access to urban parks amongst a diverse urban population.

Our analysis found only weak evidence of disparities in access between different ethnic groups in the population. However, we found very statistically significant indications of unequal access to public parks with regard to income deprivation, whereby the most deprived population had the poorest access to parks. Of course this cross sectional observation does not, in itself, provide an insight into the reasons why these disparities may exist.

Pearce (2003) contended that environmental equity studies are often flawed because they ignore a fundamental aspect of capitalism, that the rich have the ability to pay for a nicer place to live. He took an economic perspective, arguing that equity could only be properly assessed with respect to how much each community paid for a benefit (or to avoid a disamenity), and whether their benefits or costs were commensurate with those payments. Pearce's arguments are supported by many North American studies (see Been and Gupta 1997; Lambert and Boerner 1997; Mitchell *et al*. 1999; Szasz and Meuser 2000; Yandle and Burton 1996), which concluded that apparently unfair pollution burdens usually result from economic not racist factors, particularly from a move-in of minority and poor social groups, due to lower house prices for instance, after an environmental nuisance was created. Indeed, it is quite possible that the residents of poorer communities in our study may receive other benefits which compensate for their poorer access to urban parks. It is also noteworthy that the most affluent populations did not have the best access, again suggesting that compensatory mechanisms, possibly associated with the availability of private land, were present. Nevertheless, it is important to note that the concept of equal access for all was one of the principles upon which the public parks movement was founded.

It could be argued that, due to economic forces, improvements in park provision may only achieve temporary gains for otherwise disadvantaged populations. As the environment in an area improves, wealthier social groups may be attracted to it, making it difficult for the original disadvantaged social group to remain in the now improved area. These exclusionary processes may operate, for example, via rising housing costs or more general issues of social prejudice. This perspective ignores, however, the value of short and medium term gains in environmental quality in the lives of the original area inhabitants. Furthermore, house price rises due to improved environmental conditions may enable existing home-owners in the area to pass on more wealth to their children which is a permanent improvement for the next generation.

As with any study, our results will in part be influenced by aspects of our study location and chosen methodology. Our findings are based on a detailed analysis undertaken in a socially and environmentally diverse, yet singular, urban area. We chose to study Birmingham due to the interest generated by this diversity, coupled with availability of very high quality data in the city. From our analysis it is not possible to determine whether similar associations would be apparent elsewhere. However, our research has demonstrated the application of a methodological framework that could be readily applied in other contexts. We also assume that the distribution of households, with respect to deprivation and ethnicity, within each LSOA is uniform. In reality, this will not be the case, although we chose to study LSOAs because of their small size and hence relatively homogeneous nature. In our development of a park typology, we attempted to select locations that would be available and attractive for recreational use amongst the general population. However, any such typological classification will be, at least in part, subjective. It is possible for example that in some areas, patches or waste land or other types of green space may compensate for poor availability of parks or enhance current levels of provision by providing some of the same functions.

In our study we have measured access in terms of road distances, and our only measure of ‘quality’ has been the size of the parks. In reality, of course, quality is multifaceted and will be associated with a range of factors surrounding facility provision and standards of maintenance. Research suggests that there is a national trend for deprived areas to contain parks with relatively poorer maintenance, and since the 1960s, support for provision of open spaces in urban areas has declined (ILAM Services and Harding 2000, Urban Parks Forum, 2001). The focus of investment and facility development has shifted instead to suburban and rural country parks (Reeves, 2000). This tendency to suffer from under-investment has led to a loss of perceived amenity value, most noticeably in inner city locations. Given that the poorest populations and members of ethnic minorities in Birmingham (and most big cities) tend to reside in inner city areas, this means that levels of disadvantage may be greater than those apparent from the comparisons we have made if more subtle aspects of quality of provision are considered.

The findings of this study reveal reduced access to a public environmental amenity among certain social groups, in particular those living in the most deprived communities. The lack of open-air sports facilities may well have consequences for general health levels in each population, given that public open spaces are increasingly recognised as important places for physical exercise (see Bedimo-Rung *et al.* 2005; Foster *et al.* 2005; Giles-Corti *et al*. 2005; Hillsdon et al. 2006; Jones et al. 2007). Therefore, although our findings relate directly to social inequities, they may have public health implications as well.

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AN IDEA FOR PHENOMENOLOGICAL THEORY OF LIVING SYSTEMS

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ABSTRACT

An idea for developing of new science field, *biodynamics*, as biophysical macroscopic theory is propounded. The functioning of living organism as an organized entirety is the main specificity of the life. Hence it is quite reasonable to describe behaviour of biological systems in terms of own theoretical basis. In this article a new state variable *vitality* as integral characteristic of biological object and measure unit *bion* are stated. A quantity *biological energy* is introduced as energy form related to biological selfregulation. Quantity *synergy* is suggested as measure of selfregulation quality. Biological principle for maximum synergy in healthy living systems is stated. On the basis of variational principle an equation describing recovery process of a biological object after disturbance is obtained. The quantity *optimal vitality*, related to homeostasis, decreases in lifespan scale and its evolution is described by ordinary differential equation. The potential lifespan maximum of several species at different life conditions may be calculated at different parameters of the equation. A wide range of environmental influences on the living organism could be promptly and easily assessed in the terms of the biodynamics approach. Such an approach could be used for a simple estimation of a patients' health status.

INTRODUCTION

XX century brought colossal discoveries in the field of molecular biology. In the same time unified theory of living mater on phenomenological level is not created. Such a theory could help study the behaviour of the native *b*iological *o*bject (BO) in its entirety. This may be a new step in exploration of living systems in the context of environmental condition changes, diseases etc. The great complexity and different organization levels of BOs embarrass a direct application of physical theories to biological systems. Notwithstanding, serious attempts have been made to describe quantitatively different aspects of the life phenomena on the basis of physical theories – thermodynamics, electromagnetism, hydrodynamics, quantum mechanics etc. Shrödinger (1944) suggested that the essence of the life is that living organisms consume negative entropy (negentropy). Goodwin (1963) tried to create a biological statistical mechanics and thermodynamics on the basis of kinetics of synchronized biochemical oscillators. Rosen (1967) formulated optimal principles in biology. Szent-Györgyi (1968) elucidated some mechanisms of cell regulation in the terms of bioelectronics. Prigogine and Nicolis (1978) developed theory of dissipative structures, as an extended irreversible thermodynamics, to explain self-organization processes in nonequilibrium systems. Davidov (1979) gave a quantum-mechanical interpretation of some biological phenomena. Thermodynamic approach was applied to the structure and functions of macromolecules (Di Cera 2001). Kleidon and Lorenz (2005) presented a coherent study of geosphere-biosphere couplings in the context of maximum entropy production principle. Kurzynski (2005) proposed a thermodynamic approach combined with describing of molecular machines. Many authors emphasized the great importance of information in the functioning of BO. Quastler (1964) represented the problems of the emergence of biological organization on the basis of biological aspect of information. Trincher (1965) tried to extend thermodynamics via introducing of a concept of structural information in BO. Eigen (1971) explained the evolution of macromolecular structures taking into account laws of information exchange. Volkenstein (1994) considered life evolution in its informational aspects.

The great significance of all these considerations, however, does not abolish the need of a general phenomenological approach to BOs. Phenomena as thermal conductivity, diffusion, electric current etc. are not describable in the terms of mechanics and thus new fields as thermodynamics and electrodynamics with their concepts and laws were created. On thermodynamic level it is not possible to underline the essence of life. All attempts to construct an extended thermodynamics of irreversible processes, including living matter, remain artificial and not quite adequate. Blümenfeld (1967; 1974) noted that the true way to a general life theory is not a creation of biological thermodynamics.

Really, the thermodynamic and electrodynamic laws are valid for different aspects of BO functioning but they do not explain the essence of life – selfregulation and behaviour of BO in its entirety. A new science field – BIODYNAMICS is needed.

Indeed, the biological regulation has been regarded in details in cybernetic aspect. Our view is, however, that the biological selfregulation should be an object also of physics.

Although the life activity is based on biophysical and biochemical processes the perfect co-ordination of these processes forms already a new quality of matter organization. Thus, it is advisably to put in correspondence of BO behaviour new type quantities as integral characteristics of BO on macroscopic level. Here we introduce the quantity "vitality" as a basic biodynamic quantity. Thus, the following juxtaposition can be stated:

Classic dynamics – mass
Electrodynamics – charge, field intensity
Chromodynamics – colour charge
Thermodynamics – temperature, pressure, concentrations etc.
Biodynamics – vitality

Naturally new type of measurements should be expected. The author presumes a creation of a new device and believes that by means of such a device one will be able directly to measure vitality in the future.

Such an approach will avoid the great complexity in the quantitative description of living systems via thermodynamics, chemical kinetics etc.

The attention in this article is drawn on recovery processes of BO after disturbances running in time intervals much shorter compared to BO lifespan. On the other hand, the evolution of optimal vitality during the lifespan of BO is studied.

A POSSIBLE THEORETICAL BASIS OF BIODYNAMICS

We think BO as a macroscopic object, which saves its features and character only in its integrity. The living system demonstrates a new level of material organization non-described previously in physics.

We introduce a new quantity, *vitality* (V) uniquely determining the state of a given BO. Thus V is an integral characteristic of BO functioning in its entirety. In thermodynamics the temperature is a measure of kinetic energy of the molecules. In biodynamics the vitality should be a measure of the health status of BO. Obviously, vitality is related to the informational aspect of BO functioning. We propose the respective measurement unit of the vitality in SI system to be called *bion* (*b*).

We assume that V could be in principle measured by a new type device – *vitalimeter*. Such an instrument should measure some electromagnetic wave emitting by BO, a wave (or wave complex) being an integral characteristic of BO functioning. Electromagnetic waves of different frequencies, generated by human, animal and plant organisms in their metabolic activity were measured yet many years ago (Presman 1968). The explorations in this way were continued (Godik and Guljaev 1991; Elizarov 1997). The recent development of advanced technologies have been gone rather far and this fact promises well success in searching of some device, reflecting resultant information about BO. A new constructed apparatus, being able to detect some wave as integral BO characteristic, could be calibrated in a manner that to show V in bions. For instance, one bion may be defined so that the excellent standard of human's health corresponds to vitality of 100 bions.

Not only the frequency/length of the wave but also the wave amplitude gives information for BO status. Thus, at least two new quantities should be defined. However, here for simplicity we shall take into account only one quantity (understanding, for instance, the wavelength). Here we are not interested in the incidence of the wave in the space. The very value of the vitality at a certain moment is important.

We introduce also a quantity *optimal vitality* (W). That is the optimal vitality value, corresponding to state of excellent health of BO and reflecting homeostasis characteristics evolutionarily established for the respective species. W is genetically determined and in time intervals much shorter compared to lifespan it may be regarded as a constant. During the life, however, W decreases due to aging processes. After different transitory disturbances in BO status V temporarily can deflect from optimal vitality, i. e. $V \neq W$. Then a transitional process is running and $V \rightarrow W$. That is a *recovery process*.

The total energy E of a natural system is sum of the mechanical energy E_M, and internal energy E_I (Gyarmati 1970):

$$E = E_M + E_I$$

The internal energy contains heat energy, chemical energy etc. (Prigogine and Defay 1954):

$$dE_I = dQ - pdv + \Sigma\mu_i dn_i$$

It is reasonable to establish in biodynamics a respective specific energy. We shall cal it *biological energy* (B). We could suppose that it is a function of $V(t)$ and $\dot{V}(t)$ (where $\dot{V}$ is the rate of change of the vitality in time):

$$B = B(V, \dot{V})$$

The biological energy should be a part of internal energy:

$$dE_I = dQ - pdv + \Sigma\mu_i dn_i + dB$$

B is the energy providing biological selfregulation (on the basis of enzyme synthesis, resonance energy transfer between biological macromolecules, electric charge transfer, immune response etc.). All these energies in macroscopic aspect could be denoted as biological energy B.

We introduce also a state function *synergy* $G(V)$, which uniquely determines the state of a given BO:

$$dG = \frac{dB}{V} \qquad (1)$$

as a measure of the quality of the BO selfregulation (therefore, of the biological organization). G reflects the degree of coordination and synchronization of the regulatory links in BO. It could be an indicator of BO health and youth. G is genetically determined. G increases in organism growth as well as in training processes. In aging processes, in severe and chronic diseases G decreases. In a mature and healthy BO the synergy G as almost constant $G(V) = G(W)$.

Recovery Process after Disturbance

When a BO is disturbed (acute disease, trauma, intoxication, environmental influence etc.) and its normal life parameters are violated, i. e. $W - V(t) \neq 0$, the genetic information potential switches feedback control (repair, immune system reaction, enzyme synthesis etc.) to restore BO to its physiological homeostasis. A recovery process starts. We assume that in case of damages $V(t) < W$. Here we consider recovery processes, running in time interval much shorter compared to the lifespan of BO.

Now we try to define the balance of biological energy in phenomenological aspect.

We assume the genome energy as composite of two parts: *potential genome energy* U_W and *recovery energy* U_V:

$$U = U_W + U_V \qquad (2)$$

The quantity U_W = const is characteristic for a given species. The recovery energy U_V, should be proportional to the difference $W - V(t)$, i. e. $U_V = k\ (W - V)$. U_V should be a positive function; hence we may present it as a positive determined quadratic form:

$$U_V = \frac{1}{2}K(W - V)^2 \tag{3}$$

where K ($[K]$ = [kg m^2 b^{-2} s^{-2}]) is the *genome inductivity*, representing the integral feedback control strength. It is clear that U_V has minimum at $V(t) = W$. Therefore, in a non-disturbed state BO does not spend recovery energy.

We assume that the *power of immune response* P, expressed on phenomenological level, should be proportional to the rate of change of the vitality. To be a positive function P should be constructed as follows:

$$P = M\dot{V}^2 \tag{4}$$

where M ($[M]$ = [kg m^2 b^{-2} s^{-1}]) is *coefficient of immune memory*.

The immune response has a cumulative effect. The state of a BO at a given moment depends not only on the synthesis of immune factors at that moment but on the summary effect of immune response in all prior moments. Therefore the *immune reaction energy* Z in the recovery process should have the form:

$$Z(t) = \int_{t_0}^{t} P d\tau = \int_{t_0}^{t} M\dot{V}^2 d\tau \tag{5}$$

Because BO behavior is considered on phenomenological level, we are interested in the total effect of immune response and here we do not differentiate cell and humoral immunity. We assume that the constant M characterizes the total immune potential of BO.

The accomplishment of the recovery process may be embarrassed due to waste products of metabolism (non-fully oxidized substances, macromolecules damaged by free radicals) and toxicants (heavy metals, bacterial and virus toxins etc.) occurring in cell and decreasing the efficiency of metabolic processes and cell selfregulation. Therefore, the total biological energy B could decrease at expense of *energy of metabolic resistance* R. It is reasonable to suppose that R is proportional to the rate of change of the vitality. To be a positive function R could be defined in the form:

$$R = \frac{1}{2}A\dot{V}^2 \tag{6}$$

where A ([A] = [kg m^2 b^{-2}]) is *coefficient of metabolic resistance*.

One can write the following equation for the balance of biological energy B:

$$dB = dU + dZ - dR \tag{7}$$

We define

$$\Phi_U = -\frac{dU}{dV} = K(W - V) \qquad \text{and} \qquad \Phi_Z = \frac{dP}{d\dot{V}} = 2M\dot{V} \tag{8}$$

as *biological force of feedback control* and *force of immune reactivity*, respectively. Their dimension is: $[\Phi_U] = [\Phi_Z] = [\text{kg m}^2\ \text{b}^{-1}\ \text{s}^{-2}]$.

We define also

$$L = \frac{dR}{d\dot{V}} = A\dot{V} \tag{9}$$

as *impulse of metabolic resistance*. Its dimension is $[L] = [\text{kg m}^2\ \text{b}^{-1}\ \text{s}^{-1}]$.

We assume that the functioning of the healthy living systems is based on the following biological principle:

$$G(W) = \max G(V) \tag{10}$$

It means that in its optimal, undisturbed state BO has a synergy maximum. $G(W)$ corresponds to excellent health. For recovery processes it follows from (10):

$$dG > 0 \tag{11}$$

Taking into account (1), (2), (3), (4), (5), (6), (7), (8), (9) and (11) we can write:

$$dG = \frac{(\Phi dV - Ld\dot{V})}{V} > 0 \tag{12}$$

where Φ is the total recovery force

$$\Phi = \Phi_U + \frac{1}{2}\Phi_Z \tag{13}$$

It follows from (12) that the expression

$$\Phi dV - Ld\dot{V} > 0 \tag{14}$$

is a condition for fully BO recovery.

One of the most profound concepts in theoretical physics is that the equations of motion in different fields of physics can be obtained on the basis of integral variational principles.

The well known variational principle of Hamilton allows a common treatment of dynamic problems in mechanics, electrodynamics, optics, thermodynamics, quantum mechanics etc. By means of appropriately chosen Lagrangeans the basic equations in physics can be introduced. This approach has a great heuristic concern. The presence of variation principles in all physics fields clearly shows that a basic nature law takes place. This promises that in fields, where no other approaches exist, a variational principle from the Hamilton type could help to obtain adequate equations, describing the characteristic processes.

We propose the following integral principle:

$$\Gamma = \int_{t_0}^{T} (U + Z - R)dt = \max \tag{15}$$

choosing the Lagrangean: $L = L\,(V\,(t), \dot{V}\,(t), t) = U + Z - R$,

where U, Z and R are determined by the equations (2), (3), (5) and (6).

After variation of (15)

$$\Gamma'(\varepsilon)\big|_{\varepsilon=0} = 0 \tag{16}$$

where ε is an arbitrary parameter, the following biodynamic equation is obtained:

$$\ddot{V} + \frac{2M}{A - 2M(T - t)}\dot{V} + \frac{K}{A - 2M(T - t)}V = \frac{KW}{A - 2M(T - t)} \tag{17}$$

under initial conditions:

$$V(t_0) = V_0 \qquad \text{and} \qquad \dot{V}(t_0) = \dot{V}_0 \tag{18}$$

V_0 is the state of disturbed BO from where the recovery process starts and $\dot{V}_0$ is the start rate of time change of V. T is the time period of the recovery process. The equation (17) has a physical sense and aperiodic solutions when the following conditions are valid:

$$A > 2MT \tag{19}$$

$$M^2 > (A - 2MT)\,K \tag{20}$$

Obviously, at a given value of M, in greater contamination of the organism (higher A value) the time T of the recovery process will be longer.

The stationary solution of equation (17) is a stable knot.

Equation (17) is solved numerically. Some solutions at different values of the parameters are displayed in Figure 1. The value of T = 10 days was arbitrary assumed for the recovery process after some disturbance (for instance: influenza, poisoning, burn etc.). We stated that the normal state of BO corresponds to W = 100 bions. We chose an arbitrary value for the start of recovery process: V_0 = 60 bions. In principle, on the basis of many empirical data one can determine the real average recovery time periods for different diseases and damages and real W for different species and ages. Using them the characteristic parameters in equation (17) can be calculated.

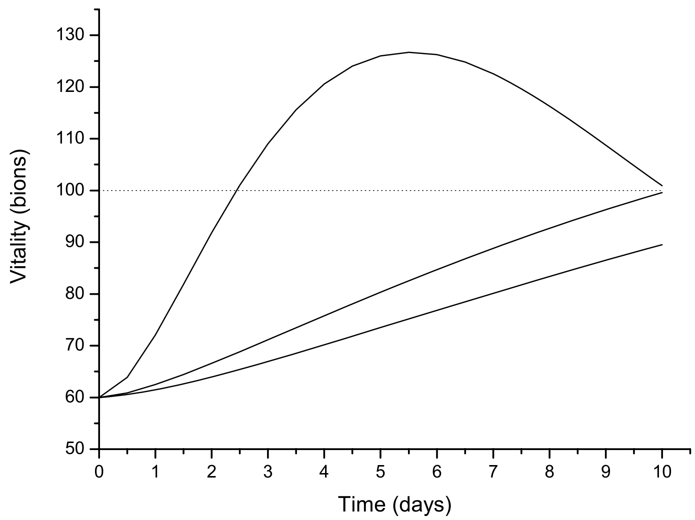

Figure 1. Time courses of the quantity *vitality* during the recovery period as numerical solutions of equation (17). The time interval of 10 days for the recovery period after some disturbance was arbitrary chosen (T = 10). A value of 100 bions for *optimal vitality* was assumed (W = 100). The initial condition was V_0 = 60 bions. The displayed time courses were calculated at different values of characteristic constants: A = 9, M = 0.4, K = 0.93 (over-shoot curve); A = 11, M = 0.5, K = 0.17; A = 12, M = 0.5, K = 0.13.

Time courses of several biological parameters, similar to these shown in Figure 1, are very typical for different transitory processes in biological systems.

Sinergy and Entropy Changes During the Lifespan of a Biological Object

In lifespan scale the following cases could be distinguished regarding the synergy G and entropy S changes:

During development and growth

$dG > 0$ $\quad$ $dS > 0$ $\quad$ $dG > dS$

Near completion of development and growth

$G = \max$ $\quad$ $dS > 0$

3) At mature age

$dG \leq 0$ $dS > 0$ $dG < dS$

4) At aging

$dG < 0$ $dS > 0$ $dG \leq dS$

5) Death

$G = 0$ $S = \max$

What means the inequality $dG < dS$ at mature age? G can remain almost constant during many years (maximum comfort conditions for BO) or decrease weakly ($dG \leq 0$). But this decrease is less compared to entropy increase (i. e. notwithstanding that the entropy increase leads to age changes in macromolecules and structures, the integrity of the regulatory links remains or changes slower than structure aging). The synergy is not reciprocal to entropy. The inequality $dG < dS$ shows the stability of BO selfregulation. For instance, the genetic functions demonstrate a relative resistance against to the chronic action of damaging agents, particularly heavy metals (Topashka-Ancheva et al. 2003). The difference in changes of entropy and synergy once more indicates that via thermodynamics (in spite of its adjustment to biological systems) one does not attain adequate description of the life processes.

EVOLUTION OF OPTIMAL VITALITY (*W*) DURING THE LIFESPAN OF A BIOLOGICAL OBJECT

Up to now we considered the optimal vitality W as a constant quantity because our attention was drawn only on processes much shorter compared to the lifespan. The optimal vitality W, however, decreases in lifespan scale due to aging processes (genetic mutations, alterations in the regulatory links of genetic apparatus and hence quantitative and qualitative changes of proteins and attenuation of their self-renewal (Frolkis 1969). The simplest quantitative assumption about W evolution during the life is that the rate of W change is proportional to the time:

$$\frac{dW}{dt} = -qt \tag{21}$$

where q ($[q] = [\mathrm{b\ s}^{-2}]$) is a parameter reducing the optimal vitality. We call it *aging factor*.

The parameter q should be a time function. The temp of the aging is most intensive after the age of 25 years (in human) and then it decreases with time (Strehler 1962). Quantitatively this could be expressed by the following differential equation:

$$\frac{dq}{dt} = -\alpha q \tag{22}$$

under initial condition

$$q_0 = q(t_0), \qquad t_0 = 25 \text{ years} \tag{23}$$

where q_0 ($[q_0]$ = [b s^{-2}]) and α ($[\alpha]$ = [s^{-1}]). The constant α can be called *aging correction*, because at higher values of α the parameter q decreases faster with time and hence, as follows from (21), the rate of aging decreases. Respectively, when q decreases slowly the aging processes go faster.

The analytical solution of (22) is

$$q = q_0 e^{-\alpha(t - t_0)} \tag{24}$$

Taking into account (24) the equation (21) can be written as

$$\frac{dW}{dt} = -q_0 e^{-\alpha(t - t_0)} t \tag{25}$$

The analytical solution of (25) is

$$W = W_0 - \frac{q_0}{\alpha^2}(\alpha t_0 + 1) + \frac{q_0}{\alpha} t e^{-\alpha(t-t_0)} + \frac{q_0}{\alpha^2} e^{-\alpha(t-t_0)} \tag{26}$$

The constant α may be determined from the solution (24) after taking a logarithm:

$$\ln q = \ln q_0 - \alpha\,(t - t_0) \tag{27}$$

The equation (27) is an equation of a straight line with angular coefficient α. Using the values of q, a plot of ln $(q - q_0)$ as a function of $t - t_0$ could be constructed and α determined.

The q-values could be calculated in the following way. Human individuals in perfect (accordingly to the respective age) health could be selected in different age groups ranging by five years (25–30, 30–35, 35–40 etc.). Within these groups q may be considered approximately constant. Then the analytical solution of equation (21) has the form:

$$W = W_0 - \frac{1}{2} q t^2 \tag{28}$$

and respectively:

$$q = \frac{2(W_0 - W)}{t^2} \tag{29}$$

W-values for the different age groups could be empirically measured (of course under a reliable statistics) and on the basis of (29) values of q, specific for the respective age periods, could be calculated. The value of q_0 may be determined in individuals of 24–26 years old. If the constants q_0 and α were known $W(t)$ would be drawn. Thus, we shall have a picture of a normal aging, i. e. aging in individuals, who are not burden with chronic diseases. The same procedure could be applied in people with certain chronic diseases, in smokers, etc. It is seen from (29) that at a greather difference $W_0 - W$ the parameter q has a higher walue. For instance, at age 60 years W of a sick man will be less than W of a healthy man ($W_{\text{sick}} < W_{\text{healthy}}$) and respectively $W_0 - W_{\text{sick}} > W_0 - W_{\text{healthy}}$. Therefore, $q_{\text{sick}} > q_{\text{healthy}}$. This indicates a faster aging process in the sick. In illness at young age the value of q_0 may be higher than the normal and this could reflect on the further life and aging pace.

In most cases the life mode can play a significant role for q modification. The healthful nutrition, going in for sports, natural regimen etc. could increase α-constant in large extent. Consequently the rate of q decrease increases and hence the duration of the individual life could increase.

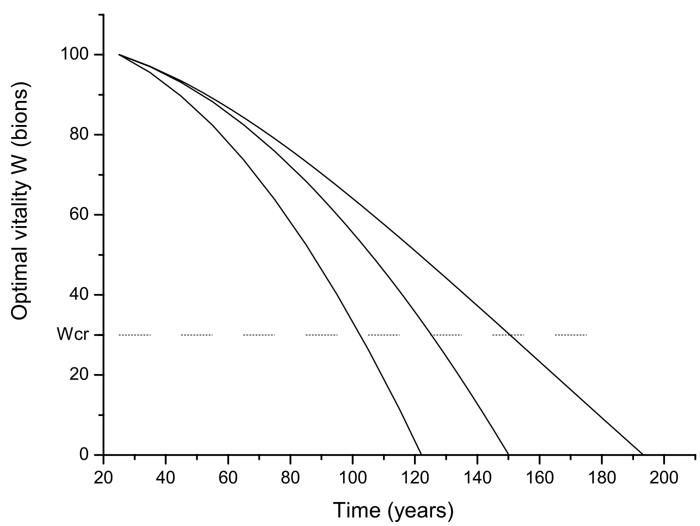

Figure 2. Evolution of the optimal vitality W during the lifespan. The maximum value of optimal vitality W is assumed of 100 bions. In human context it should correspond to the age of 25 years. A value of 30 bions is assumed as Wcr. Three analytical solutions (26) of $W(t)$ are drawn, calculated at different values of the parameters ($q_0 = 0.01$, $\alpha = 0.0061$; $q_0 = 0.01$, $\alpha = 0.0012$; $q_0 = 0.015$, $\alpha = 0.0012$). The respective curves cross the dotted line Wcr in points corresponding to 150, 125, and 102 years. These points could be considered as possible potential maximums of life duration at different conditions.

In Figure 2 analitical solutions of equation (26) are presented. They are calculated under initial conditions $W_0 = W(t_0) = 100$ bions and $t_0 = 25$ years and at different values of the parameters q_0 and α. The value Wcr corresponds to that value of vitality, under that the selfregulation falls and life recovery processes are impossible. The values of X-axis, corresponding to the points of the dotted line, indicate the lifespan of *Homo sapiens* in different conditions. The points $T_{W\text{cr}}$ correspond to the absolutely life potential in the respective conditions, not to the real end of the individual life. Usually the concrete lifespan is (much) shorter than $T_{W\text{cr}}$ (often due to different fortuitous factors). In principle $T_{W\text{cr}}$ may be considered as genetically determined possible lifespan maximum for a given species but it could vary in a wide range depending on diseases, life conditions, and life mode.

CONCLUSION

It is impossible to deduce macro-characteristics of living systems on the basis of the numerous processes on molecular level. Because of that it will be a great benefit to have a measurable (one or a few) macro-characteristic(s) uniquely determining the status of BO as an entire unit. Thus, the behaviour of BO would be explored and predicted. In exemplification of this idea here we considered the simplest case of only one integral variable – vitality V.

Such an approach is very important not only for practical purposes. It is also of great theoretical significance. Biological selfregulation provides a new quality of matter. It is quite reasonable to evaluate the state of living matter in terms of specific energy form. No kind of energy known in physics can be put in correspondence to biological selfregulation in order to explain its integrity. The health of BO essentially depends on selfregulation quality and it seems to be very tempting to assess BO via adequate quantities. Thus, the creating of new science field, *biodynamics*, could be a substantial step to a more profound study of living matter.

The general responses of BO to environmental, therapeutic, and other influences as well as to diseases could be effectively studied. Biodynamics approach will be of a great importance in medicine for diagnosis and therapy. A simple and prompt assess of the healthy status of the patients could be made and in patient's files abreast of the other data could be added data as vitality V , optimal vitality, and synergy G as important integral biomarkers. Valuable evaluations could be carrid out about the aging rate and life duration via studing of optimal vitality W evolution. Many empirical investigations could provide reliable data for determining the characteristic lifespan $T_{W\mathrm{cr}}$ for several species. Essential correlations could be established between environmental conditions specificity and mean human lifespan.

Satisfactory values of the parameters introduced here (K, M, A, q_0, and α) may be determined via experiments, but it is also of essential interest to attempt to express these constants as functions of some parameters of BO on molecular level. For this purpose many targeted empirical research are needed.

Naturally, new device is needed to measure such quantities. The author is optimist regarding the further technical development and the possibility to study the vital status of BO via integral characteristics. The author hopes that the idea shared here may stimulate the scientific thought for further efforts toward development of a phenomenological life theory.

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A NEW TRAIT OF GENTOO PENGUIN: POSSIBLE RELATION TO ANTARCTICA ENVIRONMENTAL STATE?

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ABSTRACT

Some morphological traits of Antarctic animals could be considered in the context of a trend to more direct relation between environmental conditions and possible adaptive mechanisms of animal's organism. Penguins are excellent object for biomonitoring. Here a preliminarily report is presented regarding a new trait, a spot-like coloration ("yellow spot") of the bill, observed on the upper mandible of Gentoo penguin (subspecies *Pygoscelis papua ellsworthii*). The spot varied in size and colour. It was recorded among chicks over two months old and adult birds (normal and molting). The trait had no significant relationship to the animal' s sex. Among all inspected females 31% and among all inspected males 27% exhibited beak spot. Three breeding colonies were investigated at three different geographical locations at the Antarctic Peninsula – Livingston Island, South Shetlands (62°38′ S), Wiencke Island (64°52′ S), and Petermann Island (65°10′ S). Yellow spot was found with different frequencies at these three locations: 20%, 36%, and 30%, respectively. All spotted penguins from the three colonies were 32% when compared to all non-spotted. The possible reasons for the spot-like coloration are discussed. The trait could be a phenotypic characteristic. It could play some role in the mate choice. A possible connection to carotenoid pigments content does not be eliminated in the context of Gentoo diet. A probable cause for the beak spot appearance seems to be the increasing of ozone depletion above Antarctica. The ultraviolet radiation enhances free radical production. Other studies reported an increase of the flux of transsulfuration pathway as a defense reaction, resulting in elevated level of cysteine. When cysteine concentration is raised, an attaching of cysteine to melanin synthesis pathway occurs and this results in formation of reddish pigments.

INTRODUCTION

Antarctica environment is closely related to the global change of our planet and hence it is a topic of increasing importance. Climatic features, atmospheric regime, and temperature and water balance depend on the state of Antarctic continent. The investigation whether Antarctica is influenced by anthropogenic pollution is of great interest. In this context the biomonitoring could provide valuable data. Results reported by Metcheva *et al.* (2006) suggest that due to annually molting penguin feathers are an excellent monitoring tool of Antarctica environmental state, being precise indicator for detection of metal levels. This allows assess possible contamination trends.

During the morphological investigations on Gentoo penguin (*Pygoscelis papua ellsworthii*) a spot-like coloration ("yellow spot") was observed at the base of the upper mandible of some individuals. It varied from clear yellow-orange to reddish. Colour patterns of terrestrial birds have been well studied, but there is little research on seabird coloration (Jones and Hunter 1993; Jouventin *et al.* 2005).

Among the six genera belonging to family Spheniscidae, the genus *Pygoscelis* is the most widely distributed (Del Hoyo *et al.* 1992). Three species belong to *Pygoscelis*: Chinstrap (*P. antarctica*), Gentoo (*P. papua*) and Adelie (*P. adeliae*). Gentoo penguins breed on subantarctic islands and on the Antarctic Peninsula (Stonehouse 1970). There are two subspecies of Gentoo – *P. p. papua*, J. R. Forster, 1781 and *P. p. ellsworthii*, Murphy, 1947. The subspecies *P. p. papua* is distributed in sub Antarctic up to 60° S; *P. p. ellsworthii* inhabits the Antarctic from 60° S up to 65° S (Del Hoyo *et al.* 1992). The subspecies *P. p. ellsworthii* is of smaller size and bill proportion compared to *P. p. papua* (Martinez 1992).

Gentoo penguin populations inhabiting the Antarctic Peninsula have been studied with respect to foraging behavior (Trivelpiece *et al.* 1986), morphometry (Stonehouse 1970), UV reflectance (Jouventin *et al.* 2005) etc. However, this trait ("yellow spot") observed has not been described in the literature before.

Some authors (Stevenson and Anderson 1994; Siefferson and Hill 2005) that study different particular colorations in birds tend to explain the function of these phenomena in terms of health, mate choice behavior or intraspecific signaling. Saks *et al.* (2003) have established that brighter yellow breast feathers in male greenfinches signals immunocompetence and health status. Thus, females prefer more ornamental males, able to provide parasite resistance genes for the offspring. Some of the colour patches are at the same time also ultraviolet markings. Jouventin *et al.* (2005) have reported UV beak spots in King penguin (*Aptenodytes patagonicus*) and Emperor penguin (*Aptenodytes forsteri*). They have found UV peaks of reflectance, overlapping with spots of colour on both sides of the lower mandible, which have appeared orange (with variations among individuals from yellow to red). The authors suggested that UV beak spot could be an indicator of sexual maturity having a possible role in pairing. UV reflective patches are of concern in the context of UV vision in birds, which may be used also for foraging (Sűtari *et al.* 2002) and hunting (Koivula *et al.* 1997; Koivula *et al.* 1999).

Other interesting problems are whether such kind of markings (colour only or colour and UV reflectivity) might appear as consequence of environmental changes or it depends on the diet, biochemical disturbances and parasite infection. Most probably a complex reason might take place. Similar traits could also be used for comparative population studies.

In the present study the distribution of spotted *P. p. ellsworthii* in three Antarctic locations – Livingston Island, South Shetlands (62°38′ S), Wiencke Island (64°52′ S), and Petermann Island (65°10′ S) is reported and probable reasons for the beak spot appearance are discussed. Particularly, a possible reason related to the specific Antarctic environment is outlined.

MATERIALS AND METHODS

Populations Studied

Field measurements were carried out on adult, nonmoulting and molting Gentoo penguins (*P. p. ellsworthii*), inhabiting Livingston Island (62º38´ S, 60º24´ W, South Shetland Islands), Wiencke Island (64°52′ S, 63º30´ W, Palmer Archipelago), and Petermann Island (65°10′ S, 64º10´ W). The birds were tested during the Antarctic summer seasons, from January to March, – at Livingston Island in years 2002 – 2005; at Petermann Island in 2002-2003, and at Wiencke Island in 2003-2004. At Livingston Island the studied colony varied from 84 to 110 couples. At Petermann and Wiencke Islands the colonies were larger, about 1000 nests per island. Additionally, at Livingston Island twelve marked couples of *P. p. ellsworthii* as well as the offspring in the crèche were observed in December 2005 - January 2006.

The penguins were captured using a hand net. After inspection the morphological traits were measured according to the Commission for the Conservation of Antarctic Marine Living Resources – Ecological Monitoring Programme (CCAMLR EMP) recommendations (CCAMLR 2004).

All the penguins were marked with glass-encapsulated TROVAN identification electronic transponders. These transponders, implanted subcutaneously, have demonstrated to be a reliable means to identify individual penguins. The TROVAN system enables long lasting marking, automatic detection of birds and quick identification (Clarke an Kerry 1998). The penguins were checked for the appearance of spot on the beak when they were marked.

Blood Samples for DNA Analysis

Blood sampling for sex identification and DNA analyses were performed by two different ways according to the CCAMLR EMP Standard Methods Recommendations. Approximately 1 ml of blood was drawn from the cubital vein with a syringe and placed into tubes with K_3·EDTA or into heparinzed tubes. DNA was extracted using a standard phenol-chloroform method as described by Sambrook *et al.* (1989). Sex determination was performed by PCR as described by Itoh *et al.* (2001).

Discriminant Analysis

Sex determination of Gentoo from the Petermann Island was carried out with discriminant analysis, as described EMP Standard methods, Hobart (CCAMLR 2004) with little modification. The equation was $Z = 0.922*L + 3.885*H$ were L and H are the length and high of the bill, respectively. The discriminate value was $D = 103.302$ instead of the described 112.608, because the localization of the minimum at the male-female distribution of D was at the 103.302 point. Data were verified with the values of body mass differences (only for registered nesting couples) – males were usually heavier than females. The results were confirmed with PCR assay according Savov et al. (2004).

Statistical Treatment

The percentages of spotted individuals from Livingston Island, Wiencke Island, and Petermann Island were compared and statistically analyzed for their significance.

Differences in the trait distribution between males and females were tested using the χ^2-criterion for table 2 x 2. Trait distribution in the penguins at different locations was tested with exact Fisher's test (for two-tailed probability of the II type error) (Sokal and Rohlf 1995; Dubrova 2000).

RESULTS

Gentoo penguins from Antarctic Peninsula (Figure 1) were tested for presence/absence of beak spot (Figures 2 and 3) as follows: 157 individuals at Livingston Island (or about 81% of the breeding colony), 114 – at Wiencke Island (11% of the colony), and 201 – at Petermann Island (20% of the colony). The spot is located on the upper mandible of the bird (Figure 2). It begins at the flashy core and extends onto the hardened part of the beak. In different individuals the spot size ranges from very small (1 – 2 mm) to quite large (20 – 25 mm). The largest spots spread over almost all the upper surface of the bill. We named the observed new trait "yellow spot" because of its typical colour. However, the colour of the spot varied from yellowish to red with yellow, orange, and pink intermediate forms in different birds. The scheme in Figure 4 gives a picture regarding size and colour variations of the spot.

Other visible peculiarities in body or feather coloration of beak-spotted Gentoo penguins were not recorded.

The trait was observed year-round, not only during molt. Over the time of exploration the spots did not change their appearance.

The "yellow spot" was observed also in adults and chicks inspected. Among adult birds the frequency of this trait was approximately two times higher than among chicks.

To prove preliminarily a possible heritable basis and to estimate the age-related process of spot appearance, commencing with the hatching, we observed additionally 3 pairs with spots (both of parents), 2 pairs without spots and 7 mixed pairs (with spot in only one of the parents) at Livingston Island in December 2005 – January 2006. From the beginning of hatching to about 3 weeks of age no beak spot was found in the offspring (Figure 5).

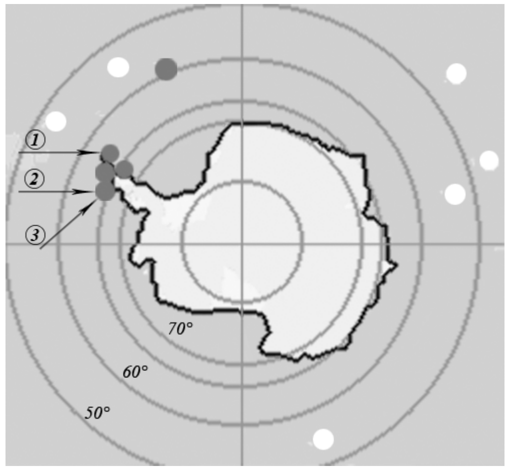

Figure 1. Gentoo penguin distribution map: the white dots indicate the breeding areas of the subspecies *Pygoscelis papua papua* and the black dots – the breeding areas of the subspecies *Pygoscelis papua ellsworthii*. 1 – Livingston island; 2 – Wienke island; 3 – Petermann island.

Figure 2. Adult Gentoo penguin (*Pygoscelis papua ellsworthii*) with spot on the upper mandible.

Figure 3. Adult Gentoo penguin (*Pygoscelis papua ellsworthii*) without spot on the upper mandible.

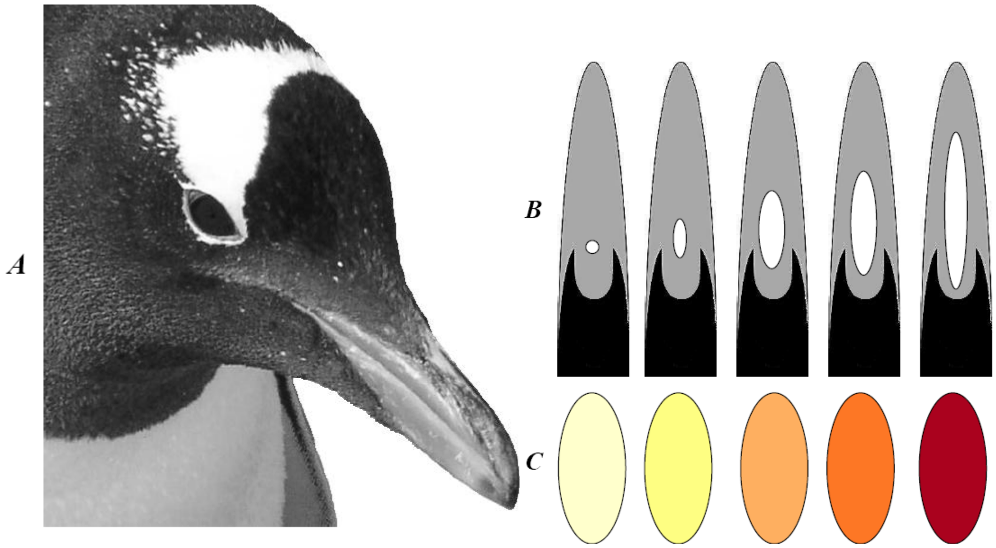

Figure 4. A scheme of the “Yellow spot”, observed on the upper mandible of Gentoo penguins (*Pygoscelis papua ellsworthii*): place of the spot on the mandible and spot size variations.

Figure 5. One-month Gentoo penguin (*Pygoscelis papua ellsworthii*) without spot on the upper mandible.

Similar data were obtained at the other locations (Petermann and Wiencke Islands), where recently hatched chicks with beak spot were not found. Spots were observed, however, in two-month chicks (Livingston colony), when they have formed crèche (Figure 6). Among 75 juveniles, 3 two-month chicks (4%) exhibited a small spot in the base of the upper mandible.

Figure 6. Two-month Gentoo penguin (*Pygoscelis papua ellsworthii*) with an about 2 mm "Yellow spot" on the base of the upper mandible.

The spot distribution among males and females is presented in Table 1. The DNA analysis was carried out on 93 individuals in the Livingston colony and on 185 individuals in Petermann colony. The analyses revealed that at Livingston Island 37 of the samples were females and the rest 56 were males. Respectively, at Petermann Island 94 penguins were females and 91 – males. Among all inspected females 31% exhibited beak spot and among all inspected males colour spot on the beak was observed in 27% of individuals. There was no statistically significant difference in the frequency of spot appearance in both sexes (Table 1).

Table 1. Distribution of the "yellow spot" between male and female individuals of Pygoscelis papua ellsworthi

Location	Sex	*n* (all inspected)	With beak spot		Without beak spot		χ^2	*P*
			n	Frequency in %	*n*	Frequency in %		
Livingston Island	Male	56	15	27	41	73		
	Female	37	9	24	28	76	0,069	0.98
	Total	93	24	26	69	74		
Petermann Island	Male	91	25	27	66	73		
	Female	94	31	33	63	67	0,66	0.78
	Total	185	56	30	129	70		
	Male	147	40	27	107	73		
All groups	Female	131	40	31	91	69	0,37	0.93
	Total	278	80	29	198	71		

The distribution of the trait in the three Gentoo colonies (at Livingston, Wiencke, and Petermann islands) for the penguins investigated during 2002 – 2005 (without those observed in the summer season 2005/2006) is presented in Table 2.

Table 2. Distribution of the "yellow spot" in the three colonies of Pygoscelis papua ellsworthi, inhabiting different Antarctic geographical areas. Frequencies (%) of spotted individuals and Fisher's test data are given

Population	Location	Total	n		% Spotted	Statistical significance (exact Fisher's test)	
			With beak spot	Without beak spot		Comparison between populations	Two-Tailed probability
Livingston Island	62º38′ S 60º24′ W	157	31	126	19.7	Livingston - Peterman	0.0014
Wiencke Island	64º52′ S 63º30′ W	114	58	56	50.9	Peterman - Wiencke	0.0004
Petermann Island	65°10′ S 64º10′ W	201	61	140	30.3	Livingston - Wiencke	0.00012
All		472	150	322	31.8		

All inspected birds were divided into two categories – "with spot" and "without spot". The average frequency of all spotted individuals is 31.7%. The differences in the percentage of spotted individuals among all the three colonies are statistically significant. The highest frequency of the trait was found in the colony of Wiencke Island followed by the colonies of Petermann and Livingston (Table 2).

DISCUSSION

On the basis of the result that the distribution of the revealed beak spot in males and females *P. p. ellsworthii* does not differ significantly (Table 1) one could safely state that the "yellow spot" is not related to the sex of Gentoo penguin.

The "yellow spot" is a characterization both of non-molting and molting penguins.

This trait may be a polymorphic characteristic. In such case it will be of interest to study its genetic architecture. The problem of Gentoo population analysis is important today because Gentoo is one of the indicator species of Antarctic ecosystem (Zhu *et al.* 2005) and a comparison of populations by trait frequencies could be useful for population studies and monitoring programs of Gentoo penguin.

At the present stage of the study we have not yet collected data supporting an assumption regarding a heritable basis of the trait. The fact that no spot was recorded in Gentoo chicks bellow two months of age suggests a possible correlation between the spot appearance and age, i. e. the spot appears in growing up offspring to play some role related to mature birds. Such an assumption is reasonable taking into account that in the crèche only 4% of the two-month chicks exhibited a small spot and that in adult birds the frequency of the spot was about five times higher than in juveniles.

Much attention has been paid to the significance of colour and UV phenomena in avian intrasexual competition or intrasexual selection. Jouventin *et al.* (2005) have established that recently paired King Penguins (*Aptenodytes patagonicus*) had shown higher UV reflectance than courting ones. So, these authors consider the UV ornaments as a factor, which plays a role in pairing of breeding males and females and could serve as an indicator of sexual maturity. Also Mougeot and Arroyo (2006) have noted that UV signals play key roles in social and sexual signaling in birds. European starlings (*Sturnus vulgaris*) (Benett *et al.* 1997), Blue tits (*Parus caeruleus*) (Anderson *et al.* 1998; Hunt *et al.* 1998), and Bluethroats (*Luscinia s. svecica*) (Anderson and Amundsen 1997) use UV-reflecting plumage cues in mate choice. On the other hand, there are studies indicating that UV vision in birds plays an essential role in their foraging and hunting behaviour. So black grouses prefer UV-reflecting berries (Sűtari and al. 2002), kestrels are attracted to the vole urine and faces marks that reflect UV light (Viitala et al 1995; Koivula *et al.* 1999; Zampiga *et al.* 2006). The hunting success of nocturnal owls is best during clear nights due to the visibility of the scent markings in UV light (Koivula *et al.* 1997).

Endoparasitism is viewing as a cause for the coloration variety (McGraw and Hill, 2000). It was found (Saks *et al.* 2003) that coccidian infection reduces the expression of plumage coloration in greenfinches (*Carduelis chloris*) by creating a deficiency of carotenoids available for deposition in ornamental feathers. Golemanski (2002) first described intestinal coccidiosis in *P. papua* (Livingston Island).

One could suppose some relationship between spot and carotenoid pigments. Red, orange and yellow coloration is usually related to these pigments. Saks *et al.* (2003) have established that the plumage coloration in male greenfinches, signalizing their immunocompetence and health status, is carotenoid-based. The combination of carotenoid pigments with proteins generates many colors, from the brilliant yellow to red, in crustaceans, fish, and birds. The general distribution and metabolic pathways of carotenoids have been investigated in details (Katayama *et al.* 1971; Goodwin 1984; Davis 1985; Matsuno and Hirao 1989). We have not analyzed biochemically Gentoo beak but it seems reasonable to suppose at least partial carotenoid contribution in beak coloration because of Gentoo diet. It consists of about 50 – 80% crustaceans, mainly krill, which are a rich source of carotenoids (Berrow at all. 1999). However, there are reports regarding the potential for melanins to produce yellow colors in birds' plumage (McGraw *et al.* 2004). These authors have not detected carotenoid pigments in feathers of five avian species, including King Penguins (*Aptenodytes patagonicus*) and Macaroni Penguins (*Eudyptes chrysolophus*). More over McGraw *et al.* (2004) suggested that the yellow appearance of penguin and domestic chick feathers might be attributed to a new form of plumage pigment, never before described from bird feathers.

A probable reason for appearance of the beak spot may be related to some aspects of the changes in Antarctic environment and especially to the increased ozone depletion above Antarctica. As known ozone layer protects the earth surface from the ultraviolet radiation. Evidence is provided that UV radiation generates H_2O_2 (Peus *et al.* 1998). In presence of H_2O_2 and under UV rays reactive oxygen species (ROS) are formed. What kind of way might lead from ozone depletion and ROS to "yellow spot"?

The pigment melanin causes the black colour. It is an essential component in the bill structure. Incorporation of melanin granules into the bill keratin increases the hardness of the bill (Bonser and Witter 1993). Attaching of cysteine to DOPA-quinone after oxidative cyclization and polymerization results in the formation of reddish pigments (Angelov *et al.*

1995). DOPA-quinone is the third step of the melanin synthesis pathway beginning from tyrosine. Such a reaction is possible to occur in case of an increase of the concentration of cysteine, taking part in desintoxication and antioxidant processes.

The low-molecular-weight thiols cysteine and especially glutathione are important antioxidants acting in cells. In the biochemical anabolic pathway the cysteine is a precursor of glutathione. Reduced glutathione (L-gamma-glutamyl-L-cysteinyl-glycine, GSH) is formed in a two-step enzymatic process including, first, the formation of gamma-glutamylcysteine from glutamate and cysteine, and second, the formation of GSH from gamma-glutamylcysteine and glycine (Nikolov 1971; Franco *et al.* 2007). The production of GSH mainly depends on the amount of available cysteine (van der Crabben *et al.* 2008).

The cysteine synthesis is involved in the transsulfuration pathway. The first step of this pathway, from homocysteine to cystathionine, is catalyzed by cystathionine beta-synthase (CBS). The enzyme transsulfurase (cystathionase) converts cystathionine to cysteine. Persa *et al.* (2004), exploring some biochemical reactions in eye, showed that a transsulfuration pathway is present in the lens and that oxidative stress of H_2O_2 could increase the flux of this pathway activating the CBS enzyme. Thus, a lens under oxidative stress accumulates free and protein-bound cysteine. They reported also that oxidative stress transiently up-regulates the gene expression of CBS both in human lens epithelial cells and in pig lens.

It seems reasonable to suppose that transsulfuration pathway exists in the penguin's bill and likely the accumulation of ROS in the cells as a result of the enhanced UV radiation co-operate to an increase of CBS synthesis and CBS activity. The increase of cysteine production and hence the GSH level may be considered as adequate adaptive reaction to the change of environmental conditions. On the other hand, the elevated cysteine level plays a role for involving of cysteine in melanin synthesis pathway via attaching to DOPA-quinine. The formation of reddish pigments could reflect in beak spot coloration.

The frequency of the spot appearance in the three investigated geographical points did not unambiguously show a cline in the trait distribution (Table 2). Still the lowest frequency (19.7%) was found in the colony of the most north point (Livingston Island). The highest percentage of spotted penguins was found at Wiencke Island, situated between Livingston and Petermann Islands. Wiencke Island is by $2^{o}14'$ southly from Livingston Island. The ozone depletion increases in south direction, to the pole.

Longer studies and targeted investigations are required to determine precisely the most probable cause (or cause complex) for the appearance of this trait and to clarify its possible function.

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ASSESSING POPULATION VIABILITY OF FOCAL SPECIES TARGETS IN THE WESTERN FOREST COMPLEX, THAILAND

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ABSTRACT

The Western Forest Complex (WEFCOM) in Thailand covers approximately 19,000 km^2. This protected area complex comprises 11 national parks and 6 wildlife sanctuaries. During 1999-2004, the Danish Government provided financial support to the Royal Forest Department to manage this forest complex through the ecosystem management approach. The WEFCOM Project employed rapid ecological assessment (REA) to determine the current distribution statuses of wildlife species, develop a Geographic Information System (GIS), and define habitat uses of wildlife. This paper is based upon the achievements of the WEFCOM Project. It aims to define suitable habitats of selected key wildlife species in the WEFCOM and to assess the current and desired statuses under a population viability estimate for those species. The focal wildlife species were sambar *(Cervus unicolor)*, gaur *(Bos gaurus*), banteng *(Bos javanicus),* Asian elephant *(Elephas maximus)*, and tiger *(Panthera tigris.* We used logistic multiple regression to determine habitat uses of wildlife and employed minimum dynamic area and landscape matrix surrounding suitable habitats as criteria to assess population viability. The results indicate the current suitable habitat mainly remains in Huai Kha Khaeng and Thung Yai wildlife sanctuaries. In addition, the current viability condition is good for sambar, fair for gaur, elephant and tiger; and poor for banteng. However, landscape matrices outside the suitable habitats for all species range from moderate to high connection of native vegetation. If the project aims to upgrade the viabilities to the next level in the next 10 years, park rangers and multi-stakeholders have to increase the amount of suitable habitats for all species from 12,630 km^2 or 67% of the WEFCOM to 16,750 km^2 or 89%. By doing this, the number of suitable patches would significantly decrease and the mean patch size would increase substantially, thereby indicating less fragmentation.

Keywords: Western Forest Complex (WEFCOM); population viability; habitat suitability; landscape indices; GIS.

1. INTRODUCTION

The World Conservation Union (IUCN) defines a protected area as "an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means" (IUCN, 1984). In Thailand, there were 282 protected areas, covering about 18% of the country's land area in 2004 (Trisurat, 2006).

Management of protected areas previously was limited to the boundary legally declared in the National Gazette. Cooperation with park officials beyond the park boundary for effective protection and management was relatively low and multi-stakeholders besides the responsible agency have been rarely involved in management although the New Constitution of Thailand of 1997 clearly defined their roles and responsibility in natural resources management (DARUDEC, 1999)**.** In the past four decades, protected areas have been selected on a site-by-site basis in an *ad-hoc* way, and often based on the opportunity to preserve remaining forest, as well as to promote tourism. These management practices are unlikely to ensure the long-term protection of biodiversity and the ecological processes upon which biodiversity depends as defined in protected areas' management objectives (IUCN, 1984). Therefore, the Royal Forest Department (RFD) and Danish Cooperation for Environment and Development (DANCED) implemented the Western Forest Complex (WEFCOM) Project during 1999-2004. The overall objective for this initiative was to maintain the health of the ecological systems by using the "Ecosystem Management Approach" with community participation.

The ecosystem approach is a strategy for management of land, water and living resources that promotes conservation and sustainable use in an equitable way, which was adopted at the Second Conference of the Parties of the Convention on Biological Diversity (Smith and Maltby, 2003). This approach has recognized the need to incorporate ecological processes, disturbances and biological population viability into the planning processes. By conserving viable samples of the whole ecosystem, it is anticipated that all of the species contained within them will, at least, have a fighting chance to survive in the long-term.

Viable population is defined as the minimum number in populations (MVP) of species that can persist for long periods of time (Wielgus, 2002). There are many methods for assessing population viability, ranging from the quantitative and data-gathering approaches to more expert-driven and qualitative methods (Beissinger and McCullough, 2002). In practice, there are relatively few species for which population viability analysis has been performed because this technique is available only for a data-rich species. Thus, many scientists use the 50/500 rule of thumb as an effective population size over the short-term (Soule, 1987). For instance, the British Columbia Ministry of Environment established a benchmark population of grizzly bears ranging from 100-250 animals and determined the reserve sizes that can accommodate these populations (Wielgus, 2002). More recent analyses suggest that an effective population size of about 1,000 is needed to allow continued evolution and prevent

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the accumulation of harmful mutation (Allendorf and Ryman, 2002). Based on MVP-related research over the past 30 years, Traill *et al*. (2007) found that the median MVP for mammals was 3,876 individuals. For practical implementation, there are increasingly fewer populations, especially of large mammals, that would meet the effective population size of 1,000 or more. Thus, a promising approach to maintaining MVP is to increase connectivity among fragmented habitats. The common qualitative technique or expert opinion to assess population viability is based on the criteria of species occurrence, habitat condition and landscape context surrounding the occurrence (Groves, 2003). Recently, the methods for assessing the viability of species that combine static habitat models to accommodate the minimum viable population with population viability analyses has become a promising approach in regional conservation plans, especially when digital data are available (Brito and Figueredo, 2003; Leroux *et al.*, 2007). This approach is named minimum dynamic area (MDA), which describes the smallest area with natural disturbance regime, which maintains internal recolonization sources, and hence minimizes extinction risk (Pickett and Thompson, 1978).

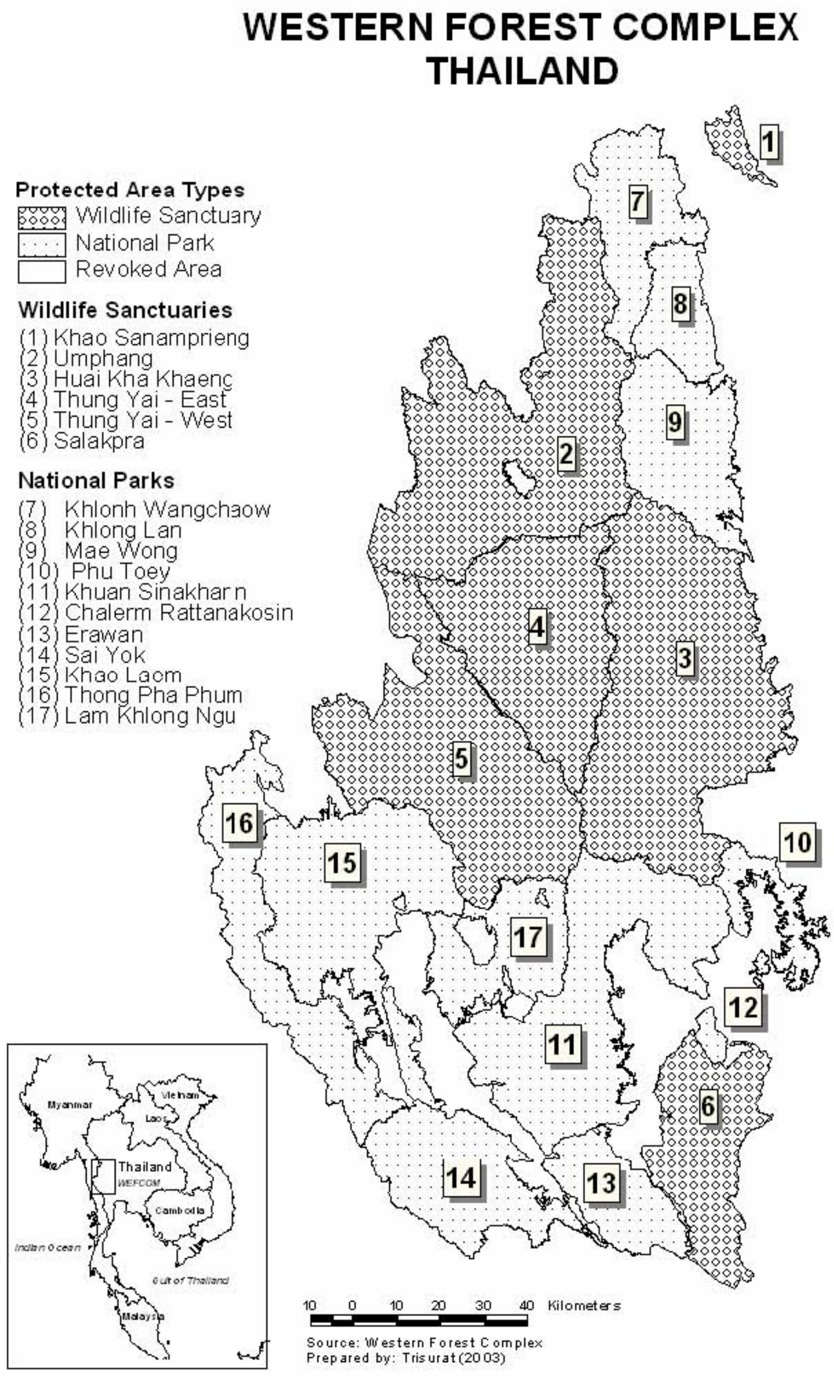
This paper is based on the achievements of the WEFCOM project. It aims to define suitable habitats of selected key wildlife species in the WEFCOM and to assess the current and desired status of population viability for these species.

2. Study Area

The Western Forest Complex (WEFCOM) is situated along the Thailand-Myanmar border. It comprises 17 contiguous protected areas, including six wildlife sanctuaries, nine national parks and two proposed national parks (Figure 1). The toal land area of WEFCOM is approximately 19,000 km^2 or approximately 4% of the country's land area. Among these 17 areas, Huai Kha Khaeng Wildlife Sanctuary is the largest protected area, covering 2,780 km^2. Salakpra Wildlife Sanctuary is the oldest protected area in this complex having been declared as the first wildlife sanctuary in 1965. There are 162 ranger stations scattered in the WEFCOM landscape mainly situated in the eastern buffer zone of the complex.

The WEFCOM is the largest intact forest area in Thailand and also within mainland Southeast Asia. It is situated in six provinces in western Thailand. between latitudes 14° 08′ - 16° 37′ North and longitudes 98° 11′ - 99° 32′ East. The WEFCOM is part of the Tenassarim Range extending southward along the Myanmar border. The landscape in the north and the west is rugged highlands. The area slopes gently towards the south and is drained by the Huai Kha Khaeng, which is the main perennial stream in this complex (WEFCOM, 2004).

Based on Landsat image interpretations and field assessments in 2000, approximately 90% of the total land area is under forest cover. Mixed deciduous forest is dominant in the complex covering the highest percentage of the WEFCOM area (6,172 km^2 or 32%). Approximately 36% of the WEFCOM is comprised of various evergreen forests. Roughly one third can be considered as relatively intact and undisturbed forest. Large tracts of intact and healthy forest still occur in Thung Yai Naresuan and Huai Kha Khaeng Wildlife Sanctuaries but the forest becomes more scattered and fragmented in other areas (WEFCOM, 2003, 2004). Remaining forest cover along the boundary and surrounding enclave communities is threatened by agricultural encroachment. A socio-economic survey revealed that there were 112 communities situated inside the WEFCOM harboring approximately 5,400 households and 27,700 individuals. Besides this, there were another 103 villages located within a 3-km distance of the WEFCOM, mainly found along the eastern border (WEFCOM, 2002).



Map 1. Protected area system of the Western Forest Complex in Thailand.

The WEFCOM has been nationally and internationally recognized as the key area of terrestrial biodiversity in mainland Southeast Asia. It is located at the crossroads of three plant geographies: Indo-Burma, Indo-China and Indo-Malaya; and two zoo-geographies: India Indo-China and Sundaic Sub-region (Nakhasathien and Stewart, 1990; Smitinand, 1987). Based on Wikramanayake *et al.* (2000), the WEFCOM encompasses two important ecoregions, namely the Kayah-Karen montane rain forests ecoregion and Tenasserim-South Thailand semi-evergreen rain forests**.** This bio-geographical overlap provides a unique assemblage of Asian species. Therefore, UNESCO designated Huai Kha Khaeng and Thung Yai Naresuan Wildlife Sanctuaries, two of the largest protected area units in the core area of the WEFCOM, as a Natural World Heritage Site in 1991. Some endangered species are tiger *(Panthera tigris),* Asian elephant *(Elephas maximus)*, gaur *(Bos gaurus*), banteng *(Bos javanicus)*, tapir *(Tapirus indicus)*, great hornbill *(Buceros bicornis)*, rufous-necked hornbill *(Aceros nipalensis)*, green peafowl *(Pavo mulicus),* and giant frog *(Rana blythii).*

3. METHODS

The general processes consisted of four steps, namely: 1) identify species conservation targets; 2) estimate habitat suitability for selected species; 3) assess the current and desirable condition of targets' viability; and 4) delineate the congregation locations of target species in the WEFCOM landscape. Activities for each step are summarized as follows:

3.1. Identify Species Conservation Targets

Conservation targets are those features or elements of biodiversity (ecosystem, species and genetics) that planners seek to conserve within a system of conservation areas (Groves, 2003). In this study, they are those species that make the WEFCOM a globally important conservation site. Wildlife specialists and the planning team comprising protected area staff, scientists and NGO representatives, set four criteria to select the species targets, namely, wide-range distribution, endangered status or ecosystem indicator, specialist availability and public interest.

3.2. Develop Habitat Suitability Maps for Selected Species

The WEFCOM Project employed ecological rapid assessment (REA) (Sayre *et al*., 2000) to gather wildlife occurrences in the study area. Wildlife signs and visual sightings were recorded by park rangers who had been trained in map reading, Global Positioning System (GPS) and identification of wildlife tracks and signs prior to actual survey. In addition, we applied the logistic multiple regression model to generate the suitable habitats for selected species (Trisurat 2003). The present and pseudo-absent data (chosen outside 1 km buffer from present locations) were treated as dependent variables in the habitat suitability model.

The independent variables included biophysical and human disturbance factors. The biophysical factors were vegetation type, distance to river and stream, slope, elevation and aspect, while the human factors consisted of distance to ranger station and distance to villages. The raster-based modeling in GIS ArcView 3.2 (ESRI, 1992) of 100 m resolution was used to perform all spatial analysis functions. Seventy-five percent of wildlife observations were used to develop the model and the remaining 25% were used to test the model accuracy. According to Petdee (2000) and Prommakul (2003), sambar, banteng and gaur are primary prey for tiger, therefore the suitability maps of these ungulate species were aggregated to derive a prey coverage as an additional layer for tiger habitat.

The logistic multiple regression model is written as:

$$\text{Prob}_{event} = \frac{e^{Zi}}{1+e^{Zi}}$$

where Z_i is the linear combination model of species i

The output maps produced from the predicted models were continuous probability values ranking from 0.0 – 1.0. Later these probability values were categorized into 4 classes to determine habitat suitability as follows:

Prob. Value 0.0 – 0.2	=	Unlikely
Prob. Value 0.2 – 0.4	=	Less Likely
Prob. Value 0.4 – 0.6	=	Likely
Prob. Value 0.6 – 1.0	=	Most Likely

3.3. Assess the Status of Species Targets' Viability

We used the Five-S Framework developed by the Nature Conservancy (2000) to evaluate the long-term viability of a focal conservation target's occurrence in the WEFCOM landscape. In fact, this framework provides three criteria for assessing the persistence of focal species: size, condition and landscape context. For the size criterion, we used the extent of suitable habitats (likely and most likely) to support MVP or minimum dynamic area (MDA) as a proxy indicator. In addition, we used habitat fragmentation (the percentage of native vegetation surrounding the suitable habitats (2-km buffer) as a landscape context criterion. Condition attributes of wildlife population (e.g. species composition, structure and biotic interactions) were not taken into account due to limited population data.

The MVP size of each species was estimated according to the 50/500 rule, carrying capacity and the recommendation of Thai wildlife experts. The MDA is simply derived by multiplying the MVP and the home range of species. For instance, the home ranges of tiger in the Thung Yai are between 50 and 200 km^2 and its average coverage is 80 km^2 (Prommakul, 2000) and the optimum MVP of tiger in the WEFCOM is 100 individuals. Therefore, the estimated MDA is 8,000 km^2. Meanwhile, a simple grading scale (very good, good, fair or poor) was used to assess the current and desired conditions in the next 10 years. Table 1 elaborates the context of each viability class.

Table 1. Criteria for assessing viability of species conservation targets in the WEFCOM

Ranking [1/]	Ecological indicators Size [2/]	Landscape context [2/]
Very good: functioning at an ecologically desirable status, and requires little human intervention	The extent of likely or most likely suitable habitats can accommodate >80% of viable population size.	Highly connected, the suitable habitats (patch > 2 km^2) are surrounded by intact natural vegetation (>60% of intact forest within 2 km).
Good: functioning within its range of acceptable variation; it may require some human intervention	The extent of likely or most likely suitable habitats can accommodate 60-80% of viable population size.	Moderately connected, the suitable habitats (patch > 2 km^2) are surrounded by moderately intact natural vegetation (> 40-60% of intact forest within 2 km).
Fair: lies outside its range of acceptable variation and requires human intervention	The extent of likely or most likely suitable habitats can accommodate 40-60% of viable population size.	Moderately fragmented, the suitable habitats (patch > 2 km^2) are surrounded by altered vegetation (> 20-40% of intact forest within 2 km).
Poor: restoration or preventing extirpation practically impossible	The extent of likely or most likely suitable habitats can accommodate <40% of viable population size.	Highly fragmented, the suitable habitats (patch > 2 km^2) are entirely or almost entirely surrounded by altered vegetation and human-induced land use (< 20% of intact forest within 2 km).

Remarks: 1/ described by TNC (2000); 2/ defined by the planning team and wildlife experts

3.4. Delineate the Congregation Areas of Target Species

The current congregation areas were simply derived from combining the likely and most likely suitable habitats of all target species. The output grid map shows the current location of suitable habitats of focal conservation target species. On the other hand, the extend of suitable habitats for each species to desired level of population viability was obtained from expanding the existing suitable habitat to meet the expected size based on the probability values as defined in the previous step. Later, all desired suitability maps were aggregated as done for the current status.

4. Results and Discussion

4.1. Selected Target Wildlife Species

Five wildlife species were selected by wildlife scientists and a planning team as the conservation targets. These species were tiger, Asian elephant, gaur, banteng, and sambar based on the selection criteria and appropriate observations to run a logistic model (Pattanavibool *et al*., 2003; Vanichbancha, 2001). The observations for elephant, sambar, gaur, tiger, and banteng were 960, 700, 641, 224, and 131 points, respectively.

Tiger, elephant and banteng are classified as endangered species by IUCN (2000). According to Lekakul and McNeely (1977), tigers are found in a very wide range of habitat types; they only require sufficient prey species, water and shelter from the sun and occupy a large home range (50-200 km^2), the average size of which in Thung Yai is approximately 80 km^2 (Prommakul, 2003). They also require good protection from tiger and prey poaching pressures (Karanth *et al*., 2004). In addition, Simcharoen *et al*. (2007) used photographic capture-recapture sampling to estimate tiger density in the core area of Huai Kha Khaeng. The sample area yielded a density estimate of 3.98 tigers per 100 km^2. Elephant is a top herbivore and found in a variety of forested areas. The home range sizes of elephant herds are between 105 and 320 km^2 (Sukumar, 1989). Similarly, banteng lives in loose herds of 2-20 individuals. Prayurasiddhi (1997) reported that the annual home range size was 44 km^2 for banteng herds in Huai Kha Khaeng. Gaur is classified as a vulnerable species by IUCN (2000). Gaur live in herds of 3-40 individuals and the home ranges of gaur herds are between 29.9 and 52.1 km^2 (Conry, 1989). Sambar still exist in many protected areas in Thailand and make a significant contribution to the long-term integrity and conservation values of the WEFCOM. It is a preferred prey species of several carnivores, including tiger.

4.2. Suitable Habitat Models

The results of logistic multiple regressions indicated that three physical factors and two anthropogenic factors were significantly related to the distributions of elephant, sambar, gaur, tiger, and banteng. The environmental factors were elevation, slope, distance to stream, distance to village, and distance to ranger station. The logistic regression models and overall accuracy at cut-off of 0.5 are shown below.

Z_{sambar} = 1.5191 – 0.0009Alt -0.0002Rst - 0.0136Slp – 0.0003Str+0.0003Vil; overall accuracy 68.06%

$Z_{banteng}$ = -1.3795 - 0.0018Alt -0.0008Rst - 0.0939Slp – 0.0005Str + 0.0020Vil; overall accuracy 91.97%

Z_{gaur} = -3.3434 - 0.0042Alt -0.0001Rst - 0.0946Slp – 0.0002Str + 0.0003Vil; overall accuracy 83.13%

$Z_{elephant}$ = 1.4603 - 0.0013Alt -0.0001Rst -0.1109Slp – 0.0003Str +0.0002Vil; overall accuracy 83.32%

Z_{tiger} = 1.1335 + 0.0024Alt -0.0003Rst - 0.1327Slp – 0.0003Str + 0.0003Vil; overall accuracy 84.18%

where Alt = altitude (m); Rst = distance to ranger station (m);

Slp = slope (%); Str = distance to stream (m);
Vil = distance to village (m).

The GIS habitat models indicated that most species prefer to inhabit low altitude, close to ranger stations, low slope, close to streams and far from villages. These areas are safe from illegal poaching and other human disturbances with near year-round water sources. The overall accuracies for all species except sambar, were greater than 83%, being especially high for banteng because its habitat is concentrated in small patches. For sambar, the model indicates low accuracy because it uses various vegetation types. In addition, the pseudo-absent data may contain occurrence locations. Figure 2 shows the likelihood of habitat uses of the five focal species in the WEFCOM, while Table 2 presents the coverage of each suitable class. The distributions of each species are detailed below.

Suitable habitats of sambar (likely and most likely) are found in deciduous forest and open areas in the core area and in the southern part of the WEFCOM, covering approximately 8,032 km^2 or 43% (Figure 2a). Sambar is unlikely to be present in densely populated areas and the steep terrain mainly in the northern and western parts of WEFCOM. Banteng or wild ox is now restricted to small and fragmented populations congregated along Huai Kha Khaeng stream. Other possible patches are in Khao Laem and Salakpra (Figure 2b). The suitable habitats cover less than 4% of the complex. The main threats to this species are poaching, habitat destruction and human encroachment, and overgrazing by domestic cattle (Prayurasiddhi, 1997). Besides, the habitats of banteng have been degraded in recent years due to the RFD and Department of national Park, Wildlife and Plant Conservation (DNP) have implemented the policy of 100% forest fire prevention nationwide, especially in protected areas. This misunderstood concept influenced vegetation community dynamics and dependent fauna. Parts of open deciduous forests and grassland which are favorable habitats for ungulate species have been invaded by pioneer species such as *Cratoxylum* spp. and *Eupatorium odoratum*.

Table 2. Predicted suitable habitats for selected wildlife species in the WEFCOM

	Extent of Suitability Class (%/km^2)				
Species	Unlikely	Less Likely	Likely	Most Likely	Suitable habitat [1/]
Sambar	37.9	19.2	14.6	28.3	42.9
	7,099	3,596	2,736	5,296	8,032
Banteng	89.4	7.3	2.6	0.7	3.4
	16,731	1,362	492	140	632
Gaur	41.1	17.1	12.8	29.0	41.7
	7,699	3,211	2,390	5,427	7,817
Elephant	26.6	21.7	18.3	33.6	51.9
	4,951	4,058	3,425	6,292	9,717
Tiger	63.6	16.7	9.3	10.4	19.7
	11,922	3,126	1,736	1,944	3,680

[1/] = Likely suitability + most likely suitability.

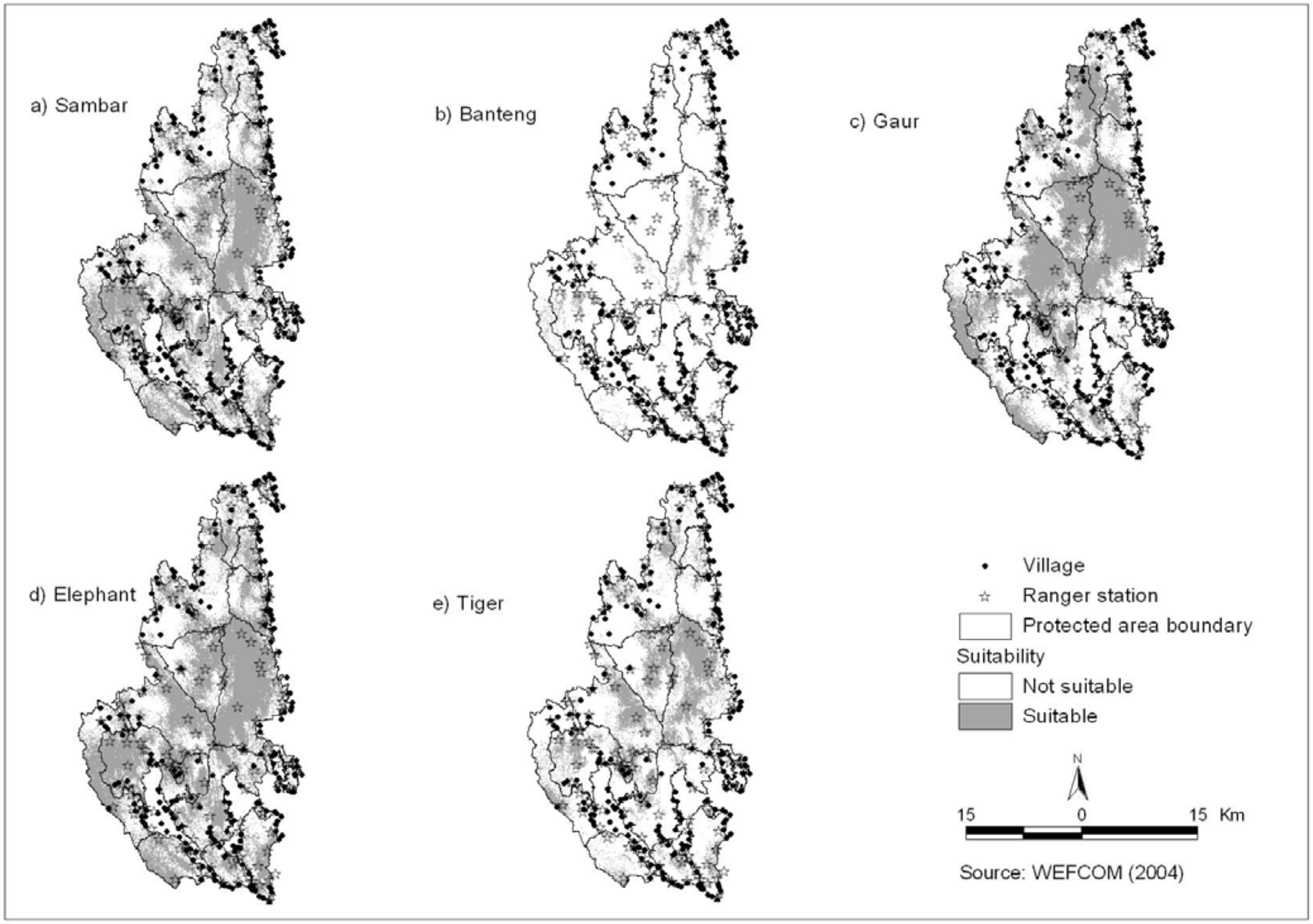


Figure 2. Current suitable habitats of selected species in the WEFCOM based on probability values.

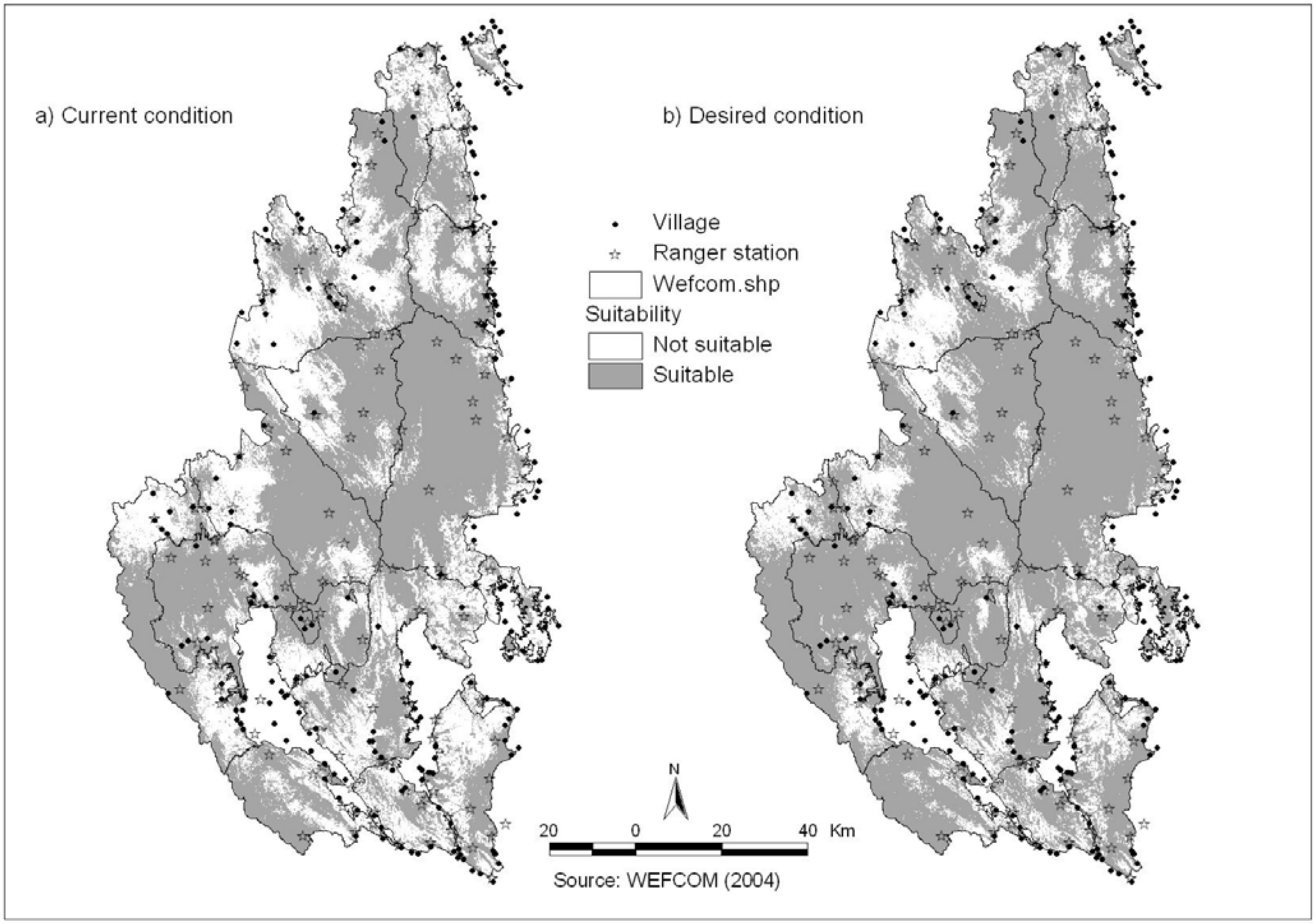


Figure 3. Comparison of congregation areas of suitable habitats for all species in current condition and desired condition.

Table 3. Assessing population viability in WEFCOM

	Species target	Category	Key attribute	Indicator	Viability Assessment [1/]				Current Rating [2/]	Desired Rating [3/]
					Poor	Fair	Good	Very good		
1	Sambar	Size	Minimum dynamic area to support viable population (MVP = 3,000; HR[4/] = 1.7-4.0 km^2 (Sankar 1994); MDA = 7,500 km^2)	The extent of likely or most likely suitable habitats in km^2	<3,000	3,000-4,500	4,500-6,000	6,000-7,500	Very good	Very good
		Landscape context	Habitat fragmentation	% intact forest surrounding 2-km buffer of suitable habitats	<20%	20-40%	40-60%	> 60%	Very good	*NA* [5/]
2	Banteng	Size	Minimum dynamic area to support viable population (MVP = 500; HR[4/] = 44 km^2[2/]/herd (Prayurasiddhi, 1997); MDA = 4,400 km^2)	The extent of likely or most likely suitable habitats in km^2	<1,700	1,700-2,600	2,600-3,500	3,500-4,400	Poor	Fair

Table 3 – Continued

Species target	Category	Key attribute	Indicator	Viability Assessment [1/] Poor	Fair	Good	Very good	Current Rating [2/]	Desired Rating [3/]
	Landscape context	Habitat fragmentation	% intact forest surrounding 2-km buffer of suitable habitats	<20%	20-40%	40-60%	> 60%	Very good	*NA*
3 Gaur	Size	Minimum dynamic area to support viable population (MVP = 2,000; HR[4/] = 29.9 – 52.1 km^2/herd (Conry, 1989); MDA = 13,300 km^2)	The extent of likely or most likely suitable habitats in km^2	<5,320	5,320-7,980	7,980-10,640	10,640-13,300	Fair	Good
	Landscape context	Habitat fragmentation	% intact forest surrounding 2-km buffer of suitable habitats	<20%	20-40%	40-60%	> 60%	Good	*NA*

Table 3 – Continued

	Species target	Category	Key attribute	Indicator	Viability Assessment [1/]				Current	Desired
					Poor	Fair	Good	Very good	Rating [2/]	Rating [3/]
4	Elephant	Size	Minimum dynamic area to support viable population (MVP = 500; HR[4/] = 105-320 km^2/herd (Sukumar, 1989); MDA = 20,000 km^2)	The extent of likely or most likely suitable habitats in km^2	<8,000	8,000-12,000	12,000-16,000	16,000-20,000	Fair	Good
		Landscape context	Habitat fragmentation	% intact forest surrounding 2-km buffer of suitable habitats	<20%	20-40%	40-60%	> 60%	Very good	*NA*

Table 3 – Continued

	Species target	Category	Key attribute	Indicator	Viability Assessment [1/] Poor	Fair	Good	Very good	Current Rating [2/]	Desired Rating [3/]
5	Tiger	Size	Minimum dynamic area to support viable population (MVP = 100; HR[4/] = 50-200 km^2 (Prommakul, 2003); MDA = 8,000 km^2)	The extent of likely or most likely suitable habitats in km^2	<3,200	3,200 -4,800	4,800-6,400	6,400 -8,000	Fair	Good
		Landscape context	Habitat fragmentation	% intact forest surrounding 2-km buffer of suitable habitats	<20%	20-40%	40-60%	> 60%	Good	*NA*

1/ Viability assessment is based on measurable size and landscape context criteria; 2/ at present time; 3/ in the next 10 years; 4/ home range; 5/ Not applicable.

Figure 2c reveals that the distribution of gaur is more limited than that of elephant (Figure 2d) because it is more sensitive to human pressure. The suitable habitats cover approximately 42% of the WEFCOM area and it is most likely found in the core area. On the other hand, the chance to observe gaur in other protected areas is minimal. In fact, elephant can be found in a variety of habitats (Sukumar, 1989) but the GIS habitat suitability map shows that the current suitable habitats are basically situated in the core area of WEFCOM and areas along the Myanmar border (Figure 2d), covering approximately 9,717 km^2. Areas in the west, east, north and parts of southern landscapes are not suitable for elephant because there are a lot of human settlements and they are easy accessible. Figure 2e shows that the most suitable habitats for tiger can be found in Huai Kha Khaeng followed by Thung Yai East and Thung Yai West. The total suitable areas cover approximately 20% of the WEFCOM. The results are consistent with the studies of Prommakul (2003) and Simcharoen *et al*. (2007) which revealed that the home range of tigers in Huai Khai Khaeng is smaller than in Thung Yai due to higher abundance of prey species.

4.3. Current and Desired Conditions of Population Viability

The existing suitable habitats of sambar encompass approximately 8,000 km^2, thus they have potential to hold more than 3,000 individuals. On the other hand, the suitable habitat of banteng is minimal and ranked as poor condition (Table 3). It can accommodate less than 40% of a viable population size (500 individuals). However, the largest suitable habitat patch is located in the core area of Huai Kha Khaeng and surrounded by dry diptercarp forest and well protected by park rangers. Even though the actual population size of gaur is not known, the existing suitable habitats (7,800 km^2) are assumed to accommodate approximately 1,000-1,200 individuals (40-60% of viable population). In addition, the adjacent area within a 2 km buffer is highly intact. Thus, the size criterion is classified as fairly viable, while landscape context is in good condition.

The existing suitable habitat of elephant covers about 9,700 km^2 and could hold approximately 240-250 individuals. The size criterion is ranked as fair. However, the landscape matrix is highly connected and has very high potential to facilitate elephant movement in the WEFCOM landscape. The suitable habitats of tiger encompass approximate 3,700 km^2. Based on the average home range size reported by Prommakul (2003), the current suitable habitats are likely to accommodate approximately 40-50 tigers, thus, they are in fair viability status but the landscape context outside occurrence patches is moderately intact with natural vegetation.

The project aims to upgrade the viabilities of all species (except sambar) to the next level in the next 10 years. In order to achieve this target, park rangers and multi-stakeholders have to increase the amount of suitable habitats for banteng, gaur, elephant and tiger to an area between 1,700-2,600 km^2, 7,980-10,640 km^2, 16,000-20,000 km^2, and 6,400-8,000 km^2, respectively (Table 3).

4.4. Location of Congregation Areas of Population Viability

We overlaid the current suitable habitats of all five species using GIS method to derive current congregation areas, and the desired suitable habitats to derive desired condition to support viable populations. The results showed that the total area of current congregation habitats cover approximately 12,630 km^2 or 67% of the WEFCOM (Figure 3a). Concentrations of five focal species are clustered in three places. The largest patch is located in Huai Kha Khaeng and adjoining Thung Yai Naresuan. On the ground, the survey teams observed that there are a number of migratory routes of the landscape species e.g. tiger, elephant, gaur found in these areas. The second dominant area is located in the western part of WEFCOM extending along the Myanmar border. The smallest patch can be found in the north.

Meanwhile, the desired congregation habitats cover nearly 16,750 km^2 or 89% (Figure 3b). Basically, these areas cover the whole of Huai Kha Khaeng, 80% of Thung Yai East and West and extend to the Myanmar border. In the north, the size of small and fragmented patches increases significantly. The desired areas could hold more wildlife population, in addition to connect fragmented and patchy suitable habitats. However, areas along the western boundary and in the south close to villages are still not feasible to support viable populations.

CONCLUSION

The WEFCOM project aims to maintain the health of the ecological systems by using species conservation targets. Five species were selected, namely sambar deer, banteng, gaur, elephant and tiger. Their habitat suitability areas were determined using logistic multiple regression method. The results of GIS habitat models indicated that most species prefer to inhabit low altitude, close to ranger station, low slope, close to stream and far from village locations. The suitable habitats (likely and most likely) of sambar deer, banteng, gaur, elephant and tiger covered approximately, 43%, 3%, 42%, 52% and 20% of the WEFCOM landscape, respectively.

The MVP of sambar, banteng, gaur, elephant and tiger in the WEFCOM defined by the planning team and wildlife experts were 3,000, 500, 2,000, 500 and 100 individuals, respectively. We used the MDA or suitable habitats to accommodate MVP population and habitat fragmentation surrounding the suitable to assess the viability of target species. We compared the MDA and predicted suitable habitat derived from the GIS habitat modeling and found that the viability of sambar is in very good condition, while the viability status of gaur, elephant and tiger is in fair condition. More importantly, the current viability status for banteng is extremely poor. However, landscape matrices outside the suitable habitats are in good or very good condition for all species. The planning team of WEFCOM would like to upgrade the level of viabilities of these species to next level in the next 10 years. In order to achieve these targets, park rangers and multi-stakeholders have to increase the congregation habitats from 12,630 km^2 or 67% of the WEFCOM to 16,750 km2 or 89%. By doing this, the fragmented suitable patches would become more aggregated.

The results of GIS modeling may include omission errors (false negative) and commission errors (false positive) derived from pseudo absence data and the grid-based habitat suitability models. In addition, the predicted MDA may overestimate the actual species extent. Nevertheless, the results of this initiative are of value and the approach can become effective tool to implement ecosystem approach when demographic data is limited to do perform traditional population viability analysis.

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PROTECTION OF RIPARIAN LANDSCAPES IN ISRAEL

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ABSTRACT

Riparian landscapes are natural habitats of unique ecological and scenic values, which are highly sensitive to human intervention and impact. Yet, due to their qualities, and especially the presence of water, they are also usually attractive for recreation purposes. This is more so in arid and semi-arid zones like Israel. Nevertheless, in the past, the importance of riparian landscapes in Israel did not receive adequate attention in policy and planning. As a result, over the years they were exposed to various negative impacts, including pollution by industrial and agricultural effluents, exploitation of water for agricultural and other purposes, and land use conflicts. Although in recent years with the growing awareness of their ecological and recreational potential, considerable efforts are being invested in the rehabilitation of deteriorated riparian landscapes, their protection is still deficient.

This chapter reviews and examines policy tools used for the protection of riparian landscapes in Israel, based mainly on regulations, reports and existing literature. It concludes by offering some lessons for policy-making in general and suggestions for improving the protection of riparian landscapes in Israel in particular.

Keywords: environmental policy, river corridors, conservation, open spaces.

INTRODUCTION

Riparian landscapes are natural habitats of unique ecological and scenic values, which are highly sensitive to human intervention and impact (Goren, 2000). Yet, due to their qualities, and especially the presence of water, they are also usually attractive for development as well as for recreation purposes. This is more so in arid and semi-arid zones like Israel (Burmil, 1999; Patten, 1998). Nevertheless, in the past, the values of riparian landscapes in Israel did not receive adequate attention in policy and physical planning. As a result, they were exposed over the years to various negative impacts, including pollution by industrial and agricultural effluents and household sewage, exploitation of water for agricultural and other purposes, political disputes and land use conflicts (Amir-Shapira and Feldman, 1999; Gabbay, 1998). In recent years, mainly since the year 2000, with the growing awareness of their ecological and recreational potential, considerable efforts are being invested in the rehabilitation of deteriorated riparian landscapes. Nonetheless, according to a recent report most of the rivers in Israel and their surroundings still suffer from pollution and other negative impacts (Amir-Shapira, 2007).

This chapter reviews the protection of riparian landscapes in Israel. It presents the policy tools used for protection of riparian landscapes up to the year 2000, examines their effectivity and reveals embedded deficiencies. The methodology is based on the review and content analysis of various sources, mainly laws, reports and literature. The first part of the chapter introduces the importance of riparian landscapes in general, covering among others ecological, environmental and scenic aspects. It than presents the subject of riparian landscapes in Israel and the factors that affected policy and priorities concerning the use of water in general and protection of riparian landscapes in particular. The second part reviews and examines protection tools, focusing on legislation, institutional structure and physical planning. The third and last part of the chapter discusses the deficiencies and weaknesses that were revealed and proposes improvements to the existing state.

THE IMPORTANCE OF RIPARIAN LANDSCAPES

According to Naiman and Décamps (1997) a riparian zone encompasses the stream channel and that adjacent portion of the terrestrial landscape from the high water mark toward the uplands, where vegetation might be influenced by elevated water tables or flooding. The width of a riparian zone and the diversity of its functional attributes are related to the size of the stream, its position within the drainage network, the hydrologic regime and the local geomorphology (Gregory et al., 1991; Naiman and Décamps, 1997). In other words, a riparian zone may be regarded as a linear physical landscape entity composed of aquatic and terrestrial components and the interface between them. Riparian landscapes are unique ecosystems, highly important ecologically and environmentally, and they constitute a visually and functionally outstanding component of the open space system. They form complex habitats, richer than the average with species of plants, animals and microorganisms, thus contributing to overall biodiversity (Gregory et al., 1991; Naiman et al., 1993). These habitats and the richness of species they sustain are especially sensitive to various impacts and interferences, including seasonal or other changes in water physical qualities (like temperature, salinity or electric mobility) or quantities (Allan, 2004; Goren, 2000; Karr, 1994; Naiman and Décamps, 1997; Pollock et al., 1998; Shandas, 2007; Stauffer and Best, 1980). They are considered the most diverse, dynamic and complex habitats (Goren, 2000; Gregory et al., 1991; Naiman and Décamps, 1997).

Riparian ecosystems perform a variety of environmental and ecological services (Allan, 2004; Brauman et al., 2007; Hale and Adams, 2007; Naiman and Décamps, 1997; Patten, 1998). Many of these are considered life-supporting systems (De Groot, 1992; Naveh, 1997), although they are difficult to evaluate in economic terms (Chavas, 2000; Constanza, 2000). Due to their linear nature, riparian landscapes are natural ecological corridors, allowing connectivity between habitats and patches in the landscape (Beier and Noss, 1998; Bentrup and Kellerman, 2004; Jongman, 1995; Machtans et al., 1996; Naiman et al., 1993; Ndubisi et al., 1995; Shkedi and Sadot, 2000; Taylor et al., 1995; Walmsley, 2006; Weber et al., 2006). This is especially important in populated areas, where riparian landscapes may be the last remnants of an open natural space within a built-up area. Another function that is especially important in populated areas is their potential as catchement basins for floods, thus avoiding damage to property and lives (Brody et al., 2007; McHarg, 1969; State Comptroller, 1993). They are also attractive for recreation and leisure activities, and due to their linear form are natural candidates for greenway planning, combining opportunities for recreation with conservation of nature, landscape and heritage values (Ahern, 1995; Baschak and Brown, 1995; Bryant, 2006; Fábos, 2004, 1995; Jim and Chen, 2003; Lewis, 1964; Li et al., 2005; Little, 1990). Open lands along rivers and streams are also often used for agriculture, because of their fertility, due to embedded sediments, and relatively level plains (Bentrup and Kellerman, 2004; Karr, 1994).

Riparian landscapes are extremely vulnerable to human impact. Surface water from all over the drainage basin might carry with it soil particles and various pollutants, including pesticides, fertilizers and agricultural wastes into the stream. Their potential for conservation, recreation or agriculture is diminished by conflicts and liabilities from various sources. Pollution by industrial and agricultural effluents and overflow of sewage from treatment plans harms the landscape, disqualifies water for irrigation, prevents recreational water-related activities (e.g. swimming and boating) and repels potential users in general. Exploiting river water for irrigation decreases the availability of water for natural system functions. Though riparian landscapes are attractive for development and recreation, they may be contradictory to certain types of agricultural uses. Moreover, floods may cause damage to agriculture and other uses within the flooded area.

Nevertheless, the presence of water is a potentially dominant factor that attracts development. Unfortunately, often the resulting development ends up with the construction of buildings and infrastructure too close to the water line, thus interfering with the ecological functions of the riparian system.

Considering their uniqueness and attractiveness on the one hand and their vulnerability to various impacts on the other, riparian landscapes are in need of effective protection from inappropriate uses. In Israel, a hot and dry land, such landscapes are especially important. The next section describes the factors that affect rivers and riparian landscapes in Israel.

THE RIVERS IN ISRAEL

The priorities concerning water and riparian landscapes in Israel stem from physical conditions – mainly geomorphology and climate – combined with ideological and geopolitical factors.

Israel is situated on the eastern side of the Mediterranean basin, with geomorphology and climate changing both along the north-south axis and the east-west one. The north and center of the country lie within the Mediterranean climate zone, characterized by a short rainy winter and a long, hot and dry summer while the south of the country is more desert-like. The mountainous northern areas are the rainiest with an average of 800-1000 millimeters per year, decreasing in the central zone the a yearly average of 500-600 millimeters. Eastward and southward the average decreases to 100 millimeters and less. These quantities may fluctuate from year to year, and, in addition, there is high occurrence of droughts. All these factors add up to a continual condition of water shortage (Menahem, 1999).

The area of the State of Israel is intersected longitudinally by a series of mountain ranges that divide it into an eastern basin, where rivers flow towards the Jordan River, the Sea of Galilee and the Dead Sea, along the natural eastern borders, and a western basin, where rivers flow into the Mediterranean Sea. The western basin's climate is milder and relatively rainy, while the eastern basin's is hot and dry. Due to the limited rain quantities, many river sections are in fact seasonal streams, flowing during winter and spring, and drying out in the summer until the next rainy season. In the dry south, the streams are characterized by short strong flows following rain events, which dry out quickly. Only a few rivers that are fed by year-round springs have water flowing in all seasons.

Seasonal streams are exceptionally sensitive because of the fluctuations in water availability for habitat performance in addition to the fact that some of them do not enjoy a strong flow even in the rainy season. These characteristics affect their public conceptual image as landscapes fit for conservation or suitable for recreation purposes. River sections that run through areas declared as nature reserves or national parks are protected, along with the whole area, under the National Parks and Nature Reserves Law of 1963. However, a river or stream crossing an area that is not characterized by special scenic or nature values were usually not grasped as deserving protection. Consequently, they are under pressures for development, especially in areas of level topography, such as the inner and the coastal plains.

The most important rivers, considering water discharge amounts and landscape impact are in Israel's western basin, crossing the coastal plain where the majority of the population (about 80%) is concentrated. These also have the highest potential for recreation. However, their proximity to densely settled areas has resulted in their deterioration due to various negative impacts, such as: trapping riparian waters for agricultural use and other purposes, pollution by agricultural and industrial effluents, overflow of sewage from treatment facilities, construction or agricultural cultivation close to the water line, neglect and garbage disposal (Amir-Shapira and Feldman, 1999).

In addition to this, because of the scarcity of water resources and frequent droughts, the national water policy focused on keeping control over all water sources and prioritizing the use of water for agriculture and other uses. For example, since the mid 1950s, most of the water from the Yarkon springs was captured and transported to agricultural fields in the Negev (the southern region of the land) through the Yarkon-Negev pipeline; as a result, the Yarkon River, the main river in the core, densely-populated area of Israel - once a wide deep stream that the British soldiers had to cross by boats when conquering the land from the Turks in the year 1917 – deteriorated into a narrow and shallow stream, where most of the flow consisted of industrial effluents and initially-treated sewage. The negative impacts on riparian landscapes call for examination of existing protection and management tools and their effectivity.

PROTECTION OF RIPARIAN LANDSCAPES IN ISRAELI LEGISLATION

The protection of landscapes by legislation is a universally accepted model for the conservation of outstanding scenic or natural values (Maruani and Amit-Cohen, 2007).

Legislation is a source of authority and constitutes a strongly effective policy tool. Yet this tool has its drawbacks, among them low flexibility, requiring a long, complicated bureaucratic process whenever a change in legislation is desired. This is also a source of conflict between conservationists and developers and landowners. On the other hand, protection based on a statutory declaration is stronger than any other protection tool, and provides the relevant authorities with enforcement measures.

In Israel, legislation concerning water resources, including rivers, is complex, involving a multitude of laws and regulations as well as a multitude of authorities and organizations that are meant to enforce them (Kaplan, 2004). This section presents three laws that are the most relevant to the protection of riparian landscapes, as follows: the Water Law, the Drainage Law and the Rivers Authorities Law.

The Water Law

The Water Law, enacted in 1959, should be understood in the context of the general scarcity of water resources in Israel, the relative average low rainfall and the frequent droughts, on the one hand, and the centralistic governance style and intensive involvement of the State, on the other (Menahem, 1999). The main objectives of the law were to secure the State's sovereignty over all water sources and ensure their utilization for the benefit of Israeli society. The law determines that "… the water sources in the State are owned by the public, controlled by the State and designated for its population and development needs. The water sources for that matter are the springs, the streams, the rivers…" etc. (Water Law, sec.1-2). The law regulates the management of water sources, including allocation for users and preservation of water quality. For these purposes, the law created several institutions, among them a National Water Board, headed by the Water Commissioner. The law gave priority to the agricultural sector, which at the time was regarded not only as a leading sector in the national economy but also as the ideological and political elite of Israeli society (Menahem, 1999; Schiffman, 1999). This was reflected in various attributes of the law, among them its subordination to the Minister of Agriculture, including the power to appoint the Water Commissioner, who was to lead the design and implementation of water policy in Israel. Thus, it is no wonder that the first seven elected commissioners were from the agricultural sector, as were also most of the National Water Board members (Menahem, 1999). Only forty years later, in the 1990s, following ideological, political and social change processes in Israeli society, including the decrease in the economic and ideological importance of agriculture and the acceleration of development (Maruani, 2005; Schiffman, 1999), the Water Law was transferred to the authority of the Minister of National Infrastructures and some of its powers were split among several other institutional structures. Laster (2004) claims that this split in authorities is the reason for the decrease in water quality, in contrast to Western Europe where a centralistic approach was adopted.

The Water Commissioner, among others, used his powers collect water from springs and rivers, and allocate it to consumers, thus reducing the natural flow, ignoring the ecological consequences, which, in turn, also had a negative impact on the attractiveness and availability of the surrounding area for recreation (Laster, 1995).

The only reference in the Water Law to the protection of land near water sources is the available option to define buffer strips for purposes such as "…protection of water, of water source …", that are wide "… no more than is necessary for the purpose of the buffer strip…" (sec.14-15). No references are made to purposes involved in the protection of landscape or other values embedded in the terrestrial area outside the water itself.

The Water Law reflects a utilitarian approach towards water resources, and almost completely ignores other values. Some years ago the law was amended, and to the list of uses for water allocation was added the "…protection and rehabilitation of nature and landscape values, including springs, rivers and wetland habitats" (sec.6). However, there is no other reference to such a goal anywhere else in the law, and its implementation is totally dependent on the awareness and the good will on the part of the decision makers. It should also be noted that the interests of the Head of the Water Authority (who replaced the original Water Commissioner, following an amendment in 2006) and the Ministry of National Infrastructures do not coincide with the interests of landscape conservation. This was even truer in the past, when the main interest of the Water Commissioner and the Ministry of Agriculture was the supply of water to the agricultural sector.

The Drainage Law

The Drainage Law (or in its full name: the Drainage and Flood Protection Law) was legislated in 1957, after floods in the mid 1950s covered vast areas, mainly agricultural fields, causing severe economic damage. The objective of the law was to prevent the recurrence of floods by forming suitable institutions to manage drainage. This law, too, was subordinated to the Minister of Agriculture – and still is - since agricultural lands were conceived as being most threatened by potential floods. The priority given to agriculture is expressed in the first section of the law, which defines "drainage" as "…any operation intended to concentrate, to store, to carry or to remove surface or any other water which harm or may harm agriculture, public health…" etc.

The Drainage Law states that the "…Minister of Agriculture may… establish a drainage authority…" (Drainage Law, sec.11), but the establishment of such an authority is not obligatory. The law also specifies the duties and powers of such an authority, including regulating drainage and initiating drainage projects within its jurisdiction. The roles of a drainage authority as they are specified and defined in the law do not refer to the protection of the relevant riparian landscapes in any other way. In addition to drainage authorities, the law determines the establishment of a National Drainage Board to advise the Minister on matters of drainage, such as the declaration of drainage zones or the approval of drainage projects (sec.2). This is an obligatory body, complementing the relevant institutional structure for regulating drainage and preventing floods.

The Drainage Law defines some relevant terms for its purposes including "channel" and "buffer strip." A Channel is defined as "…river, stream… and any other water route… where water is flowing or standing always or occasionally." A buffer strip is defined as "strips of land along both sides of a channel (sec.1). The law prohibits agricultural cultivation or construction within a buffer strip. However, according to the law, the overall width of buffer strips on both sides should not exceed half the channel's width, and no more than 5 meters each (sec.5-6). It is needless to say that the potential protection of the riparian habitat is very limited given such conditions.

The Drainage Law, like the Water Law, expresses the priority given to agriculture. Most drainage projects during the 1960s and 1970s were intended to solve drainage problems in agricultural and open areas, although in populated areas potential damage from floods to property and persons is much higher. Moreover, since the legislation of the Drainage Law in 1957, the scope of development for residential, occupational and infrastructure uses increased greatly, much of it was at the expense of open and agricultural lands where rains could have previously penetrated the soil. As a result, the amounts and intensity of surface flow towards rivers increased considerably, and with them the risk of floods. In spite of that, the Drainage Law was not updated to include instructions regarding measures for the control of drainage in new development plans. This neglect resulted in recurrent flood events in various areas, causing millions dollars worth of damage (Laster, 2004; State Comptroller, 1993, 1999b).

The Rivers Authorities Law

The Rivers Authorities Law (RA Law: the full name being "Rivers and Springs Authorities Law") from 1965 complements the Water Law and the Drainage Law by referring not only to the protection of the water but also to the land adjacent to it, thus expressing the values of riparian landscapes for the first time in Israeli legislation. This expression is also reflected in the ministerial subordination; when legislated, the RA Law was subordinated to both the Ministry of Interior and the Ministry of Agriculture; however, it was transferred to the Ministry of Environment after it was created in 1989.

The RA Law states that the "…Minister may… establish an authority for a certain river or part of it… or impose on a drainage authority powers of a river authority…" (RA Law, sec.2). That is to say, a river authority – like a drainage authority – is not obligatory. Among the duties of a river authority, the law counts "protection of the landscape and nature values along the river on both sides…" but also regulation of the river's water flow and drainage within its jurisdiction (sec.3). This means that there is an overlap between the duties of a Drainage Authority and that of a River Authority, albeit they are related to different ministries. Laster (2004) claims that the law was intended to manage the rivers on a watershed approach basis, but actually it did not enable that, since it demanded subordination to the Water Law and the Water Commissioner. Moreover, the jurisdiction of a River Authority does not necessarily cover a whole watershed. For example, the jurisdiction of the Yarkon River Authority was limited to 20 meters on each side of the river.

The RA Law was implemented for the first time in the year 1988 – 23 years after its legislation – with the establishment of the Yarkon River Authority. It took six more years to establish the Kishon River Authority, in 1994, which was the second, and, up–to-now the latest authority based on this law. Laster (2004) comments that the reason it took so long to implement the law was the original subordination to two ministers. Another criticism of the law relates to the absence of a national body, something like the National Drainage Board. In other words, the RA Law represents a particularistic approach, referring to each river separately and lacking a broad vision on a national scale.

INSTITUTIONAL STRUCTURE

While legislation is a source of regulative powers, there is a need for institutions to use these powers and enforce the regulations. In Israel, there are several institutions that have to do with management and protection of riparian landscapes, the most important of them being the Drainage Authorities, the River Authorities and the Rivers Administration. They differ by their status, composition, main objectives, powers and budgeting.

Drainage Authorities

Drainage Authorities (DAs) may be established by the Minister of Agriculture, as already mentioned, subject to the consent of the Minister of Interior and the relevant local municipalities, which are also represented in its composition. The DA is responsible for managing drainage zones within its jurisdiction, including initiating, developing and maintaining drainage projects. The powers of a DA may contribute greatly to the protection of the relevant riparian landscapes, since managing drainage requires, among other things, restrictions on development along the water route.

Following the legislation of the Drainage Law, the Minister of Agriculture issued an ordinance in 1960 establishing 26 DAs. The ordinance specified the jurisdiction allocated for each DA, generally consisting of low-elevated plains, mainly agricultural lands (State Comptroller, 1993). Laster (1995, 2004) comments that the large number of DAs was due to political pressures rather than hydrological needs. Most of them actually operated as organs of the relevant Regional Councils - which are the local municipalities in the rural zones – and were dominated by representatives of the agricultural sector, thus reinforcing its control over water sources.

The recurrence of severe flood events implies the existence of shortcomings and deficiencies in the Drainage Law's implementation in general and in DAs' operation in particular. Especially memorable are the floods of winter 1991-2, when river overflows flooded large areas all around Israel, disrupting the course of everyday life: people had to be temporarily evacuated from their homes, roads became impassable, large agricultural areas were under water and there were even some fatal casualties. The overall direct and indirect damage to households, businesses, public property and agriculture amounted to tens of millions of dollars. Following those events, the State Comptroller (1993) issued a report that pointed out various faults in the DAs' functioning, stating among others that the drainage infrastructure had been neglected over the years and the sums required for proper planning, regulating and maintenance of many rivers were not allocated and invested as should have been done.

In 1996, after studying the State Comptroller's report, the Minister of Agriculture issued an ordinance reorganizing the DA system. Their number was decreased from 26 to 11, each covering a jurisdiction overlapping a natural drainage basin, and together covering the whole country. Each DA is directed independently of the Regional Council system, intended to apply a whole watershed approach rather than serve local interests (Laster, 2004). Although since this reorganization floods have reccurred, it seems that - especially since 2000 - DAs are taking more active measures to prevent flooding, revealing a more environmentally-oriented approach, including the conservation of landscape and ecological values in the riparian zones, in collaboration with other institutions and organizations, such as the Ministry of Environment, the Nature and Parks Authority and the Society for the Protection of Nature (Carmel Drainage Authority 2004).

Rivers Authorities

A River Authority (RA), with powers to limit and control development along the river, is a potentially effective tool in the protection of riparian landscapes. However, this potential cannot be fully realized, partly due to constraints imposed by the RA Law, such as the limited size of the area under the RA's jurisdiction. The RA's effectivity is also limited by its obligation to comply with the Water Authority (RA Law, sec.4), even in cases when their interests are contradictory. An RA's composition is more complex than a DA's, including several government officials. Thus, conflicts between government officials and local municipalities' representatives may also hamper the RA's functioning. Another potential source of conflict is the existence of a DA in the same jurisdiction since the duties and responsibilities according to the Drainage Law and the RA Law partly overlap.

The RA Law states that an RA is appointed to manage a particular river and is supposed to operate independently, following its management's objectives and policies. However, there is lack of a master organization on a national scale to design and lead a comprehensive policy towards the protection of riparian zones. With the absence of national policy, the influence of local interests increases, thus allowing development and infrastructure on or adjacent to riverbanks that should have been preserved.

Nevertheless, an RA is still the only institutional structure that is essentially specified for riparian nature and landscape protection in Israel. This may be exemplified by the Yarkon River Authority (YRA), which since its establishment in 1988 has initiated a master plan for the Yarkon River, seeking, among other goals, to restore the riparian ecosystem and contribute to environmental quality, aesthetic values and climate amelioration (Rachmimov 1996). The YRA develops bicycle trails and areas for recreation along the river and is currently monitoring water quality etc. The YRA was, in fact, a pioneer and a model in river restoration in Israel. Regretfully, however, only one more RA was established till now: the Kishon River Authority (in 1994). Both the Yarkon and the Kishon are large rivers, passing through densely populated areas - the Yarkon in the Tel Aviv metropolis, in the center of the State, and the Kishon in the northern Haifa metropolis - that were in a severely deteriorated state due to pollution from multiple sources, water trapping, etc. However, several other large rivers in a similar condition could have profited from a similar specified institutional structure to manage and restore them.

The Rivers Administration

The Rivers Administration (RAD) was established in 1993 as a mutual initiative of the Ministry of Environment and the Jewish National Fund (JNF), the latter being a historical non-governmental organization that is currently intensively involved in forestry and outdoor recreation. Other institutions and organizations that take part in the RAD are the Nature and

Parks Authority, the Ministry of Interior, the Ministry of Agriculture, the Water Authority, the Israel Government Tourist Corporation and the Society for the Protection of Nature which is a non-governmental organization (Amir-Shapira and Feldman, 1999; Gabbay 1998). The declared goals of RAD include: conservation of high-quality open spaces along river channels, controlled development of recreation and tourism foci within riparian zones and rehabilitation of rivers to a state enabling sustainability of unique habitats and landscape values (Amir-Shapira and Feldman, 1999). RAD initiates and promotes plans for the restoration of rivers, issues guidelines for existing and future River Authorities, supports the establishment of local river administrations and is actually involved in many restoration projects that are in progress, especially since 2000. For instance, the RAD takes part in the steering committee of the successful restoration project for the Alexander River – a large coastal river in the Sharon region, and one of the first to enter a restoration program along with the Yarkon River. This is done in collaboration with many other bodies, including the Alexander Drainage Authority, the Emek Hefer Regional Council, the Emek Hefer Streams Society, the Water Authority, the JNF, the Israel Government Tourist Corporation, the Nature Conservation Research Institute, the Ministry of Environment, the Hadera Environmental Association, the Nature and Parks Authority, the Society for the Protection of Nature, the District Planning Commission, the Ministry of Interior and the Israel Lands Administration (Cohen-Shoel 2003). It is clear that when so many organizations are involved, conflicts and clashes of interest are unavoidable and may hamper conservation efforts. For example, the Israel Lands Administration is supposed to manage all public lands, which in Israel amount to 93% of the area of the State. However, since the 1990s, it actually acts as the State's main developer, initiating large intensive development plans wherever possible, driven by economic interests (Maruani, 2005). Such a development-oriented organization is bound to confront conservation-oriented bodies like the Nature and Parks Authority and the Society for Protection of Nature. The RAD, which is guided by a statewide vision regarding rivers and riparian landscapes, can bridge such controversies and promote restoration and conservation efforts.

Nevertheless, the protection offered by the RAD is limited since this is not a statutory body, and consequently lacks regulative and enforcement powers. Whenever action against polluters or other offenders of the riparian landscape is needed, it is the Ministry of Environment that is supposed to interfere and take steps towards enforcement. Also, due to lack of obligatory organizational procedures, RAD's operations are spatially and temporally not consistent in essence, scope and timing. Therefore, in many cases, riparian landscapes in Israel are still subject to the arbitrariness of local authorities, and are not consistently regarded as worthy of protection. In addition, the RAD's potential effectiveness is reduced by budget limitations, since budget allocated for riparian management is divided among too many organizations, including DAs and RAs (Laster, 2004).

The lack of a statutory basis is a source of instability for the RAD, since it may be dismantled by a ministerial decision as quickly as it was established. Nonetheless, since its establishment in 1993, the RAD is a dominant factor in river restoration in Israel.

PHYSICAL PLANNING AS A PROTECTION TOOL

Riparian landscapes are integral parts of the land. As such, physical planning of land uses at national, regional and local levels is a potentially strong tool for their protection. In Israel, land uses are determined by a statutory planning system, according to the Planning and Building Law (PBL) of 1965 (which replaced former British mandatory legislation from 1936). The system is three-tiered, with Planning and Building Commissions at national, district and local levels, each having the power to control lower-tier decisions. All planning commissions may initiate outline plans within their jurisdiction.

National Planning

The Sharon Plan: The Sharon Plan was the first comprehensive national master plan prepared after the declaration of statehood in 1948. The plan was initiated and prepared within the (then) Planning Department of the Ministry of Labor and Construction, by a team headed by architect Arie Sharon, and published in 1951. This plan was not statutory; nevertheless it had significant long-range effects on spatial planning in Israel. The plan refers to five main facets of planning: agriculture, industry, transportation, parks and new cities. The agricultural plan is based on a national water policy that wishes to divert water out of relatively rich sources – among them rivers in the north and the Yarkon in the center of the State – and carry them to the dry south, thus enabling agricultural settlements that are regarded in the plan as a key factor in development and economic independence (Sharon, 1951). In other words, the Sharon Plan again reflects the economic and ideological values attached to agriculture, and grasps the water of the rivers as input for agriculture and not as a landscape component to be protected.

The plan for the parks in the Sharon Plan proposed conservation of certain areas of outstanding nature and landscape values. Four out of those were to be established immediately as national parks, among them two mountainous landscapes: Mount Carmel and Mount Jarmak in the Upper Galilee, and two riparian ones: the Falik Park proposed around the Yarkon and Ayalon rivers in the Tel Aviv metropolis, and a park west of Jerusalem based on the Sorek River (Sharon, 1951). However, although the Sharon Plan as well as the actual implementation of the Carmel and the Jarmak parks significantly affected spatial planning for years to come, the parks proposed around the rivers were ignored as was also the call for using river corridors as buffers between built-up areas. The Sorek corridor area, for example, was reduced over the years due to development (Amit-Cohen et al. 2005).

NOP 31: statutory planning in Israel at the national level is delineated in the National Outline Plans (NOPs). Out of almost 40 NOPs prepared up to date, only two represent comprehensive national planning. The first of the two was NOP 31, the Combined National Outline Plan for Construction, Development and Immigration Absorption. NOP 31 was prepared and approved in the early 1990s, when Israel was facing a crisis stemming from a sudden unanticipated increase in population due to mass immigration waves from the former USSR (Alterman, 1995). This was the first comprehensive national statutory plan to incorporate environmental considerations on a large scale, stating objectives like: conservation of nature and landscape resources, preservation of surface water quality, nurturing open spaces – among them riparian landscapes - for recreation, and balancing between development and conservation (Feitelson, 1993). The plan enhanced intensification of metropolitan regions in order to preserve open spaces in the rural zone. Despite these good intentions, it has been claimed that they triggered heavy development pressures in the metropolitan core of Israel, even in areas designated for conservation (Maruani, 2005).

NOP 35: the Combined National Outline Plan for Construction, Development and Conservation NOP 35 was approved in 2005, substituting NOP 31, which became obsolete in 1998. This plan, too, aspires to balance between development and conservation, taking this a step further by dividing the whole country into zones defined as development-oriented or conservation-oriented in varying degrees. Theplan specifically refers to river strips – including the water route and the banks 100 meters on each side – and requires every statutory plan to issue instructions concerning conservation of the river and its habitats, protection of its drainage functions, bank stabilization and free access to the public. This seems promising indeed, but it will take a number of years before its achievements can be assessed. However, past experience teaches us that NOP's instructions are not always kept. One example is the National Outline Plan for the Mediterranean coast, NOP 13, which prohibited construction within 100 meters of the water line. That instruction did not always stand up development pressures (State Comptroller, 1999a).

Sectorial NOPs: most national outline plans are sectorial, each dedicated to a specific subject (e.g. roads, power plants, landfills, etc.). None of the plans that have been prepared until now is designated for the protection of rivers and riparian landscapes, although in some cases, there may be a reference to rivers where this is relevant to the main plan's design. Such is the case of the National Outline Plan for Nature Reserves and National Parks, NOP 8, which offers protection to sections of riparian landscapes that are found within areas designated and declared as a nature reserve or a national park. Yet, the plan does not ensure protection along the whole water route. The National Outline Plan for Forests and Afforestation proposes plantings along riverbanks (Kaplan, 1993), but only in small limited areas, most of them outside of metropolitan zones where demand for recreation is especially high. The National Outline Plan for Tourism, NOP 12, offers another example. It designates some rivers as recreational spaces, among them the Sorek River (Amit-Cohen et al. 2005). Yet, development attractive for tourism is usually intensive and could harm existing riparian ecological and environmental values.

Regional Planning

District Outline Plans (DOPs), like NOPs, are essentially guiding plans, relating to the district under the jurisdiction of a relevant District Commission or part of it. Israel is divided into six administrational districts. Almost all of them had valid DOPs that by the early 1990s were mostly out-of-date, and none of them conceived riparian landscapes as objectives for conservation. An example for the disregard of riparian functions is the Ayalon Highway, crossing Tel Aviv through the route that once was the Ayalon River, leaving a rather narrow channel for winter water flow. Planning of this highway started in the early 1970s and it was opened for use at the beginning of the 1990s. In the winter of 1991/2, parts of it flooded, more than 140 cars were trapped in the flood, and transportation along the highway had to be stopped for some time (State Comptroller, 1993). This has since recurred several times, also causing some casualties.

The Planning Administration in the Ministry of Interior promoted preparation of new DOPs, some of which have already been approved since 2000. The new plans are much more environmentally oriented than the old ones, including special references and instructions for protection and conservation of rivers and riparian landscapes. For example, the new DOP 3/21 for the Central Area District designates "river and its surroundings" for conservation. Still, there are considerable variations between DOPs in their definitions and conservation instructions; some are guiding while others are obligatory, etc. (Maruani, 2005). In other words, the protection offered by DOPs is not consistent in scope and intensity. Moreover, since most current DOPs are relatively new, it will be some more time before their effectiveness in riparian protection can be evaluated.

Local Planning

While national and district outline plans offer general guidelines, Local Outline Plans (LOPs) are more detailed and serve as platform for issuing building permits. The permits are approved and issued by Local Commissions, which are in fact organs of the relevant local municipality, composed of the elected political representatives who constitute the municipal board. Thus, Local Commissions are interested in the promotion of local economic development, even when it is contradictory to conservation needs, and they tend to ignore a broader regional vision. District Commission's control is supposed to minimize the influence of local economic and political interests on land use decisions. However, since riparian landscapes are attractive for housing, it is no wonder that initiatives for development within riparian areas recur, assisted by interested Local Commissions which regardless of their negative impact and potential flood risk (see for instance: Shechori, 1999; Shmul, 2000; Vaserman-Amir, 1999). Development decisions are a major causal factor where floods are concerned (Brody et al., 2007; State Comptroller, 1993). The recurrent flood events in Israel, and their negative impacts and costs indicate that local development interests were not restricted by the District Commissions.

DISCUSSION

The examination of legislative, organizational and planning tools used for protection of riparian landscapes in Israel revealed various faults and deficiencies that may explain the still distressing state of these landscapes. Despite restoration efforts undertaken, mainly since 2000, almost all rivers are still polluted and ecologically deteriorated with only limited sections available and accessible for recreational uses.

Table 1 that presents a comparative assessment of protection tools shows that no one tool can be highly rated on all parameters. In addition, no parameter shows a consistently high rating for all tools. One fundamental problem is that no tool – with the possible exception of RAD - is dedicated to the objective of protecting ecological, environmental and scenic values embedded in riparian landscapes.

Table 1. Comparison of protection tools

Protection tool		Designation	Relevance	Power	Scale	Implementation
Legislation	Water Law	Low	Medium	High	National	Low
	Drainage Law	High	High	High	National	Low to medium
	River Authorities Law	High	High	High	National	Low to medium
Institutional structure	Drainage Authorities	Medium	High	Medium	Regional	Low
	River Authorities	High	High	Low to medium	Regional	Low to medium
	Rivers Administration	Very high	Very high	Low	National	Medium
Physical planning	Sharon plan	Low	Low	Low	National	Low
	NOP 31	Low	Low	Medium to high	National	Low
	NOP 35	Low	Low	Medium to high	National	?
	Sectorial NOPs	Low	Low to medium	Medium to high	National	Low
	DOPs	Low	Low	Medium to high	Regional	Low
	LOPs	Varies with plan	Varies with plan	High	Local	Varies with plan

For example, each of the laws examined makes a partial contribution to this objective although they differ in aims and scope. However, none of them regards the protection of riparian landscapes as its main aim. In addition, none of these laws reflects a watershed approach, theoretically or practically, albeit activities taking place anywhere in the watershed area, especially development and various pollution generators, eventually affect the river and the landscape along it. Moreover, partial overlap between the aims and directives of the Drainage law and those of RA Law are a constant source of ambiguity and fuzziness as to duties and responsibilities, on one hand, and inter-organizational and inter-personal frictions and conflicts, on the other. This situation stands in the way of the conservation interest.

The different tools are interconnected. Legislation determines the structure, responsibilities and operational procedures of the organization intended to implement it. Subjects not covered by the law are left to the discretion of organizational decision makers. Hence, awareness of riparian values on the part of decision makers is an important factor in effective protection. Statutory physical planning, too, relies on legislative power, and therefore inter-relations between laws may affect organizational actions. For example, the Drainage Law does not refer to statutory physical planning, while on the other hand the Planning and Building Law does not require a preliminary examination of possible impacts on drainage before the approval of a new development plan. The State Comptroller (1993) pointed out that the planning system allowed development too close to water routes and approved plans on large areas without ensuring suitable measures for infiltration of rains within their boundaries. He argues that the severe floods that were the cause for his report could have been prevented, had suitable instructions been embedded in the Planning and Building Law, thus preventing construction within flood retention areas and conditioning plan approval with proper infiltration and drainage solutions.

The protection of riparian landscapes as was formulated and implemented in Israel expresses a particularistic approach, where each river is conceived as a discrete entity, with a separate DA or RA. For comparison, nature and landscape values within areas that have been declared as nature reserves or national parks all over the state are protected centrally and managed by the Nature and Parks Authority, which is a national statutory institution, established by the National Parks and Nature Reserves Law. It seems that centralistic approach was efficient even when development pressures in Israel increased considerably towards the end of the 20th century. The establishment of the RAD indicates a conceptual change towards rivers as well but its lack of statutory position and the multitude of other relevant organizations reduce its effectivity.

The protection of riparian landscapes also reflects the evolution of environmental awareness in Israel (see also: Fletcher, 2000; Vogel, 1999). For example, the Water Law from 1959 almost completely ignores the environmental functions of water sources, including rivers, while the RA Law from 1965 already regards the protection of riparian environmental values as one of its main aims. The legislation also reflects the prevailing priorities in Israeli society at the time, affected greatly by ideological and national security considerations. In the past, agriculture and development were given priority; agriculture was conceived as a main economic basis and development of spatially dispersed small agricultural settlements also grasped as a tool for dominating national space while environmental needs were overlooked (Hershcovich, 2006; Schiffman 1999). It should be noted that all three laws examined were enacted before the global environmental revolution of the late 1960s. Moreover, as a consequence of the Stockholm Convention in 1972 Israel was one of the first nations to establish an environmentally designated institution in the form of the Environmental Service that was established in 1973 within the Prime Minister's office, and later on as part of the Ministry of Interior. However, the assimilation of environmental awareness was slow, especially among decision makers, until the 1990s when development pressures increased considerably, following a sudden increase of population due to large immigration waves, threatening nature and landscape values, especially in the coastal area and in vicinity of water bodies. This also was one of the triggers for initiation of RAD.

It should also be noted that split authoritative powers, multiplicities and deficiencies that characterize the protection of riparian landscapes in Israel, tend to be typically characteristic of environmental issues, which are naturally complex, interdisciplinary and bound up with economic and social conflicts. In addition, since its independence in 1948, Israel has been facing enormous challenges more than any other developed state, including an unstable geopolitical situation and recurrent wars, absorption of mass immigration waves and serious social conflicts (Alterman, 1995; Fletcher, 2000; Vogel, 1999). Nevertheless, all this still does not explain why former protection frameworks have not been reconstructed in spite of the advances in environmental management and administration in general. For instance, the Drainage Law that was mainly intended to prevent floods is still under the authority of the Ministry of Agriculture although severe damage caused by floods in recent years was mainly in urban areas and not in agricultural fields (State Comptroller, 1993). There is no doubt that the present state of affairs calls for improvement.

CONCLUSION

Riparian landscapes constitute extremely vulnerable ecosystems. They need protection to preserve the unique aquatic habitats with their biodiversity richness and ecological processes as well as their value for scenic and recreational purposes. In spite of that, their protection in Israel is defective, lacking comprehensive suitable legislation, a statutory institutional structure on a national scale and a sectorially designated NOP. The existing state of affairs is characterized by a complex array of authoritative powers, some split and others overlap, and by deficiencies in formulation and implementation of policies. Only limited segments of specific riparian landscapes may, in fact, be regarded as functional healthy ecosystems.

Several lessons can be drawn from the above discussion. We wish to focus here on those that seem the most important and practical for the State of Israel in the immediate future. First, there is need for a revision of present legislation, integrating together existing laws – mainly Drainage Law and RA Law – rephrasing their aims and directives, and rearranging the institutional structure and its powers according to updated environmental and other needs. This should be done considering a whole watershed approach as has already been suggested by Laster (1995).

Second, the prevailing, rather particularistic, approach should be replaced by a comprehensive centralized one, based on a vision and needs on a national scale. This ought to be reflected in all types of protection tools but especially in the institutional structure, as by establishing a national statutory designated organization (similar to the Nature and Parks Authority) or, alternatively, empowering the existing RAD by adequate legislation, including broader definition of its powers and duties.

Third, increasing environmental awareness in general, and awareness of riparian landscapes' ecological, environmental and scenic aspects in particular, are a key element in promoting protection and conservation of such landscapes. This is true for the general public, as has already been claimed by Lowry (1998), but is even more important where decision makers are concerned. Therefore, educational activities, formal and informal, carry great significance for improving and intensifying riparian protection efforts.

Finally, there is hope for riparian landscapes, even when severely deteriorated, providing suitable protection, restoration tools and a plan of action (see for instance: Harnik 2007, Kirk 2005, Tjallingii 2000). This is especially important in a small, densely populated and dry land like Israel.

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HYDRAULIC CHARACTERIZATION OF AQUIFER(S) AND PUMP TEST DATA ANALYSIS OF DEEP AQUIFER IN THE ARSENIC AFFECTED MEGHNA RIVER FLOODPLAIN OF BANGLADESH

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ABSTRACT

To determine the hydraulic characteristics of aquifers and development potential of deep aquifer for sustainable long-term use, study was undertaken by assessing water levels of different aquifer formations and conducting pumping test in deep aquifer under Meghna floodplain area of southeastern Bangladesh. Because of arsenic contamination in shallow groundwater, characterization of deeper aquifers and assess their hydraulic connectivity is now an important issue in Bangladesh. Study shows that groundwater pumping for irrigation and other uses cause large seasonal water level fluctuations that is between 2 and 4.5m, 6.5 and 11m and 6.5m in the shallow, main and deep aquifers, respectively. The trend of groundwater level fluctuations supports the hydraulic connectivity of these aquifers. Aquitards separating aquifers are not continuous regionally. This implies that uncontrolled development of deep aquifers may cause leakage of arsenic from contaminated shallow depths to aquifers below. Water levels dropping below sea level for over withdrawal may also cause saline water intrusion as well. However, during the constant-discharge pumping test for deep aquifer, water levels in observation wells open to the shallow and main aquifers showed no noticeable effect from pumping i.e. under conditions of moderate groundwater use for public supply, arsenic-rich groundwater in the shallow aquifer are not likely to be drawn into the deep aquifer. The transmissivity values of the aquifer is generally favorable for groundwater development and ranged from about 1,070 m^2/day to 2,948 m^2/day at a distance of 44 m from the pumped well. Transmissivity ranged between 1,570 m^2/day and 2,956 m^2/day at a distance of 120m. Transmissivity was calculated as 2,385 m^2/day using recovery data. Estimated storage coefficient values ranged between 0.0000375 and 0.00268, indicates that the aquifer is confined to leaky-confined or semi-confined in nature.

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Keywords: Arsenic contamination, groundwater level, irrigation abstraction, fluctuation, aquifer test, transmissivity, storage coefficient.

NOTATION

c	*D'/K'*: hydraulic resistance of the semi-pervious layer (day)
L	$\sqrt{Tc}$: leakage factor (meter)
Q	constant discharge rate at the well (meter^3/day)
r	radial distance from the pumping well (meter)
s	drawdown at the well (meter)
S	aquifer storage coefficient
S'	is the residual drawdown (meter)
s_m	maximum drawdown (meter) in a piezometer at distance *r* (meter) from the pumped well
Δs	the drawdown per log cycle of time (meter)
T	transmissivity of the aquifer (meter^2/day)
t	time from the start of pumping (minutes)
t'	time from the cessation of pumping (minutes)
t_0	time, where the straight line intersects the zero-drawdown axis (minutes)

INTRODUCTION

Groundwater is the main source for drinking and irrigation water in the lower floodplain areas of south-eastern Bangladesh and mainly withdrawn from shallow aquifer. The upper aquifer system of the area can yield large quantities of water, however, is not completely suitable for sustainable development because of quality problems. The arsenic contamination of shallow (generally up to 50m depth) groundwater has changed the potentiality of it's use. Besides, high concentration of iron, manganese and salinity at different depth levels of main aquifer makes it unsuitable for drinking use. Considering the increasing demand for municipal and rural water supplies, agricultural, industrial and other uses and quality problems in shallow and main aquifers, development of deep aquifer has already been started in some areas. However, before large scale withdrawal of groundwater from deep aquifers, understanding the natural distribution of groundwater for long term sustainability is very important. Sustainable yield from aquifers, effective use of the water stored in aquifers, preservation of water quality, and movement of water between different aquifer formations into a comprehensive management system needs to be studied carefully. Rapid and uncontrolled development of the deep aquifer could severely limit the usefulness and the productive duration of the aquifer.

Groundwater levels of different aquifers were monitored throughout Kachua upazilla (sub-district) area under Chandpur district and an aquifer test was conducted for the deep aquifer at Sreerampur village of Kachua to determine the aquifer hydraulic characteristics, potability of the aquifer system, and the response of the deep aquifer pumping to upper aquifers and to development stresses. In particular, it is essential to understand whether pumping stresses can induce arsenic contaminated water from the shallow aquifer or high salinity water from depth or the shallow aquifer to migrate into the aquifer. The electric conductivity (EC) of water pumped from the production well was also monitored during the test to determine if higher salinity water was being captured by the well during the test. The long-term constant-discharge pumping test was performed as the aquifer properties determined from the analysis of constant-discharge pumping test represent the regional hydraulic properties (Nury et al, 1998) in alluvial aquifers like Bengal Delta.

STUDY AREA

Most of Bangladesh including the study area lies within Bengal basin which began forming during the Late Mesozoic as the continental landmass of Gondwana fragmented and continued to form during the Tertiary when the Indian plate collided with the Eurasian plate resulted in the formation of the Himalayan ranges. The Bengal basin contains a 15-km to 22-km thick sequence of Cretaceous to Recent sediments and occupies some 100,000 km^2 of lowland floodplain and delta (DPHE-BGS 2001). Alluvial deposit carried by the Ganges-Bramaputra-Meghna (GBM) river systems have gradually built up the delta and Meghna estuary (Brammer 1996). Physiographically, the study area lies within Meghna estuarine floodplain under Tippera surface (Morgan et al. 1959) that is bounded by the Meghna river in the west, Lalmai hills in the east and Old Meghna estuary at its south. The total discharge of the lower Meghna river was contributed from the eastern territory and the huge discharge hit the western bank and caused erosion in the western bank and subsequent deposition in the eastern bank towards the study area (Hussain and Huq 1998). The surface of the sequence, composed of silt, silty clay, silty loam and grayish clay, has been assigned to the Chandina Formation (Bakr 1977), while the status of the underlying medium sand aquifer is not well known. The Geological Survey of Bangladesh (GSB) has dated the surface of the Chandina deltaic plain as between 3,000 and 6,000 years. The underlying sands locally contain brackish water and may belong to the Dupi Tila Formation.

Based on elevation and morphological features the area is divided into three units (BWDB-USGS 2005). Southeastern part of the upazilla has been defined as Chandina Alluvium High that always remains above normal flood level. The sediments mainly consist of clayey silt, silty clay and very fine sand. Below this oxidized zone grey colored fresh sandy silt and fine sand are present. The northwestern and southwestern part have been defined as Chandina Alluvium Medium. This part normally remains under water for about 3 to 4 months. Maximum and minimum elevation of this unit is 6.0 and 4.6 m above mean sea level (AMSL) respectively. The northeastern and central-western part of the area is defined as Chandina Alluvium Low. The surface remains under water for longer periods than the other units. In part of the southeast Bangladesh, multi-layered aquifer conditions exist. On a regional basis BWDB-UNDP (1982) described three aquifers between Holocene and Plio-Pleistocene formations. In Kachua area aquifers may be classified as; (Figure 1), (a) the shallow (1^{st}) aquifer, extends down to 40 to 80m, below the 3 to 6 m thick upper clay and silt unit.

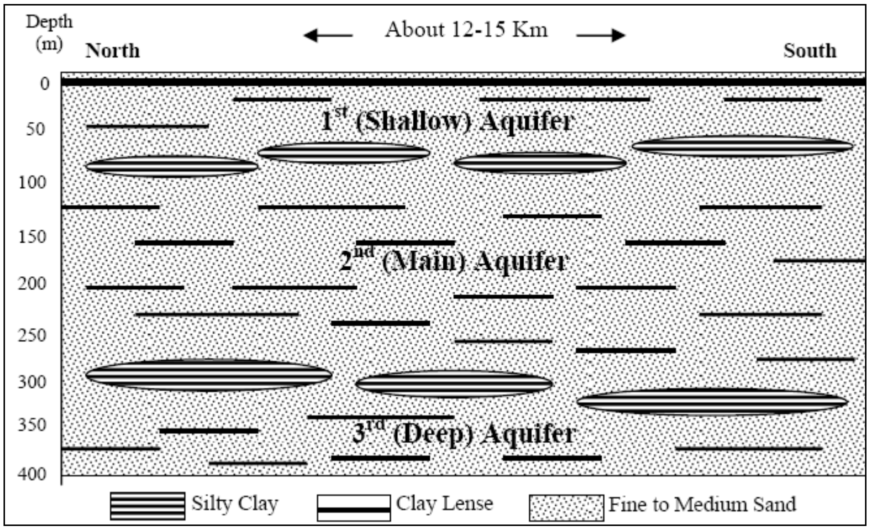


Figure 1. Aquifer system under Kachua Upazila area (Zahid et al 2007).

The aquifer sediments are composed of sand with lenses of clay. Water of this unit is severely contaminated by arsenic, (b) the main (2^{nd}) aquifer, extends down to 250 to 350m and is generally underlain and overlain by silty clay bed, and composed mainly of fine to medium sand, grey to light brown in color, occasionally inter-bedded with clay lenses. It is either semi-confined/leaky or consists of stratified interconnected, unconfined water-bearing zones. Irrigation water in drawn predominantly from these strata, and (3) the deep (3^{rd}) aquifer, encountered to depths of 400m below a 10 to 15m thick silty clay bed. This aquifer is composed mainly of grey to dark grey fine to medium sand that in places alternates with thin sandy shale/clay lenses. This deeper water bearing unit is separated from the overlying main aquifer by one or more clay layers of varied thickness.

Methodology of the Study

Observation of Water Levels in Different Aquifers

1998 to 2003 groundwater level data of 4 Bangladesh Water Development Board (BWDB) monitoring wells (20-30m deep) installed in the shallow aquifer (Table 1), 2004-05 to 2005-06 data of 13 selected Department of Public Health Engineering (DPHE) hand tubewells (180-225m deep) installed in the main aquifer (Table 2) and 2003 to 2004 data of 2 BWDB deep monitoring wells (336-352m deep) installed in the deep aquifer (Table 3) were used to asses the response of groundwater level above or below mean sea-level (MSL) considering recharge and withdrawal for different uses. Locations of monitoring wells are shown in Figure 2.

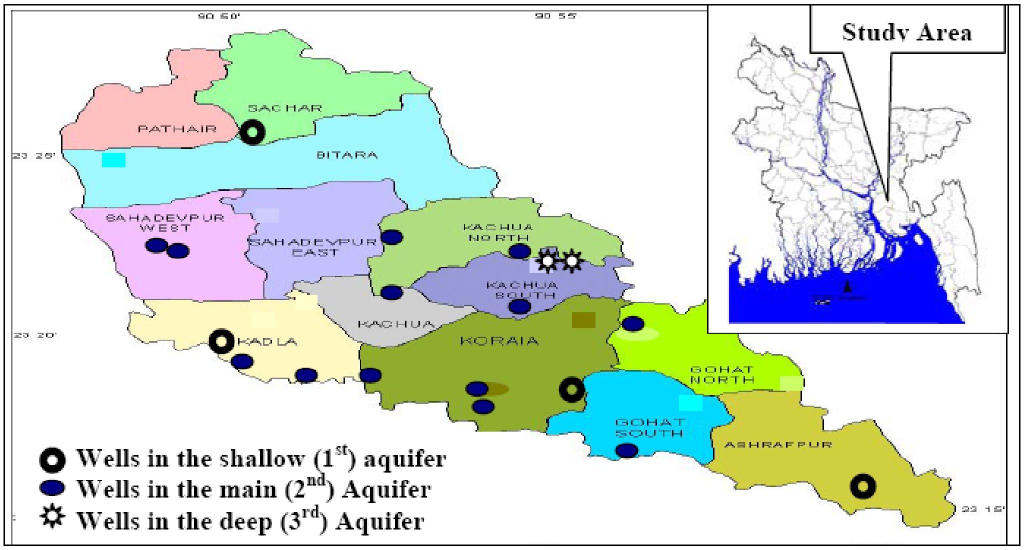


Figure 2. Location of groundwater level monitoring wells.

Table 1. Information on BWDB observation wells screened in shallow aquifer

Location	Latitude (North)	Longitude (East)	Depth (m)	Measuring point (m) Above MSL
Jagatpur	231555.0	910000.0	19.20	12.70
Machimpur	231897.7	905532.1	27.44	6.48
Sacher	232649.6	905051.2	27.44	5.36
Muradpur	232000.0	905000.0	28.66	6.53

Table 2. Tube wells selected for monitoring groundwater movement in main aquifer

Location	Latitude (North)	Longitude (East)	Depth (m)	measuring point Above MSL (m)
Nalua, Karaia	231827.3	905440.7	215	6.288
Sahedapur, Karaia	231833.6	905456.4	215	6.376
North Dumuria, Karaia	231906.1	905240.9	220	5.848
Hossainpur, Kachua South	232123.7	905515.9	220	7.016
Ghagra, Kachua South	232134.5	905222.8	218	6.335
Tetaia, Kachua North	232249.4	905331.4	213	6.317
Ujani, Kachua North	232219.0	905522.0	211	6.28
Hasimpur, Gohat North	232006.9	905651.1	191	6.342
Gobindapur, Gohat South	231724.1	905638.8	218	6.649
Singua, Sahadevpur West	232303.3	904953.9	223	5.992
Khilmeheb, Sahadevpur West	232342.0	904942.8	220	6.236
Kadla, Kadla	231852.7	905128.9	210	5.987
Chaumuhari, Kadla	231946.9	904946.6	225	7.188

Setting of Pumping Well and Observation Wells

For a well performance test, yield and drawdown are recorded to calculate the specific capacity of the well. The aquifer test at Sreerampur village was conducted mainly to provide data from which the principal factors of aquifer performance [transmissivity (T) and storage coefficient (s)] can be calculated. An aquifer test with the setup of a 365-m deep pumping well with a constant discharge of 708 gpm (gallons per minute), and 5 (five) observation wells installed at different depth levels from 25 to 352 m (Figure 3, Table 3), were performed to obtain a picture of the general hydraulic properties of the aquifer and also to predict the effect of withdrawals on the aquifer system, the drawdown in the tested well with time, and different discharges and the radius of the zone of influence for individual or multiple wells. In a uniform and homogeneous aquifer the piezometer should be installed at about the same depth as the middle of the well screen in the pumped well. Amongst observation wells, two have been installed in the pumped aquifer and others are above the confining layer that separates the two aquifer systems. The test continued for 98.5 hours and water levels were measured in both the pumped well and five piezometers. The constant-discharge pumping test was followed by recovery test. Important water quality parameters were also monitored and samples were collected at different time intervals during the test.

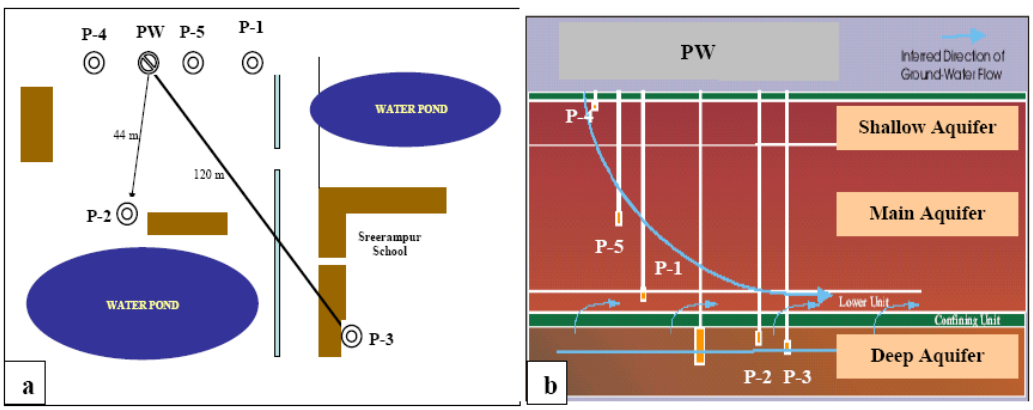


Figure 3. (a) Location and (b) position of pumping well and observation well screens.

Table 3. Major features of pumping and observation wells

Well ID	Aquifer	Depth (m)	Screen length (m)		Diameter of well (m)	Distance from PW (m)	measuring point (m) Above MSL
			From	To			
PW	Deep	365	326	362	0.35	0	6.84
P-1	Main	281	269	278	0.076	14.5	6.3
P-2	Deep	336	324	333	0.076	44.1	6.94
P-3	Deep	352	333	349	0.076	105	6.28
P-4	Shallow	25	20	23	0.076	7.5	6.72
P-5	Main	183	171	180	0.076	9.25	6.54

The flow rate of 3,860 m^3/day was determined using standard tables for the discharge pipe diameter considering a water height of 8.33 m in a manometer attached to the side of the pumping-well discharge tube. The rate at which the discharge water stream dropped from the horizontal was also measured. A flow rate of 3880 m^3/day was determined using standard tables that relate the rate of fall to discharge. The two methods were in good agreement and an average value of 3870 m^3/day flow was used to analyze the aquifer-test data.

The constant-rate test for the time duration of 98.5 hours was conducted at Sreerampur. The pumping rate was estimated and monitored using two different methods. The circular orifice weir was used to measure and monitor the discharge rate of the pump. The height of the water column, the static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various intervals during the pumping period, and time the pump stopped were recorded. Measurement of water levels after the pump stopped (recovery data) were also measured as these are extremely valuable to verify the aquifer storage coefficient calculated during the pumping phase of the test. The test was started on November 13, 2003 at 12:00 noon. Before the test began, water level transducers were placed in the pumping and observation wells. Drawdown was also recorded manually by measuring tapes. To obtain better and more reliable results pumping continued till the depression cone had reached a stabilized position. The depression cone continues to expand until the recharge of the aquifer equals the pumping rate.

Best Fit Analytical Methods for Pump Test Data

Amongst different analytical methods, it is important to select a numerical solution which is more appropriate to actual field conditions. Two analytical solutions were studied in detail to determine the most appropriate solution to the deep observation well aquifer-test data. The Papadopolous-Cooper (1967) solution for a confined aquifer with well-bore storage and the Hantush-Jacob (1955) solution for a leaky confined aquifer were determined to be the best choices. Besides, Jacob (1950) straight line plot was drawn manually and Jacob (1950), Chow (1952) and Theis recovery methods were applied using computer programs developed by Abdin (2004) for manually measured drawdown data.

The following assumptions and conditions were considered for analyzing aquifer-test data using different methods valid for confined or leaky-confined aquifer.

- All geologic formations are horizontal and the aquifer has a seemingly infinite areal extent. In reality, hydrogeologic settings rarely have aquifers that can be considered of infinite areal extent, rather they change laterally in grain size, shape or lithology that affect the shape of a time-drawdown curve. Although such aquifers do not exist in lower delta, many aquifers are of such wide extent that all practical purposes they can be considered infinite.
- The aquifer is homogeneous, isotropic and of uniform thickness over the area influenced by the pumping test. Homogenous aquifers seldom occur in lower delta of Bengal basin and most aquifers are stratified to some degree. As a result of this stratification the drawdown observed at a certain distance from the pumped well may be different at various depths within the aquifer, because of differences in hydraulic conductivity in vertical and horizontal direction. These differences in drawdown diminish with increased pumping itme.
- Groundwater has a constant density and viscosity.

- Prior to pumping, the piezometric surface were nearly horizontal over the area influenced by the pumping test.
- The aquifer was pumped at a constant discharge rate of about 3870 m^3/day,
- All changes in the position of the potentiometric surface were due to the effect of the pumping well alone,
- Pumping well was 100% efficient

Another important assumption is that the pumped well fully penetrations the aquifer and thus receives water from the entire thickness of the aquifer by horizontal flow. If the well only partially penetrates the aquifer, like Sreerampur study, the flow paths have a vertical component to them. The flow paths are, therefore, longer and converge on a shorter well screen, resulting in an increase in head loss (Driscill 1986). However, observation wells for pumping tests were placed far enough away from the pumping well to avoid partial penetration effects. If the observation well is partially penetrating and more than $1.5b(K_h / K_y)0.5$ away from the pumping well, the effects are negligible (Hantush 1964) (b is the saturated thickness, K_h and K_v are the horizontal and vertical hydraulic conductivities). This condition is valid for Sreerampur aquifer. If this condition is not satisfied, there will be an upward inflection in the response, similar to that obtained in the leaky method or for some sort of recharge boundary (Domenico and Schwartz 1997).

Theis Method for Predicting Drawdown in a Confined Aquifer

A major advance was made by Theis (1935), who was the first to develop a nonsteady-state formula which introduces the time factor and the storage coefficient. Theis developed the analytical solution for flow to a well in a confined aquifer. This is generally the base of other methods applied to similar conditions. Theis noted that when a well penetrating an extensive confined aquifer, is pumped at a constant rate, the influence of the discharge extends outward with time. The rate of decline of head, multiplied by the storage coefficient and summed over the area of influence, equals the discharge. Because the water must come from a reduction of storage within the aquifer, the head will continue to decline as long as the aquifer is effectively infinite. Since all sources of recharge are moving through a semi-confining unit, the flatness of the recharge effect on a Theis curve will continue in a horizontal manner (Lohman 1979). However, when the semi-confining layer is saturated and has a head higher than the head in the aquifer being pumped, this head differential may cause the aquitard to release water from storage in an attempt to reach equilibrium (Weight and Sonderegger 2000). As in the semi-confining scenario, the initial drawdown tends to follow the confined Theis curve. As the aquifer becomes stresses and the head lowers in the pumping well, the head change stimulates leakage from above and below to act as recharge to the system. The result is a flattening of the curve rather than following the Theis curve.

Besides the assumptions mentioned above the following assumptions are also considered for Theis solution.

- Aquifer is fully confined and discharge is derived exclusively from storage in the aquifer.

- The flow to the well is in unsteady state, i.e. the drawdown differences with time are not negligible nor is the hydraulic gradient constant with time.
- The water removed from storage is discharged instantaneously with decline of head.
- The storage in the well can be neglected.

The nonsteady-state or Theis equation which was derived from the analogy between the flow of groundwater and the conduction of heat for predicting drawdown (s) at the well is as follows:

$$s = \frac{Q}{4\pi T}\int_{u}^{\alpha}\frac{e^{-y}dy}{y} = \frac{Q}{4\pi T}W(u) \text{ and, consequently } T = \frac{Q}{4\pi s}W(u)$$

The well function $W(u)$ is the infinite series part of the analytical solution to the nonsteady, radial groundwater flow equation that is approximated by:

$$W(u) = -0.577216 - \ln u + u - \frac{u^2}{2\bullet 2!} + \frac{u^3}{3\bullet 3!} - \frac{u^4}{4\bullet 4!} + ...$$

where, $u = \frac{r^2 S}{4Tt}$ and, consequently $S = \frac{4Ttu}{r^2}$

u determines the radius of a cone of depression (Theis 1940). The radius not only increases with increasing time but, for a given time, is larger for decreasing values of storativity and increasing values of transmissivity. Theis' type curve *u* versus *W(u)* is unique only because it pertains to a particular set of conditions at the pumped well and in the aquifer (Stallman 1976).

RESULTS AND DISCUSSION

Water Level Fluctuations in Different Aquifers

Long-term groundwater hydrograph of four of BWDB wells, installed in the shallow aquifer, show maximum depth to water table in dry season and in the monsoon it regains (Figure 4). No permanent declining is observed. The average maximum and minimum water level was observed as 6 and 0.5m above MSL respectively (Table 4). Seasonal groundwater table fluctuation ranges in between 2 and 4.5m in the Upazila area. Generally, groundwater withdrawal from shallow aquifer for domestic purposes and during dry period by shallow irrigation wells is balanced with the vertical percolation of rain water and inflow from surrounding aquifers in monsoon.

Table 4. Average groundwater levels above or below mean sea-level in different aquifers

Aquifer Formation	Nos. of Wells	Depth of Wells (m)	Groundwater Level (m)		Fluctuation (m)	
			Maximum	Minimum	Maximum	Minimum
Shallow (1st)	04	20-30	6	0.5	4.5	2
Main (2nd)	13	180-225	4	-8	11	6.5
Deep (3rd)	02	336-352	4.5	-2	6.5	6.5

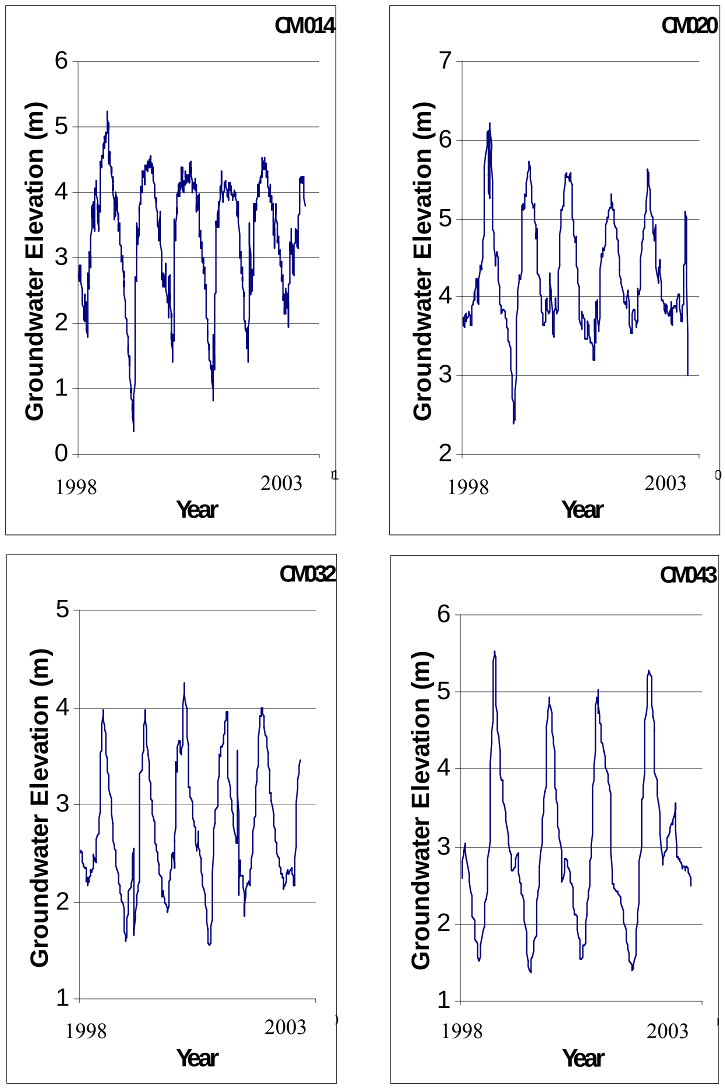


Figure 4. Groundwater level hydrograph of four BWDB wells screened in shallow aquifer at Kachua sub-district.

There is a clear difference between the amount of water that can potentially recharge the aquifer system and the actual quantity. Actual recharge is the quantity of water when the groundwater table has risen to the ground surface and no more water can enter the aquifer system. Its quantity depends on the degree of depletion of this reservoir during the dry season.

Potential recharge is the maximum amount of recharge that can occur if enough storage reservoir in the aquifer system is available. Any surplus rainfall is then rejected and contributes to surface flooding. The ultimate limit on groundwater development is controlled by the long-term average amount of potential recharge. Assessment done by WARPO (2000) indicates that when the clay is relatively thin, but exhibits low vertical permeability, the piezometric level may drop below the base of the clay. In this case the total gross quantity of groundwater abstracted from the aquifer is balanced by infiltration through the upper clay. When the upper clay varies in thickness, the piezometric level in the aquifer may locally drop below the base of the clay, creating local unconfined conditions within the aquifer and groundwater abstraction is partially balanced by leakage through the clay and partially by unconfined storage change in the aquifer. The recharge to the aquifer, which is the leakage during the period of no abstraction, may be less than the potential recharge, particularly when the vertical permeability is low.

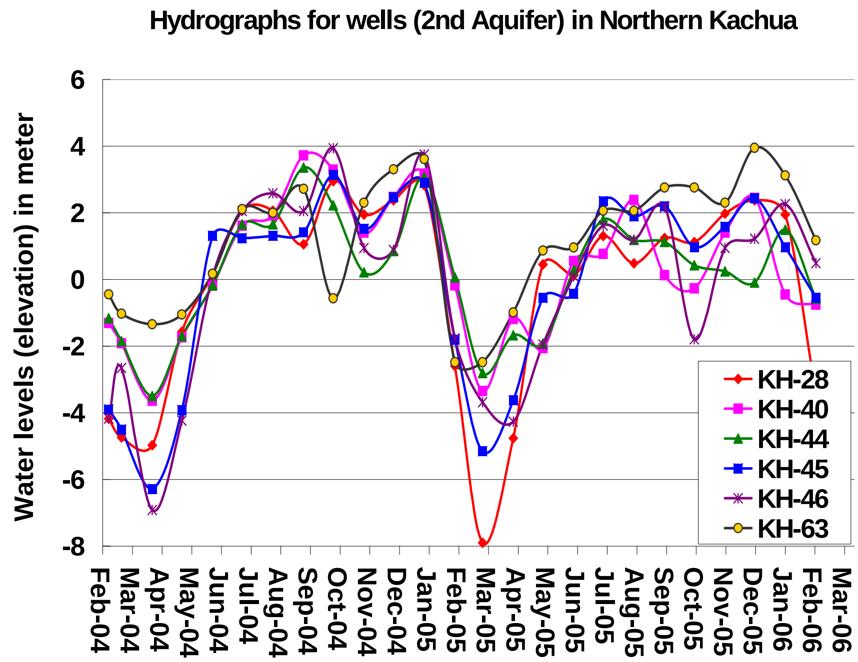
During the peak irrigation season in March and April, the hydrograph is fairly smooth from year to year and steepest rise in the hydrograph is observed immediately after the irrigation pumps are switched off (mid-April to mid-May) rather than at the start of the monsoon (late June) as might be expected. During the monsoon, the hydrographs rise steadily until the levels are within about 1-2m of the surface which indicates that a dynamic equilibrium is established between the water table, deep rooted vegetation and surface water bodies (Ravenscroft 2003). The aquifer full condition i.e. no more storage capacity is attributed before the end of June.

A shallow aquitard is common in this region at depth about 75m. Below this aquitard all deep irrigation wells are installed in the upper part while DPHE domestic and community hand tubewells are screened in the deeper part of main aquifer. Groundwater pumping for irrigation by deep irrigation wells causes large seasonal water level fluctuations (Figure 5), ranges from 6.5 to maximum of 11m (Table 4).

The average maximum and minimum water level was observed as 4 and -8m above and below MSL respectively. Withdrawal by shallow irrigation wells may also influence on huge fluctuation of water level in the main aquifer. However, these levels in the deeper part get recovered rapidly when seasonal pumping stops. This rapid recovery, parallel to water levels in shallow aquifer, reveals that shallow and main aquifers are hydraulically connected and rainfall also contributes recharge to main aquifer through shallow aquifer. However, with intensive abstraction, groundwater levels may fall towards a permanent new equilibrium state.

At Sreerampur village a deep confining layer is encountered at 302 to 320m depth, which is also common in surrounding areas of Meghna floodplain. Only two monitoring wells are installed at entire Kachua area in this deep aquifer. The average maximum and minimum water level of one hydrologic year was observed as 4.5 and -2m above and below MSL respectively (Figure 6a).

Hence the seasonal fluctuation is 6.5m that is less compare to average water level fluctuation of main aquifer (Figure 6b), but still high though the development stress in deep aquifer is almost nil. This huge fluctuation indicates the influence of irrigation withdrawal in upper aquifers.



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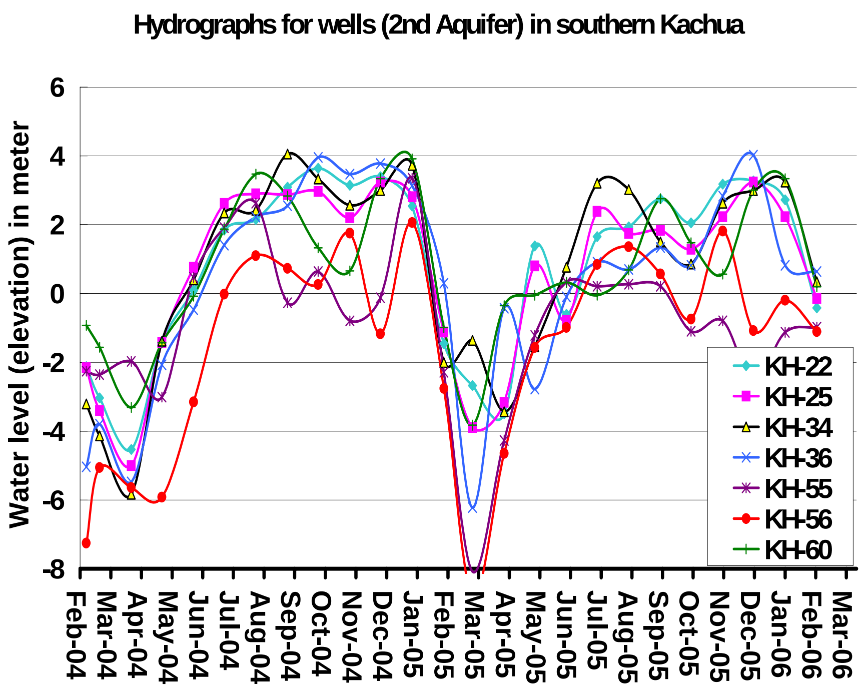

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Figure 5. Groundwater level hydrographs of hand tubewells screened in the deeper part of main aquifer.

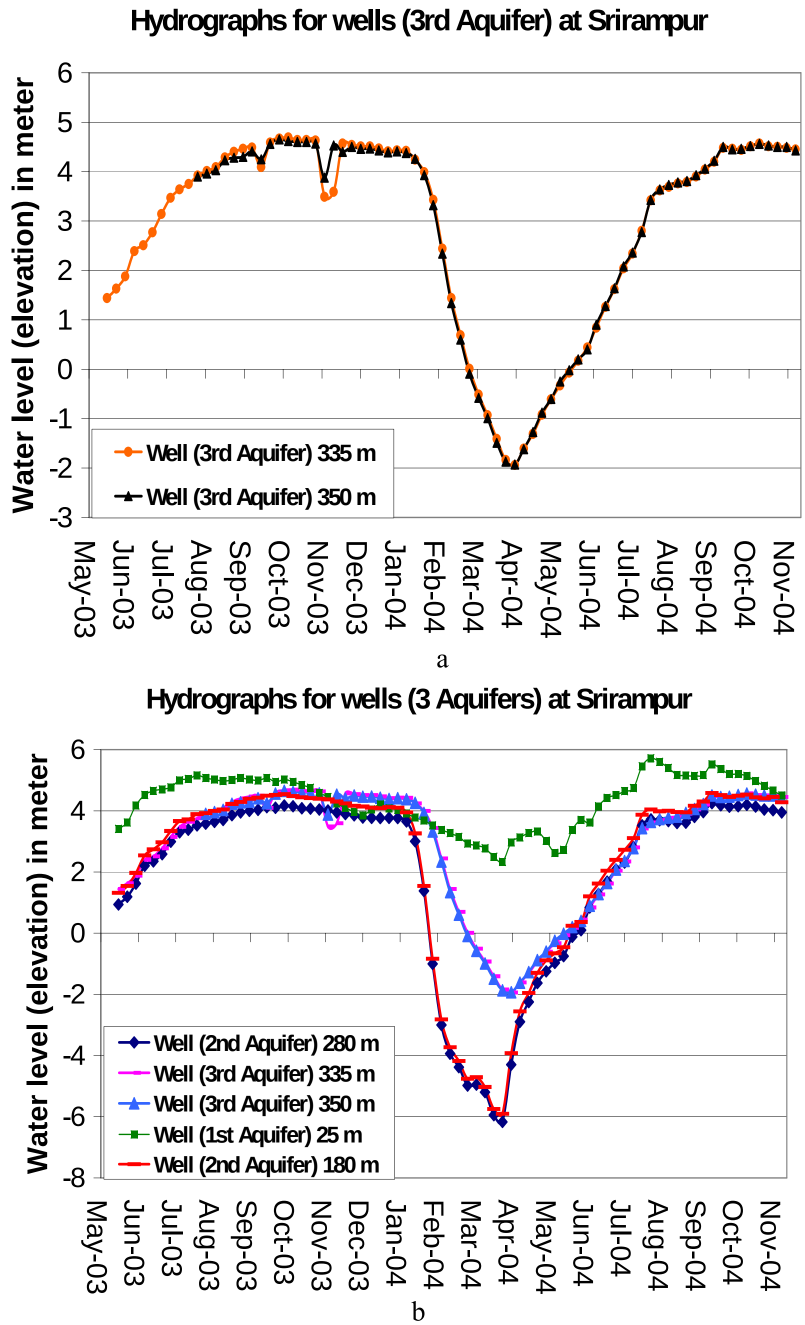


Figure 6. (a) Groundwater level hydrograph of observation wells screened in the deep aquifer; (b) Response of irrigation pumping on water level of different aquifers

In Figure 6b, water level hydrographs of five wells installed in all three aquifers within 500m^2 area are drawn for comparison study. It is clear that maximum water level i.e. static water level is almost same (about 4.5m above MSL) for three aquifers and during irrigation period, all five wells response similarly with different declining intensity. Because of continuous percolation of rain water through unsaturated zone, lowering of water level in shallow aquifer is very low (about 1.0m) that is about 10.5m for main aquifer and about 6.5 for deep aquifer. As most of the irrigation wells are installed in the main aquifer, lowering of water level is highest in this aquifer. However, the trend of water level fluctuations in different aquifers support the hydraulic connectivity of these aquifer i.e. the aquitards separating aquifers are not continuous regionally rather locally extended. This implies that uncontrolled development of deep aquifers may cause both qualitative and quantitative degradation of groundwater. Water levels dropping below sea level for over withdrawal in dry season may eventually cause saline water intrusion as well as leakage of arsenic from shallow aquifer to upper part of main aquifer.

Response of Groundwater Levels to Pumping

The water level in the pumping (deep) aquifer declined abruptly during the first 3 minutes of pumping, then stabilized at about 12.5 to 13.0m drawdown for the duration of the test (Figure 7a). The pumping phase of the aquifer test was terminated after 5,911 minutes (98.5 hours), and data was collected during the recovery phase of the test until 7,168 minutes (119.5 hours) after the test had begun. During the pumping test, water levels in observation wells open to the shallow and main aquifers showed no noticeable effect from pumping in the deep aquifer (Figure 7b).

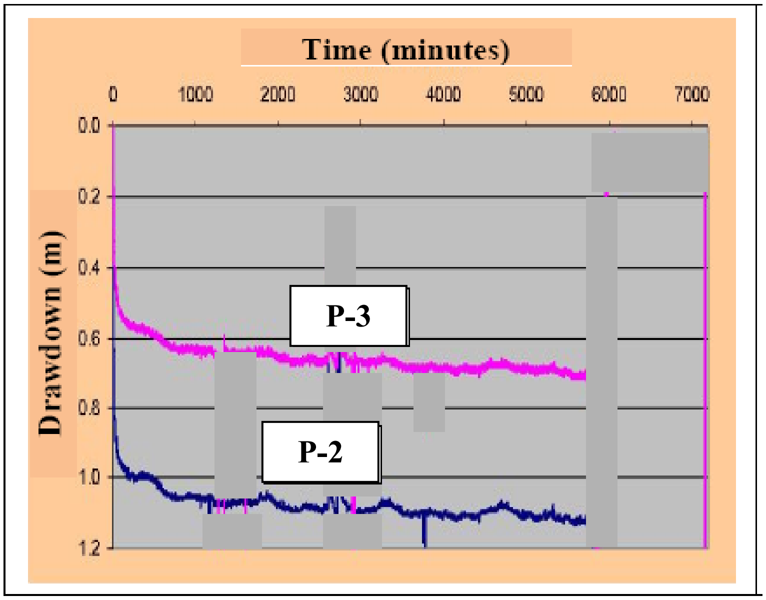
The overall fluctuation of water levels (as caused by factors other than long-term declines or barometric pressure changes) measured in P-1, P-4, and P-5 was less than about 0.04m during the test. This indicates that the 12 to15m confining unit that separates the main and deep aquifer retards the movement of ground water between the aquifers. Therefore, under conditions of moderate groundwater use for public supply, arsenic-rich, iron-rich, and saline ground water in the shallow aquifer are not likely to be drawn into the deep aquifer.

Groundwater levels in the deep aquifer observation wells responded to the withdrawal of water from the pumping well. Water levels in P-2 (44 m from the pumping well) declined about 1.1 m in response to pumping (Figure 7a). Water levels in P-3 (120m from the pumping well) declined about 0.68m in response to pumping. Small fluctuations in the measured water levels may be partly caused by variations in the pumping rate during the test as voltage in the power supply fluctuated.

Water levels in both observation wells rose rapidly at the end of the aquifer test, and had returned to within 0.05m of the pre-test water levels when data collection was stopped. Comparison of water level altitudes in the shallow and deep observation wells shows that water levels in the deeper aquifer were lower than water levels in the shallower aquifer in an area about 100m radius centered on the pumping well after about 3,600 (60 hours) minutes into the test.

Analysis of Drawdown Data

Gunther Theim (1962) published the first formula on the response equation for steady radial flow (Ferris et al. 1962), based on the work of Darcy and Dupuit, and computed the hydraulic characteristics of a water-bearing formation by pumping a well and observing the effect of this pumping in a number of other wells. Now, most of the more or less complicated flow problems can be solved by applying proper mathematical methods. Aquifer test analyses may provide unrealistic estimates of hydraulic properties (Halford and Kuniansky. 2002). However, it makes no difference in performing a test whether response curves are obtained as analytical solutions or by other methods, e.g. flow nets, digital computers, etc (Stallman 1976).



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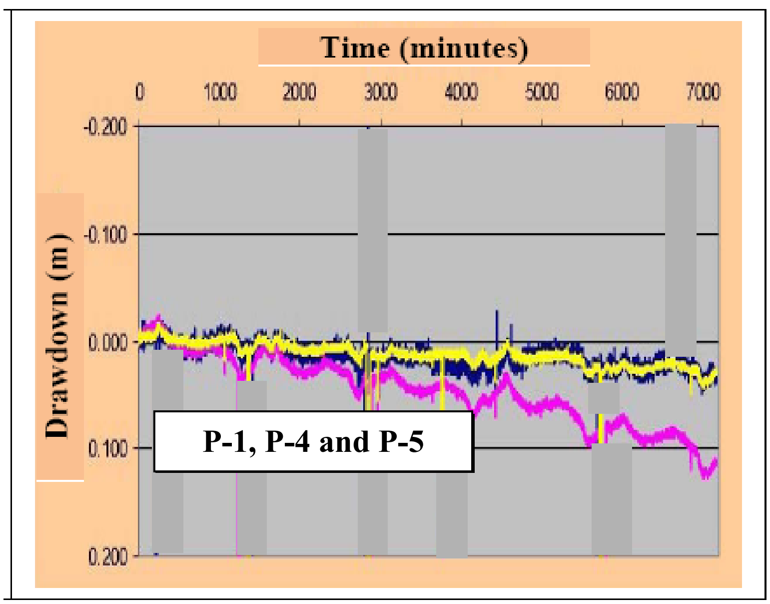

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Figure 7. Monitoring of water level (drawdown) during aquifer test (a) Observation wells in deep (3rd) pumping aquifer below aquitard; (b) Observation wells in upper aquifers.

The investigated deep aquifer under Sreerampur village may be considered as a confined aquifer as it is overlain by a 10 m to 12 m thick nearly-impervious silty clay layer, 295m below the surface. The lower boundary of the aquifer was not encountered above the investigated depth of 362 m; however, from the depositional history of the region it may be assumed that another impermeable formation can exist beneath the tested depth. A confined aquifer is a completely saturated aquifer whose upper and lower boundaries are impervious layers. However, completely impervious layers (aquatard) rarely exist in nature. A semi-confined or leaky aquifer, is a completely saturated aquifer that is bounded above by a semi-pervious layer and below by a layer that is either impervious or semi-pervious. Physically, there is induced recharge during an aquifer test through the semi-pervious layer. The rate of leakance is determined by the hydraulic conductivity of the aquitard and head difference across the aquitard. In a semi-confining scenario, confining units may pinch out laterally and part of the aquifer may become unconfined. This may true for the studied aquifer, too.

Hantush-Jacob Leaky Aquifer Model

For all practical purposes, the time-drawdown behavior before the inflection represents a withdrawal of water from storage from the aquifer, no part of which was contributed from other sources. This part of the curve, along with its straight line extension, may be analyzed with methods discussed for time-drawdown behavior. There are several ways in which this condition may be compromised in field conditions: direct recharge from streams, recharge across bounding low permeable materials etc. The problem of leakage has been extensively investigated by Hantush and Jacob (1955) and Hantush (1956, 1960, 1964). In a leaky aquifer, the drawdown curve initially follows the nonleaky curve. However after a finite time interval, the lowered hydraulic head in the aquifer induces leakage from the confining layer. If there is storage in the confining layer, the rate of drawdown is slower than that in the case where there is no storage in the confining layer (Hantush 1960).

In many aquifer tests, water is contributed from the less permeable confining units, in addition to the aquifer that is pumped (Halford and Kuniansky 2002). Hantush and Jacob (1955) presented a solution for drawdown in a pumped aquifer that has an impermeable base and a leaky confining unit above. Conceptually, this would be a four layer system, from top to bottom, a water table aquifer, a leaky confining unit, a confined aquifer, and an extremely low permeability bed rock. During the early time of pumpage, water is coming out of storage from the pumped aquifer and the leaky confining unit. Eventually, the discharge comes into equilibrium with the leakage through the confining unit from the unstressed water-table aquifer and the system is at steady-state.

The additional assumptions for the analysis are:

- Aquifer is leaky, horizontal flow stressed aquifer, vertical flow through confining unit.
- Drawdown in the water table or unstressed aquifer is negligible.
- Well storage can be neglected.
- Water instantaneously comes out of storage in the aquifer.
- Confining unit storage is negligible.

The equation is based on the drawdown of a well pumped at a constant discharge rate in a leaky aquifer (Hantush and Jacob 1955).

$$s = \frac{Q}{4\pi T} W(u, r/B)$$

where, $u = \frac{r^2 S}{4Tt}$ is dimensionless time,

$$\frac{1}{B} = \sqrt{\frac{K_Z / b'}{T}}$$

K_Z/b' is the leakance *(1/T)*, where K_Z is vertical hydraulic conductivity of the confining unit *(L/T)* and b' is thickness of the confining unit *(L)*.

Early drawdown data from the field curve match the non-leaky part of the curve, but they soon deviate and follow one of the leaky *r/B* curves. The match point method yields values of *w(u, r/B), 1/u, t* and *s*. In addition, the *r/B* curve followed by the field data is noted. *T* and *S* are readily determined from

$$T = \frac{Q}{4\pi s} W(u, \frac{r}{B}) \text{ and } S = \frac{4uTt}{r^2}$$

Unaware of the work done many years earlier by De Glee (1930, 1951), Hantush and Jacob also derived the same equation, which expresses the steady-state distribution of drawdown in the vicinity of a pumped well in a semi-confined aquifer in which leakage takes place in proportion to the drawdown. Hantush (1956, 1964) noted that if *r/L* is small *(r/L≤0.05),* the equation may, for practical purposes, be approximated by

$$s_m \approx \frac{2.30Q}{2\pi T}(\log 1.12 \frac{L}{r})$$

Thus a plot of s_m against *r* on semi-logarithmic paper, with *r* on the logarithmic scale, shows a straight-line relationship in the range where *r/l* is small. The slope of the straight portion of the curve, i.e. the drawdown difference Δs_m per log cycle of *r*, is expressed by

$$\Delta s_m = \frac{2.30Q}{2\pi T}, \text{ consequently } T = \frac{2.30Q}{2\pi \Delta s_m}$$

The Hantush-Jacob leaky aquifer solution was chosen to analyze the aquifer test data because of the possibility that there was some induced leakage of ground water across the confining unit during the test. With the advent of computer programs to analyze aquifer test data, manually plot graphs and calculate aquifer parameters by hand is generally no longer in use. This makes it much easier to analyze the data, but makes much less aware of the assumptions behind the analytical solutions. Drawdown data for the individual deep observation wells can be matched well to about 500 minutes using the Hantush-Jacob solution. Drawdown from about 200 to 500 minutes becomes nearly constant at about 1 m for P-2 and nearly constant at about 0.6 m for P-3. This response may be caused by equilibrium between leakage across the confining unit and drawdown from well pumpage. After about 500 minutes, drawdown in both observation wells begins to increase in an approximately linear manner, at a rate of about 0.00001 m/minute in P-2 and about 0.00002 m/minute in P-3. This may indicate decreased leakage through the confining unit, draining of stored water in a permeable sand lens, or the presence of a lateral barrier. Of the three possibilities, a lateral barrier seems unlikely considering the geological setting.

The best fit curve match (Figure 8a) to P-2 yielded an aquifer storage of 0.0013, aquifer transmissivity of 2,300 m^2/day, vertical to lateral aquifer hydraulic conductivity ratio of 0.0044 (Kz/Kr), and a confining unit vertical hydraulic conductivity of 0.33 m/day ($r/B = 0.1533$). The best fit curve match (Figure 8b) to P-3 yielded an aquifer storage of 0.0022, aquifer transmissivity of 2,956 m^2/day, vertical to lateral aquifer hydraulic conductivity ratio of 0.0044, and a confining unit vertical hydraulic conductivity of 0.43 m/day (r/B = 0.365).

Because the aquifer values are similar for the individual observation well data curve matches, both sets of data can be approximately fit to a single set of values (Figure 8c). The best fit curve match to both observation wells taken together yielded an aquifer storage of 0.0017, aquifer transmissivity of 2,386 m^2/day, vertical to lateral aquifer hydraulic conductivity ratio of 0.0044, and a confining unit vertical hydraulic conductivity of 0.35 m/day ($1/B$ = 0.0035).

The parameter $1/B$ in the Hantush-Jacob solution is related to the confining unit vertical hydraulic conductivity by the relation $Kv' = (T*b')/2B$, where T is the deep aquifer transmissivity and b' is the confining unit thickness. The lateral hydraulic conductivity of the deep aquifer is estimated as 23 m/day using $Kh=T/b$, where b is the aquifer thickness. The vertical hydraulic conductivity of the deep aquifer as determined from the solution derived ratio of the aquifer vertical hydraulic conductivity to aquifer lateral hydraulic conductivity ($Kz/Kr = 0.0044$) is about 0.10 m/day, about 200 times smaller than the lateral hydraulic conductivity of the deep aquifer. This may indicate that the cumulative hydraulic effect of disseminated clay and silt in the aquifer is similar to the clay-rich confining unit.

During the long-term monitoring period from May 2003 to November 2003 water levels in P-2 (deep aquifer) were from 0.15 m to 0.60 m higher than water levels in P-1. Therefore, under natural flow conditions experienced during the summer months, the groundwater gradient is upward from the deep aquifer to the shallow aquifer, and the specific discharge through the confining unit is estimated to be from about 0.004 m/day to about 0.017 m/day. Assuming a porosity of 0.30, the average velocity of water through the 12.2 m thick confining unit is 0.014 m/day to 0.057 m/day. The time for groundwater to move through the confining unit under these gradients at the estimated average velocities range from about 200 days to about 850 days.

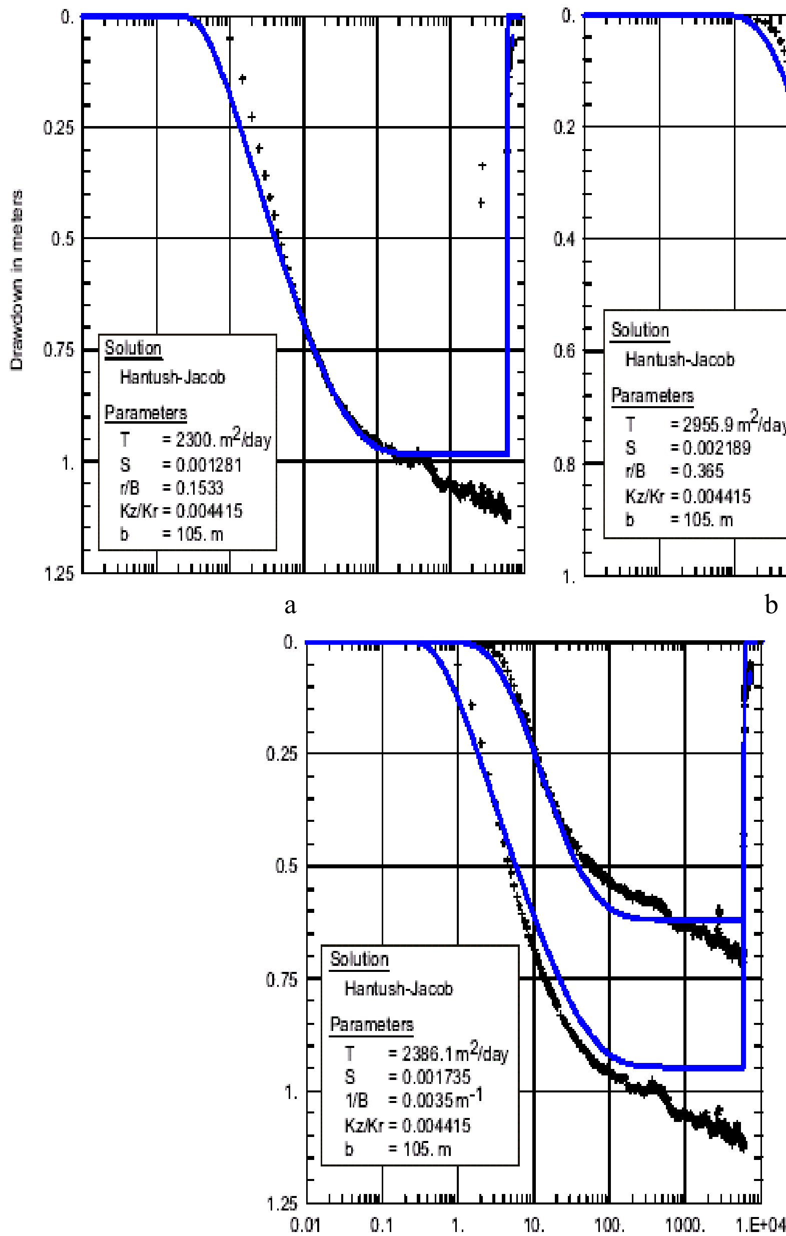

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Figure 8. Best fit Hantush-Jacob solution to drawdow.n data in semilog scale collected from (a) P-2; (b) P-3; (c) Average drawdown data for P-2 and P-3.

Papadopulos-Cooper Solution to Drawdown Data

A solution for drawdown in large diameter wells that takes into consideration the storage within the well, which is assumed to be negligible in the Theis method, has been presented by

Papadopulous and Cooper (1967). Besides the general assumptions mentioned earlier, the added conditions are

- Storage in the well cannot be neglected as well diameter is relatively large.
- The aquifer is confined.
- The well losses are negligible.

The general flow equation inside a large diameter well is (Kruseman and Ridder, 1983),

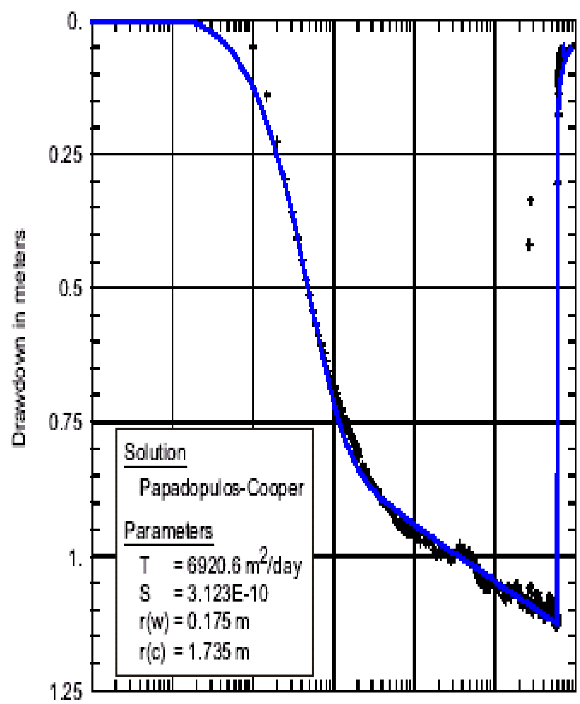
$$s_w = \frac{Q}{4\pi T} F(u_{w,} \beta)$$

where $F(u_{w,} \beta)$ is a function for which numerical values are given.

$$u_w = \frac{r_w{}^2 S}{4Tt} \text{ and } \beta = \frac{r_w{}^2 S}{r_c{}^2}$$

The index *w* stands for 'at the pumped well' and r_c is the radius of the unscreened part of the well.

The best visual fit to the complete data sets, using each observation well individually, is the Papadopolous-Cooper solution (Figures 9a and 9b). However, the best match for each set of observation well data required aquifer properties and well bore diameters that were not reasonable.



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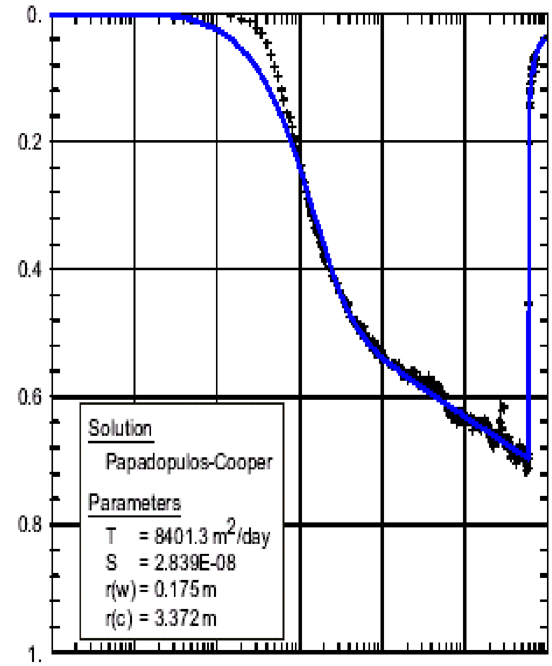

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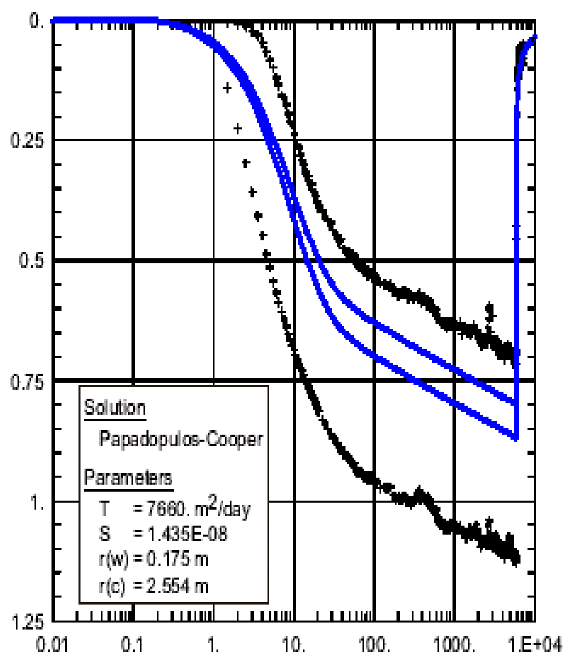

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Figure 9. Best fit Papadopulos-Cooper solution to drawdown data in semilog scale collected from (a) P-2; (b) P-3; (c) Average drawdown data collected from both P-2 and P-3.

Aquifer storage values were extremely small (on the order of 10-9). The size of the well bore needed to match the delayed drawdown response was much larger than the actual bore of the pumping well for both data sets. Both observation well P-2 and P-3 have an actual casing radius of 0.175 m. The predicted casing radius for P-2 was 1.735 m, and for P-3 that was 3.372 m. Also, the transmissivity value predicted from the data for P-2 (6921 m^2/day) differed considerably from the value predicted from the data for P-3 (8401 m^2/day). Because the transmissivity and well-bore radius values predicted from the individual observation well curve matches differed considerably, the drawdown data cannot be matched simultaneously for both observation well P-2 and P-3 using average transmissivity values (Figure 9c).

Jacob's Straight-Line Plot

The Cooper-Jacob (1946) method of time-drawdown and Jacob (1950) method of distance-drawdown are a modification of the Theis equation and assume that *u* is small. However, the conditions for its application are more restricted than for the Theis and Chow method. Cooper-Jacob and Jacob methods are valid where the time (*t*) is sufficiently large or radial distance (*r*) is sufficiently small. The Cooper-Jacob time-drawdown approach is modified to plot drawdowns at various radial distances from the pumping well. By graphing drawdown on a linear scale versus distance on a logarithmic scale, a straight line fit results (Jacob 1950). Estimates of the hydraulic properties can also be made, if the assumption of *u* being sufficiently small (0.02) is valid. The intercept where the straight-line fit crosses the zero drawdown represents the range of influence of the cone of depression (Weight and Sonderegger 2000).

The same assumptions apply to the Cooper-Jacob analytical solution as the Theis solution, but the well function $W(u)$ is calculated for $u<0.01$ in order to neglect all but the first two terms of the infinite series of the well function. A straight-line approximation of $W(u)$ is adequate for most applications even where *u* is as great as 0.1 (Halford and Kuniansky 2002).

In the Theis formula, the exponential integral can be expanded in a convergent series, so that the drawdown (*s*) may be written as (Kruseman and Ridder 1983)

$$s = \frac{Q}{4\pi T}(-0.5772 - \ln u - \frac{u^2}{2.2!} + \frac{u^2}{3.3!}\cdots)$$

From $u = \frac{r^2 S}{4Tt}$ it will be seen that *u* decreases as the time of pumping *t* increases. Accordingly, for large values of t and/or small values of r the terms beyond *ln u* in the series of the equation become negligible. So for small values of *u* (<0.01) the drawdown can be expressed as

$$s = \frac{Q}{4\pi T}(-0.5772 - \ln \frac{r^2 S}{4Tt})$$

After rewriting and changing into decimal logarithms this equation reduces to

$$s = \frac{2.30Q}{4\pi T} \log \frac{2.25Tt}{r^2 S}$$

Therefore, a plot of drawdown versus the logarithm of t forms a straight line. If this line is extended till it intercepts time-axis where s=0, the interception point will have the coordinates $s=0$ and $t=t_0$. Substitution of these values into the drawdown equation gives

$$0 = \frac{2.30Q}{4\pi T} \log \frac{2.25Tt_0}{r^2 S},$$

and because $\frac{2.30Q}{4\pi T} \neq 0$, it follows that $\frac{2.25Tt_0}{r^2 S} = 1$ or $S = \frac{2.25Tt_0}{r^2}$

If t/t_0=10 and hence $\log t/t_0$=1, s can be replaced by Δs, i.e. by the drawdown difference per log cycle of time, and it follows that

$$T = \frac{2.30Q}{4\pi\Delta s}.$$

Jacob straight-line plot was applied to interpret the time-drawdown data for Sreerampur test as time was sufficiently large and radial distance is small. Drawdown recorded manually at selected intervals was used to create the hand-drawn data graph in Figure 10.

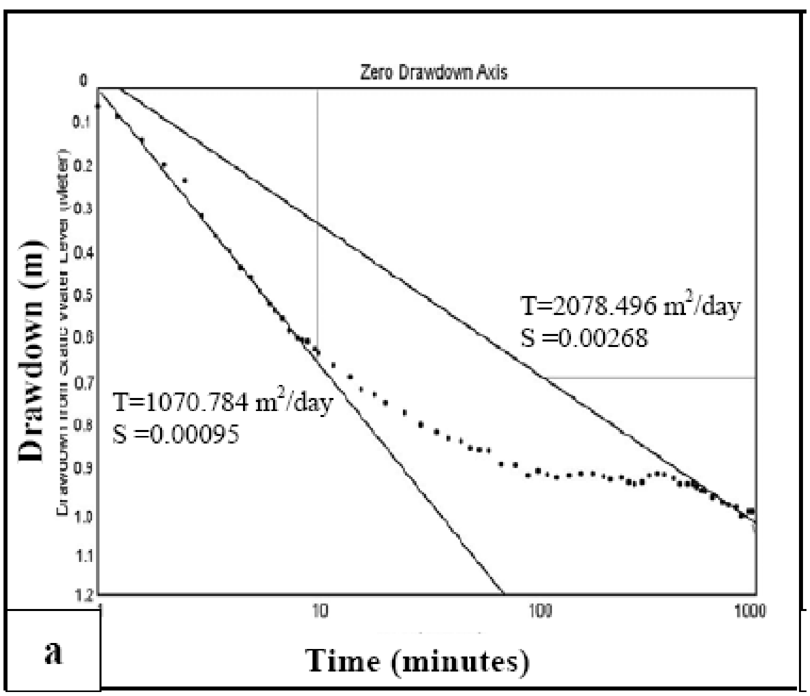

Figure 10. (Continued).

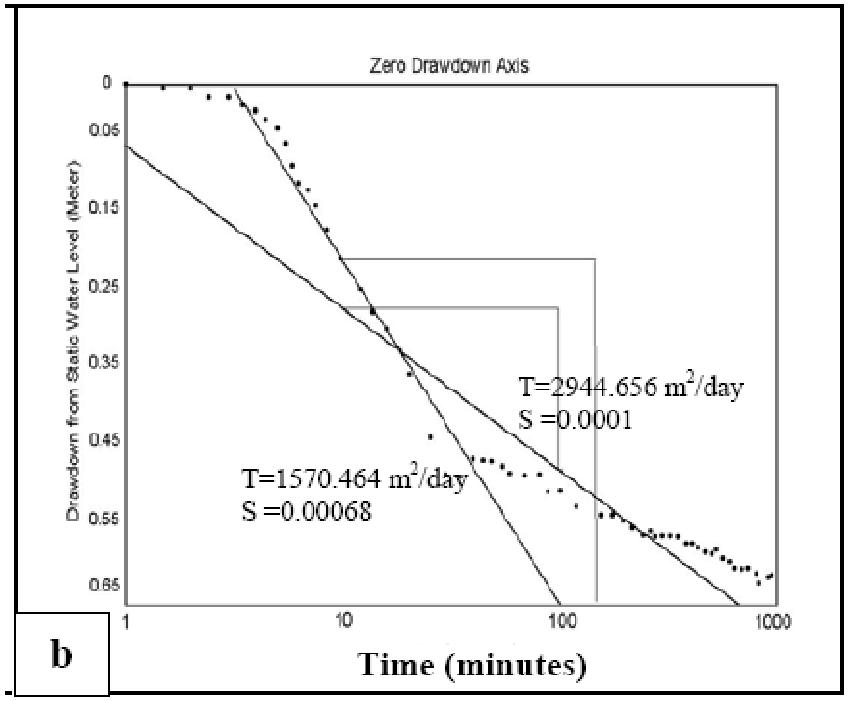

Figure 10. Jacob straight-line time-drawdown method for a confined aquifer plotted on semilog papers for (a) P-2 and (b) P-3.

In this method, the field data are plotted on semi-logarithmic paper and a straight line is drawn through the field data points and extended backward to the zero drawdown axis. This is the distance at which the well is not affecting the water level. It may intercept the axis at some positive value of time (t_0). The value of drawdown per log cycle (ΔS) is obtained from the slope of the graph.

Drawdown of the observation wells installed in the deep aquifer were used to calculate transmissivity and storativity values of the deeper formation. The rate of drawdown after 1000 minutes is negligible because the water table was nearly in the steady condition.

For P-2 two straight lines were drawn and transmissivity and storativity values were calculated as 1,070.784 m^2/day and 0.00095 (first cycle) and 2,078.496 m^2/day and 0.00268 (third cycle) respectively. The average values are 1,574.64 m^2/day and 0.001815 respectively for transmissivity and storativity.

These values are more appropriate as this well (P-2) is within a reasonable distance from the pumped well. Two straight lines were also drawn for P-3 and transmissivity and storativity values were calculated as 1,570.464 m^2/day and 0.00068 (second cycle) and 2,944.656 m^2/day and 0.00010 (third cycle) respectively. The average values are 2,257.56 m^2/day and 0.00039 respectively for transmissivity and storativity. Using computer program, transmissivity and storativity were estimated as 2,468 m^2/day and 0.000546 respectively (Figure 11).

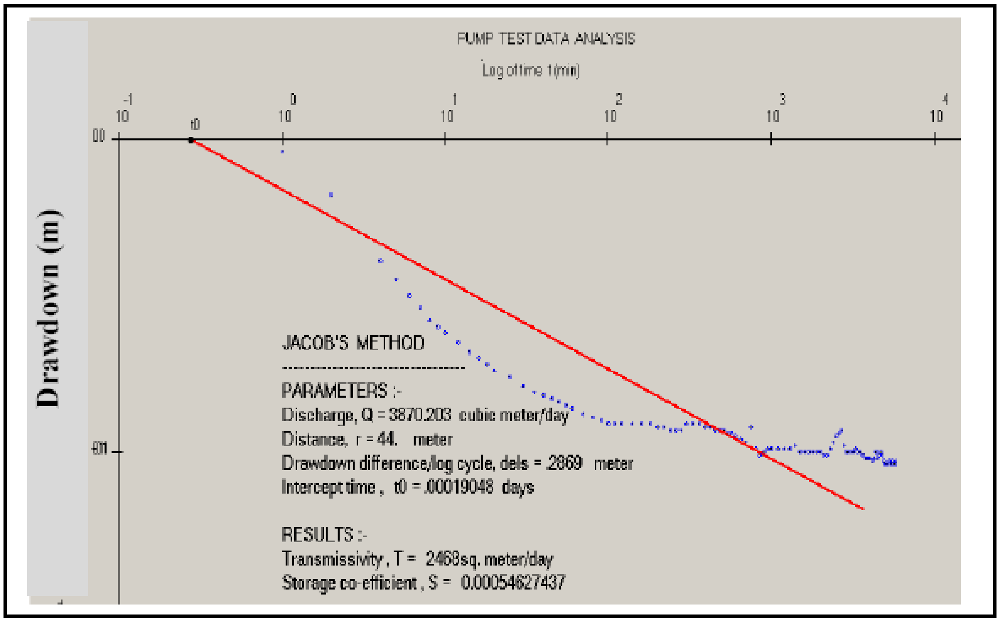

Figure 11. Jacob straight-line time-drawdown method for a fully confined aquifer using computer program for P-2.

Chow's Method

Chow (1952) developed a method which has the advantage of avoiding the curve fitting of the Theis method and not being restricted to small values of r and large values of t as is the Jacob method (Kruseman and Ridder 1983). The same assumptions and conditions are generally satisfied as for the Theis method because this method is directly based on the Theis equation.

$$s = \frac{Q}{4\pi T} W(u)$$

To find the values of *W(u)* and *u* corresponding with the drawdown *s* measured at a certain moment *t*, Chow introduced the function

$$F(u) = \frac{W(u)e^{u}}{2.30}$$

F(u) can be calculated from the drawdown (*s*) versus the corresponding time (*t*) on single logarithmic paper (*t* on logarithmic scale).

Using a computer program, transmissivity and storativity were estimated as 2,948 m^2/day and 0.0000357 respectively (Figure 12).

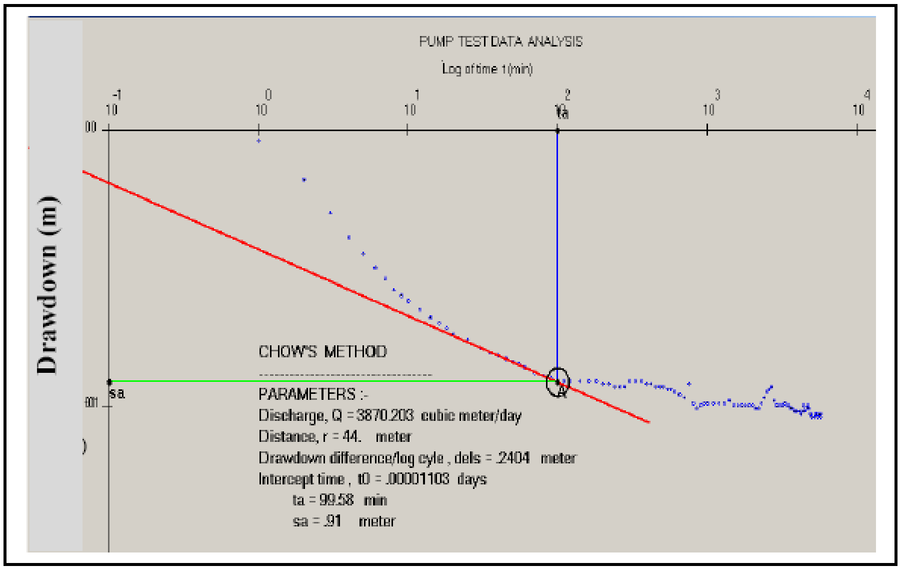

Figure 12. Analysis of data with the Chow method for P-2.

Theis Recovery Data Analysis for Confined Aquifer

The analysis of recovery data involves the measurement of the rise in water levels, also referred to as residual drawdowns, following the cessation of a period of pumping at a constant rate. The field procedure requires a drawdown measurement at the end of the pumping period (t) and recovery measurements during the recovery period (t'). The residual drawdown is plotted on a linear axis and the value of t/t' on the logarithmic axis. The analytical method is based on the Theis theory and applies to confined aquifers with fully penetrating wells. The method relies on the theory of superposition in that the water level rise after the test is assumed to be the combined response to an imaginary well recharging the aquifer and continued pumping. Imaginary recharge occurs at an identical rate to the constant discharge during the pumping test. The equation for residual drawdown after a pumping test with constant discharge is:

$$s' = \frac{Q}{4\pi T}\{W(u) - W(u')\}$$

where, $u = \dfrac{r^2 S}{4Tt}$ and $u' = \dfrac{r^2 S}{4Tt'}$

If u and u' are small, less than 0.01, then the above equation can be simplified to:

$$s' = \frac{2.3Q}{4\pi T}\log_{10}\left(\frac{t}{t'}\right)$$

A semilog plot of s' versus t/t' will yield a straight line. The slope of which is:

$$\Delta s' = \frac{2.3Q}{4\pi T}$$

where, $\Delta s'$ is the change in residual drawdown in one log cycle of t/t'. The same assumptions as for the Cooper-Jacob, straight-line method must be met, and the flow to the well is in an unsteady state when $t' > (25\, r^2 S)T$ and $u < 0.01$.

Using computer program, transmissivity was estimated as 2,385 m^2/day (Figure 13).

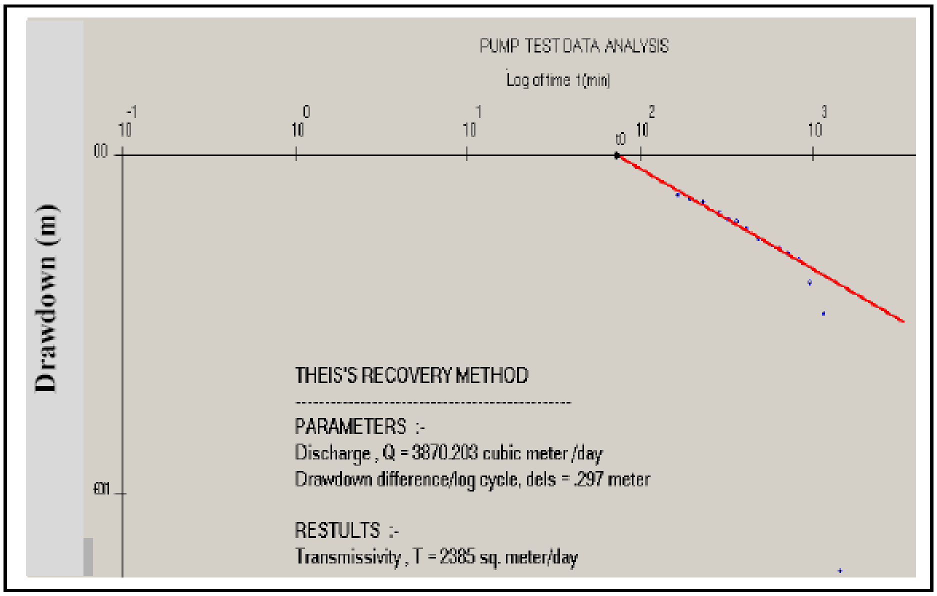

Figure 13. Analysis of recovery data with the Theis recovery method for P-2.

Comparison of Results for Different Methods

The results of the pumping test and recovery data analysis using different methods are presented in table 5. The estimated transmissivity of the aquifer using drawdown data collected at P-2 varied between 1,070 m^2/day for first cycle analysis using Jacob's straight line method and 2,948 m^2/day applying Chow's method from constant-discharge test, to 6921 m^2/day for Papadopulous-Cooper method. For P-3, the estimated transmissivity ranged between 1,570 m^2/day using Jacob's straight line method from second cycle analysis and 2,956 m^2/day using Hantush-Jacob solution, to 8,401 m^2/day using Papadopulous-Cooper method. Because of solution match difficulties, the Papadopolous-Cooper solution was not considered as the appropriate solution to the aquifer-test data.

Transmissivity was calculated as 2,385 m^2/day using recovery data analyzed by the Theis recovery method. As these are graphical methods of solution, there is often slight variation in the results, depending upon the accuracy of the graph construction and subjective judgments in matching field data to type curves (Fetter 1994).

Table 5. Aquifer properties determined from constant-discharge pumping test data using different methods

Method	Transmissivity (m^2/day)		Storage Coefficient	
	P-2	P-3	P-2	P-3
Papadopulous-Cooper	6,921	8,401	-	-
Hantush-Jacob	2,300	2,956	0.0013	0.0022
Jacob (Hand Drawn)				
1st Cycle	1,071	-	0.00095	-
2nd Cycle	-	1,570	-	0.00068
3rd Cycle	2,078	2,945	0.00268	0.00010
Jacob	2,468	-	0.000546	-
Chow	2,948	-	0.0000357	-
Theis Recovery	2,385	-	-	-

The accuracy of the numerical values of the hydraulic characteristics of water-bearing layers and less permeable strata determined during the graphical analyses and the accuracy of the assumed boundary conditions play an important role in the reliability of the results obtained by these methods.The transmissivity values estimated from the Theis curve method and the Cooper-Jacob method are generally are comparable (Weight and Sonderegger 2000), and the resulting answers are almost the same. Well losses and partial penetration have a minimal effect on transmissivity values that are estimated using the Cooper-Jacob method. Additional drawdown at later times is due to declining heads in the aquifer and the rate of decline is controlled mostly by the transmissivity of the aquifer. Analyzing the change in drawdown at later times negates the effect of a fixed offset due to well losses and partial-penetration on the determination of transmissiviy (Halford and Kuniansky 2002).

Estimated storage coefficient values ranged from 0.0000375 to 0.00268 for P-2 and from 0.00010 to 0.0022 for P-3. The estimated storage coefficients indicate that the aquifer is confined to leaky-confined or semi-confined in nature. Bouwer (1978) and Fetter (1994) suggest that storage coefficients for confined aquifer can vary from 0.00001 to 0.001, and Weight and Sonderegger (2000) suggest that storage coefficients for leaky-confined or semi-confined aquifers can vary from 0.001 to 0.03.

The sorting of unconsolidated sediments largely controls the expected range of hydraulic conductivity. Well-sorted sediment has a much larger hydraulic conductivity than poorly-sorted sediment, because finer material fills the voids between coarser grains in poorly-sorted sediment. The hydraulic conductivity of unconsolidated sediment can be estimated empirically from the grain-size distribution (Vukovic and Soro 1992). Hydraulic conductivity estimates from grain-size distributions typically have a greater uncertainty than estimates from aquifer tests (Halford and Kuniansky 2002). Using the Hantush-Jacob solution, the vertical to lateral aquifer hydraulic conductivity ratio was estimated at 0.0044, and the confining unit vertical hydraulic conductivity was estimated at 0.35 m/day. Drawdown in both observation wells becomes constant in the interval from about 200 to 500 minutes.

During the aquifer test, water levels in P-1 were about 0.4 m higher than water levels in P-2. Therefore, under pumping stresses similar to those induced during the aquifer test, the ground-water gradient is downward from the main aquifer to the deep aquifer, and the groundwater flux through the confining unit is estimated at about 0.011 m/day. Assuming a porosity of 0.30, the average velocity of water through the confining unit is 0.037 m/day. The time for ground water to move through the confining unit under this gradient at the estimated average velocity is about 330 days.

CONCLUSION

Three distinct aquifer units have been classified in the studied Meghna floodplain areas to an investigated depth of about 400m. However, there is a complex aerial variability of the hydrogeologic characteristics as a consequence of the floodplain depositional history of the formations. Groundwater level in the shallow and main aquifers varies in places due to local-scale lithologic variations, leakage, the impact of irrigation abstraction and partially by unconfined storage change in the aquifer. During the dry irrigation period pumping water mainly from the lower part of the shallow and upper part of the main aquifers, water levels in all three aquifers response to the pumping stress. The trend of water level fluctuations in different aquifer units supports the hydraulic connectivity of aquifer formations. The aquitards separating aquifers are not continuous regionally but locally extended. During the pumping test, water levels in observation wells open to the shallow and main aquifers showed no noticeable effect from pumping in the deep aquifer that indicates at least local hydraulic separation of aquifers and under conditions of moderate groundwater use for domestic and municipal supply, arsenic and/or chloride-rich groundwater in the upper aquifers are not likely to be drawn into the deep aquifer.

Aquifer test results as well as aquifer properties and characteristics of the deep aquifer show that the deep aquifer can yield significant amounts of potable water. As different hydrogeologic factors control the aquifer parameters and the graphical methods of solution depend upon the accuracy of the graph construction and subjective judgments in matching field data to type curves, solution results have varied for different method of analysis. However, all results indicate that the aquifer is confined to leaky-confined or semi-confined in nature. Slight deviations are not prohibitive to the application of different methods. When greater deviations from the above assumptions occur, special flow problems may raise. So, it is useful to evaluate data using as many methods as possible. Each may help to provide a different perspective and aid in a better interpretation. The Hantush-Jacob solution for a leaky confined aquifer was chosen as the most representative of the physical situation and this gives better results considering field condition in the deltaic floodplain aquifers.

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