Sludge Management Using Reed Beds In the Gaza Strip-Palestine

By

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Abstract

Sludge is one of the main critical environmental problems in the Gaza Strip. More than 400 m^3/day of aerobic sludge and approximately 50,000 m^3/year of anaerobic sludge are disposed of into the environment without any treatment. The random disposal of sludge pollutes the groundwater aquifer, contaminates the agricultural products and impacts the health of residents. Three new treatment plants will be constructed in the Gaza Strip to replace the existing ones. The activated sludge system is the proposed treatment technology instead of the existing stabilization ponds and aerated lagoon. It has been estimated that more than 3,700 m^3 of raw sludge will be generating daily by the year 2025 in the Gaza Strip.

Experiences of using reed bed systems for sludge dewatering in many places in Europe and USA, together with monitoring results of a three year pilot project in the Gaza Strip circumstances are promising. A reed bed system is easy to operate and maintain, and is financially attractive compared with conventional drying beds. A reed bed system can be used for a three-year cycle with an average hydraulic loading rate of 40 cm every two-weeks. The estimated cost of construction and operation of a reed bed system in the Gaza Strip is 0.50 US \$ /m^3 for sludge treatment and disposal, compared with 1.01 US \$/m^3 for conventional drying beds. The quality of accumulated sludge in reed bed systems is suitable for agricultural purposes. Accumulated sludge from the pilot plant does not have any offensive odour, is free of heavy metals and rich in organic material and nutrient. Sludge could be a good alternative to organic fertilizers, which are scarce, expensive and difficult to obtain in the Gaza Strip.

More than 795,000 m^3 of organic fertilizers are imported yearly in the Gaza Strip and cost around 10,200,000 US \$. The farmers in Gaza are willing to use treated sludge for their agricultural land. Some farmers who currently use partially treated sludge are willing to use treated sludge in the future.

Palestinian institutions are interested in solving sludge problems, and to use treated sludge in agriculture. This research proposes institutional arrangements for sludge management, and guidelines for design, operation and maintenance of reed bed systems with recommendations for future steps towards sustainable sludge management in the Gaza Strip.

Key Words: *Sewage Sludge, quality, quantity, reed beds, drying beds, hydraulic load, cost, agriculture, institutional, standards.*

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Glossary

The following definitions are based on material from a number of different sources. Some definitions appear in the same form in various sources, others have been adapted by the author. Sources used include: EPA (2002a), Crites and Tchobanoglous (1998), Kadlec et. al. (2000) and Aalbers. (1999).

Activated sludge: Material consisting largely of naturally occurring bacteria and protozoa used in and produced by one method of sewage disposal. Sewage is mixed with some activated sludge and agitated with air; organisms of the sludge multiply and purify the sewage. When allowed to settle, they separate out as a greatly increased amount of activated sludge. Part of this is added to new sewage and part is disposed of.

Aeration: the addition of air to water, usually for purpose of providing higher oxygen concentrations for chemical and microbial treatment processes.

Aerobic: Environmental conditions characterized by the presence of dissolved oxygen; used to describe biological or chemical processes that occur in the presence of oxygen.

Ammonia: Inorganic form of nitrogen; product of hydrolysis of organic nitrogen and denitrification. Ammonia is preferentially used by phytoplankton over nitrate for uptake of inorganic nitrogen.

Anaerobic: Environmental condition characterized by zero oxygen levels. Describes biological and chemical processes that occur in the absence of oxygen.

Animal (and poultry) manure: Animal excreta, including bedding, feed and other by-products of animal feeding and housing operations.

Aquaculture: propagation and maintenance of plants or animals by humans in aquatic and wetland environments.

Bacteria: Single-celled microscopic organisms lacking chlorophyll. Some cause disease, and some do not. Some are involved in performing a variety of beneficial biological treatment processes including biological oxidation, solids digestion, nitrification, and denitrification.

Biochemical oxygen demand (BOD): The amount of oxygen per unit volume of water required to bacterially or chemically oxidize (stabilize) the oxidizable matter in water. Biochemical oxygen demand measurements are usually conducted over specific time intervals (5, 10, 20, 30 days). The term BOD_5 generally refers to standard 5-day BOD test.

Biosolids: The organic solids product of municipal wastewater treatment that can be beneficially utilized. Wastewater treatment solids that have removed from wastewater by primary or secondary sedimentation.

Channel: a deeper portion of a water flow-way that has faster current and water flow.

Chemical oxygen demand (COD): a measure of the oxygen equivalent of the organic matter in water based on reaction with a strong chemical oxidant.

Constructed wetland: A wetland that is purposely constructed by humans in an area where there are no natural wetlands.

Coliform bacteria: A group of bacteria that normally live within the intestines of mammals, including humans. Coliform bacteria are used as an indicator of the presence of sewage in natural waters.

Composting: The accelerated decomposition of organic matter by microorganisms, which is accompanied by temperature increases above ambient: For biosolids, composting is typically a managed aerobic process.

Concentration: Mass amount of a substance or material in a given unit volume of solution. Usually measured in milligrams per liter (mg/l) or parts per million (ppm).

Decay: Gradual decrease in the amount of a given substance in a given system due to various loss/sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.

Decomposition: Metabolic breakdown of organic materials; the by-products formation releases energy and simple organics and inorganic compounds.

Denitrification: Describes the decomposition of ammonia compounds, nitrites, and nitrates (by bacteria) that result in the eventual release of nitrogen gas into the atmosphere.

Dissolved oxygen (DO): The amount (concentration) of oxygen gas that is dissolved in water. It also refers to a measure of the amount of oxygen available for biochemical activity in water body, and as indicator of the quality of that water.

Effluent: Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.

Evaporation: the process by which water in a lake, river, wetland or other water body becomes a vapour in the atmosphere.

Evapotranspiration (ET): the combined processes of evaporation from the water and soil surface and transpiration of water by plants.

Faecal coliform bacteria: Coliform bacteria that are present in the intestines or faeces of warmblooded animals including humans. They are often used as indicators of the sanitary quality of water. See Coliform bacteria.

Helminths and helminths ova: Parasitic worms, e.g., roundworms, tapeworms, *Ascaris, Necator, Taenia*, and *Trichuris*, and ova (eggs) of these worms. Helminth ova are quite resistant to chlorination, and can be passed out in the faeces of infected humans and organisms and ingested with food or water. One helminth ovum is capable of hatching and growing when ingested.

Fertilizer: Any organic or inorganic material of natural or synthetic origin that is added to soil to supply elements essential to plant growth.

Heavy metals: Metallic elements that have an atomic mass of more than 21 in the Periodic table.

Hydraulic Conductivity (Kf): Ability of a porous medium (such as soil) to allow water transmission.

Hydraulic Loading Rates: Amount of water or liquid biosolids applied to a given treatment process and expressed as volume per unit time, or volume per unit time per surface area.

Infiltration: The rate at which water enters the soil surface, expressed in mm or cm per day, influenced by both permeability and moisture content of the soil.

Influent: Water volume flow rate or mass loading of a pollutant or other constituent into a water body or wastewater treatment plant.

Inorganic: Pertaining to matter that is neither living nor immediately derived from living matter.

Lagoon : With respect to wastewater treatment, a pond in which algae, sunlight, and oxygen interact to restore wastewater to a quality often equal to that of the effluent from the secondary treatment stage. Lagoons are widely used by small communities to provide wastewater treatment.

Land application: The spreading or spraying of biosolids onto the surface of land, the direct injection of biosolids below the soil surface, or the incorporation into the surface layer of soil; also applies to manure and other organic residuals.

Lechate: Liquid which has come into contact with or percolated through materials being stockpiled or stored; contains dissolved or suspended particles and nutrients.

Loading rate: The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight (mass) per unit time.

Microorganism: Bacteria, fungi (moulds, yeasts), protozoans, helminths, and viruses. The terms *microbe* and *microbial* are also used to refer to microorganisms, some of which cause disease, and others are beneficial. Parasite and parasitic refer to infectious protozoans and helminths. Microorganisms are ubiquitous, possess extremely high growth rates, and have the ability to degrade all naturally occurring organic compounds, including those in water and wastewater. They use organic matter for food.

Milligrams per litre (mg/l): A unit of measurement expressing the concentration of a constituent in solution as the weight (mass) of solute (1 milligram) per unit volume (1 litre) of water; equivalent to 1 part per million (ppm) for a water density ~1 g cm^{-3}. 1 mg/l = 1000 μg/l; 1 g/l = 1000 mg/l

Mineralization: The process by which elements combined in organic form in living or dead organisms are eventually reconverted into inorganic forms to be made available for a new cycle of growth. The mineralization of organic compounds occurs through oxidation and metabolism by living microorganisms.

Nitrate (NO_3) and Nitrite (NO_2): Oxidized nitrogen species. Nitrate is the form of nitrogen used by aquatic plants for photosynthesis.

Nitrification: Biologically mediated process of the oxidation of ammonium salts to nitrite (via Nitrosomonas bacteria) and the further oxidation of nitrite to nitrate via Nitrobacter bacteria.

Nutrient: A primary element necessary for the growth of living organisms. Carbon dioxide, nitrogen, and phosphorus, for example, are required nutrients for phytoplankton (algae) growth.

Organic matter: The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.

Organic nitrogen: Organic forms of nitrogen bound to organic matter.

Oxidation: The chemical union of oxygen with metals or organic compounds accompanied by a removal of hydrogen or another atom. It is an important factor for soil formation and permits the release of energy from cellular fuels.

Parasite: An organism that lives within or on another organism and derives its sustenance from that organism without providing a useful return to its host.

Pathogens: a microorganism capable of producing disease. Pathogens are of great concern to protect human health relative to drinking water, swimming beaches and shellfish beds.

pH: A measure of acidity indicated by the logarithm of the reciprocal of the hydrogen ion concentration (activity) of a solution. pH values less than 7 are acidic; values greater than 7 are basic; pH of 7 is neutral. pH of natural waters typically ranges from ~6-8.

Phosphorus: A nutrient essential for plant growth that can play a key role in stimulating the growth of aquatic plants in streams, rivers and lakes.

Pollutant: A contaminant in a concentration or amount that adversely alters the physical, chemical, or biological properties of a natural environment. The term includes pathogens, toxic metals, carcinogens, oxygen demanding substances, or other harmful substances.

Rhizosphere: Zone of soil immediately surrounding root and rhizomes and modified by them. Characterized by enhanced microbial activity and by changes in the ratios of organisms compared with surrounding soil. More specifically, a wetland rhizosphere is the chemical sphere of influence of plant roots growing in flooded soils. Depending on the overall oxygen balance (availability and consumption), the rhizosphere can be oxidized, resulting in the presence of aerobic soil prosperities in an otherwise anaerobic soil environment.

Salinity: The total amount of dissolved salts, measured by weight as parts per thousand (ppt). Salinity concentrations range from ~0.5-1 ppt for tidal fresh waters; ~20-25 ppt for estuarine waters; ~ 30 ppt for coastal waters to ~35 ppt for the open ocean.

Salmonella: Rod-shaped bacteria of the genus *Salmonella*, many of which are pathogenic, causing food poisoning, typhoid, and paratyphoid fever in human beings, or causing other infectious diseases in warm-blooded animals. They can also cause allergic reactions in susceptible humans, and sickness, including severe diarrhoea with discharge of blood.

Secondary treatment plant: Waste treatment process where oxygen-demanding organic materials (BOD) are removed by bacterial oxidation of the waste to carbon dioxide and water. Bacterial synthesis of wastewater is enhanced by injection of oxygen.

Sediment: Particulate organic and inorganic matter that accumulates in a loose, unconsolidated form on the bottom of natural waters.

Sludge: the accumulated solids separated from liquids, such as water or wastewater, during the treatment process.

Solids: In water and wastewater treatment, any dissolved, suspended, or volatile substance contained in or removed from water or wastewater.

Stability: The characteristics of a material that contribute to its resistance to decomposition by microbes, and to generation of odorous metabolites. The relevant characteristics include the degree of organic matter decomposition, nutrient, moisture and salts content, pH, and temperature. For biosolids, compost, or animal manure, stability is a general term used to describe the quality of the material taking in to account its origin, processing, and intended use.

Stabilization pond: Large earthen basins that are used for the treatment of wastewater by natural processes involving the use of both algae and bacteria.

Tertiary treatment: Waste treatment processes designed to remove or alter the forms of nitrogen or phosphorus compounds contained in domestic sewage.

Total Kjeldahl Nitrogen (TKN): The sum total of organic and ammonia nitrogen in a sample, determined by the Kjeldahl method.

Total coliform bacteria: A particular group of bacteria that are used as indicators of possible sewage pollution.

Total Suspended Solids (TSS): A measure of the amount of small, particulate solid pollutants that are suspended in wastewater.

Toxic substances: Those chemical substances, such as pesticides, plastics, heavy metals, detergent, solvent, or any other material those are poisonous, carcinogenic, or otherwise directly harmful to human health and biota the environment.

Transpiration: The transport of water vapour from soil to the atmosphere through actively growing plants.

Trickling filter: A wastewater treatment process consisting of a bed of highly permeable medium (e.g. gravel or stones) to which microorganisms are attached and through which wastewater is percolated or trickled over the biofilm that forms on the media.

Wadi: Seasonally wet river bed

Wastewater: Dissolved or suspended waterborne waste material. Sanitary or domestic wastewater refers to liquid material collected from residences, offices, and institutions. Industrial wastewater refers to wastewater from manufacturing facilities. Municipal wastewater is a general term applied to any liquid treated in a municipal treatment facility and usually includes a mixture of sanitary and pre-treated industrial wastes.

Wastewater treatment: Chemical, biological, and mechanical processes applied to an industrial or municipal discharge or to any other sources of contaminated water in order to remove, reduce, or neutralize contaminants prior to discharge to a receiving water.

Wetland: An area that is inundated or saturated by surface or groundwater at a frequency, duration and depth sufficient to support a predominance of plant species adapted to growth in saturated soil conditions.

List of Acronyms and Abbreviations

A	Area
As	Arsenic
B	Boron
BOD	Biochemical Oxygen Demand
Cd	Cadmium
Cl	Chloride
Co	Cobalt
COD	Chemical Oxygen Demand
CMWU	Coastal Municipal Water Utility (Palestine)
Cr	Chromium
Cu	Copper
DM	Dry matter
DS	Dissolved Solids
DURP	Directorate of Urban and Rural Planning, MOPIC
EC	Electrical conductivity
Eff.	Effluent
EQA	Environmental Quality Authority (Palestine)
Ep	Evaporation
Et	Evapotranspiration
Fe	Iron
F/M	Food (organic matter)/Micro organisms
Hg	Mercury
HLR	Hydraulic loading rate
Inf	Influent
JICA	Japan International Cooperation Agency
K	Potassium
LEKA	Lyonnaise des Eaux Khatib and Alami
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
MoA	Ministry of Agriculture (Palestine)
MoH	Ministry of Health (Palestine)
MoLG	Ministry of Local Government (Palestine)
MOPIC	Ministry of Planning and International Cooperation (Palestine)
MPN	Most probable number
Na	Sodium
NGO	Non governmental organisation
NH_4	Ammonium
NO_2	Nitrite
NO_3	Nitrate
OM	Organic matter
P	Phosphorus
PARC	Palestinian Agricultural Relief Committee
Pb	Lead
PECDAR	Palestinian Economic Council for Development and Reconstrucion
PLO	Palestinian Liberation Organisation
PNA	Palestinian National Authority
PO_4	Phosphates

ppt	Part per thousand
PSI	Palestine Institute for Standardisation and Measurements
PWA	Palestinian Water Authority
R^2	Correlation value
RH	Relative humidity
Se	Selenium
SLR	Solid loading Rate
SS	Suspended solids
TDS	Total dissolved solids
TKN	Total Kjeldahl Nitrogen
TR	Trace element
TS	Total Solids
TSS	Total suspended solids
TVSS	Total volatile suspended solids
UNDP	United Nations Development Programme
UNRWA	United Nations Relief and Works Agency (for Palestinian Refugees)
UPVC	Polyvinyl Chloride
USAID	United States Agency for International Development
USEPA	United States Environmental Protection Agency
VSS	Volatile Suspended Solid
WHO	World Health Organisation
WWTP	Wastewater treatment plant
Zn	Zinc

Units of Measurements

^oC	Degree centigrade
cm	Centimetre
cm/yr	Centimetre/year
Dunum	Land area unit of 1000 square metre
g/c/d	Gram per capita per day
g/cm^3	Gram per cubic centimetre
g/kg	Gram/kilogram
hr	Hour
JD	Jordanian Dinar (JD = 1.4 US $)
kg	Kilogram
$kg/m^2.yr$	Kilogram per square metre per year
km	Kilometre
km^2	Squre kilometre
l/c/d	Litres per capita per day
m	Metre
m/yr	Metre/year
m^2	Square metre
m^3	Cubic metre
$m^3/m^2.day$	Cubic metre per square metre per day
m^3/day	Cubic metre per day
mg/l	Milligram per litre
mm	Milimetre
mS/cm	Millisiemens per centimetre
$\mu g/l$	Microgram per litre
p/km^2	Person per square kilometre
ppm	Part per million
t	Tonne (1000 kilograms)
US $	United States Dollar
%	Percent

CHAPTER 1

Background and Problem Statement

1.1 Introduction

The environment in Palestine has deteriorated due to the rapid increase in population and a scarcity of natural resources. The wastewater sector is one of the main neglected issues, as most of Palestinian residential areas do not have sewage networks and/or efficient wastewater treatment plants. The area suffers from poor management of wastewater treatment and requires urgent steps towards improving the environmental situation.

This chapter of the thesis introduces background information about the study area, assesses the existing wastewater treatment plants, and highlights the sludge problem.

1.2 Study Area

The Palestinian territories are composed of two separated areas; the Gaza Strip and West Bank. The West Bank is situated on the central highlands of Palestine. The area is bounded by the Jordan River and the Dead Sea to the East and the "1948 cease-fire line" on the North, West and South. The West Bank total area is 5788 km^2 with an overall population of 1.3 million inhabitants ***(MOPIC, 2001)***. The Gaza Strip is situated on the South West of Palestine, bordered by Egypt on the South, the Mediterranean Sea on the West and the "1948 cease-fire line" from the North and East. The total area of the Gaza Strip is about 365 km^2. The distance from North to South is 45 km and from East to West varies from 5 to 12 km. The total population of the Gaza Strip was 1.2 million inhabitants in 2002 ***(Kuhail and Nassar, 2003)***.

After establishment of the Palestinian Authority in 1994, the Gaza Strip was divided into five administrative Governorates. These are shown in Figure 1.1, and the population forecasts for each governorate are shown in Table 1.1.

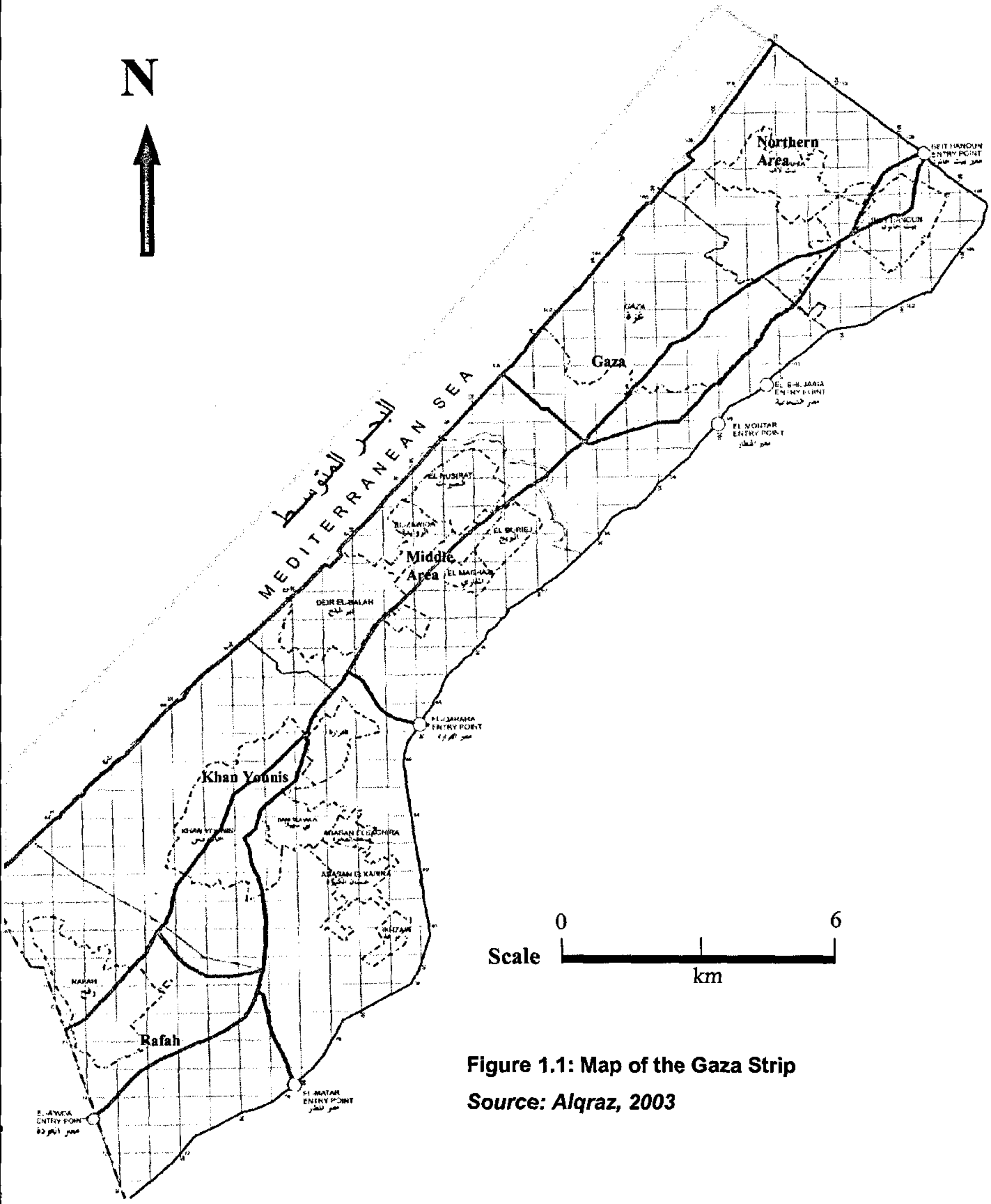


Figure 1.1: Map of the Gaza Strip

Source: Alqraz, 2003

Table 1.1: the Gaza Strip Population forecast

Governorates	1996	2000	2005	2010	2015	2020	2025
Northern area	148700	169259	198234	228614	258495	286549	318892
Gaza	354400	415835	501156	671327	839375	950816	1075038
Middle area	145200	165212	193427	223016	252129	279382	310822
Khan Younis	201400	242903	300615	546933	743731	850319	968875
Rafah	113100	128091	149339	171656	193735	213637	236801
TOTAL	*962,800*	*1,121,300*	*1,342,771*	*1,841,546*	*2,287,465*	*2,580,703*	*2,910,428*

Source: SOGREAH, 1998

Gaza and Khan Younis governorates are the most populated governorates. More than 90% of the Middle Area governorate residents are refugees while 60% of Northern Area and Rafah residents are refugees.

The Gaza Governorates are located in an arid area where water resources are scarce. Due to increasing groundwater pumping for urban water use as well as for irrigation purposes, the extraction of groundwater currently exceeds the recharge of the groundwater aquifers. This is mentioned by many authors, such as COWI (2000), OTU (1998), and JICA (1997). As a result, the groundwater level is falling and the chloride concentration increases, making the water unsuitable either for human consumption or for irrigation purposes. The uncontrolled discharge of untreated sewage to the ground and excessive use of fertilizers have led to high nitrate concentrations in certain areas, thus creating an additional pollution of the groundwater resources ***(Boliden Contech, 1998).***

The Peace process has generated a wide range of development and cooperation activities, including several projects for water resource management and wastewater collection and treatment. Virtually all urban centres of the Gaza Governorates are today covered by some ongoing-internationally sponsored wastewater project. Most of these projects concern short-term priority works. One of the main short-term goals is rehabilitation of existing wastewater treatment plant. For the long term, Palestinians plan to construct new treatment plants to cope with a rapid increase of population and high rate of new connections to sewerage systems.

1.3 Existing Wastewater Treatment

There are today three wastewater treatment plants in operation in the Gaza Strip: Beit Lahia WWTP, Gaza WWTP and Rafah WWTP. Sources of data for all WWTPs were obtained from the Ministry of Planning (MOPIC), the Palestinian Water Authority (PWA) and the Ministry of Local Affairs (MoLG) documents.

Beit Lahia WWTP

The WWTP located within the Beit Lahia municipality borders is managed by Jabalia municipality therefore, referred to as Jabalia WWTP by some authors and as Beit Lahia WWTP by others. The treatment plant was originally built by the Israeli civil administration in 1976 to treat the wastewater from the Northern Area of the Gaza Strip. It is located on a 14-hectare site at approximately 1.6 km East of Beit Lahia.

An Israeli consulting firm designed this plant as stabilization ponds and aerated lagoons. Currently, the plant consists of 7 ponds (see table 1.2) but it was constructed in stages; lagoons 1 to 4 were constructed in 1983, followed by lagoon 5 and then lagoon 7, both by Israeli contractors. A local contractor then constructed lagoon 6 when surface aerators were installed in Lagoons 1 to 4 for the purpose of cleaning out the sludge (that accumulated due to raw sewage flows). In December 1993 surface aerators were installed in lagoons 5 and 6. The plant was designed to eventually install 6 aerated lagoons operating in series and two polishing ponds operating in parallel. Of the projected eight ponds, seven have been constructed. At present, the lagoons are being operated as aerated lagoons. Table 1.2 illustrates the ponds area, depth and volume.

Each of the six aerated lagoons (No. 1 to No. 6) is fitted with four surface aerators. In addition, the two first ponds are fitted with mixers, which create horizontal flow. Treated effluent is currently directed to infiltration ponds in the adjacent dune areas, while sludge is left in ponds and randomly disposed to adjacent areas around ponds.

Table 1.2: Beit Lahia Treatment Plant Lagoons Size

Lagoon No.	Base Plan (m)	Water Depth (m)	Volume (m^3)	Surface (m^2)
Lagoon No. 1	78x58	2.4	13,310	6,660
Lagoon No. 2	78x58	2.4	12,740	6,400
Lagoon No. 3	78x58	2.4	13,480	6,740
Lagoon No. 4	78x58	2.4	12,910	6,480
Lagoon No. 5	220x70	2.4	38,570	15,230
Lagoon No. 6	210x70	2.4	34,000	15,230
Lagoon No. 7	213x67	6.75	135,940	26,930

Source: Carl Bro, 1994

Beit Lahia treatment plant receives more than 12,000 m^3 of raw wastewater daily with BOD of 450 mg/l and SS of 500 mg/l. The plant provides partial treatment concerning BOD & SS while neither pathogenic treatment nor nutrient removal is achieved. SeeTable 4.2 for more details.

Gaza WWTP

The Gaza wastewater treatment plant, located to the South of the Gaza City, was constructed in 1977 initially with two ponds (without aeration). In 1986, two additional ponds were added under a United Nations Development Programme (UNDP) funded upgrading of the plant. After upgrading, the plant was intended to operate as aerated lagoons.

Recently in 1999, the treatment plant was upgraded by constructing another pond and two bio-towers through USAID funds. The plant consists of the following structures, which are shown schematically in Figure 1.2:

- One inlet channel,
- Two parallel primary ponds, each having approximate dimensions of depth 4.0 m, volume 16,000 m^3,
- One anaerobic pond of 4.5 m water depth and 38,000 m^3 water volume,

- Two parallel bio-towers with 6.5 m height and 26 m diameter,
- Aeration pond with 4.5 m water depth and 40,000 m^3 water volume.
- Settling channel.
- Sludge holding pond with 9000 m^3 volume.
- Effluent pump station.
- Eight sludge drying beds of 430 m^2 each.

Gaza wastewater treatment plant receives more than 50,000 m^3/day of wastewater with BOD of 450 mg/l and SS of 500 mg/l. The treatment plant has a very high performance level regarding BOD and SS removal; BOD and SS in effluent are less than 30 mg/l. The nitrogen and phosphorus removal is limited and bacterial quality is not significant improved. Aerobic sludge is dewatered partially using existing drying beds while anaerobic sludge is accumulated in ponds for a few years and then disposed of randomly into open areas within the treatment plant boundaries.

Rafah WWTP

The Rafah wastewater treatment plant was designed for a capacity of 1,800 m^3/d, and for a population of 21,000. The plant includes:

- Inlet microscreen 0.4 mm,
- One aerated pond, volume 31,200 m^3 fitted with surface aerators, and mixers which create horizontal flows,
- One chlorination channel for disinfection (not in operation),
- One pumping station containing two pumps, discharging the treated effluent to the sea.

It is understood that the aerators of the plant are only operated during the day, and not on a 24-hour basis. There is no regular monitoring of the plant performance.

Currently, the daily flow rate is more than 4000 m^3, which exceeds the design capacity of the plant. In Rafah treatment plant, wastewater is only treated

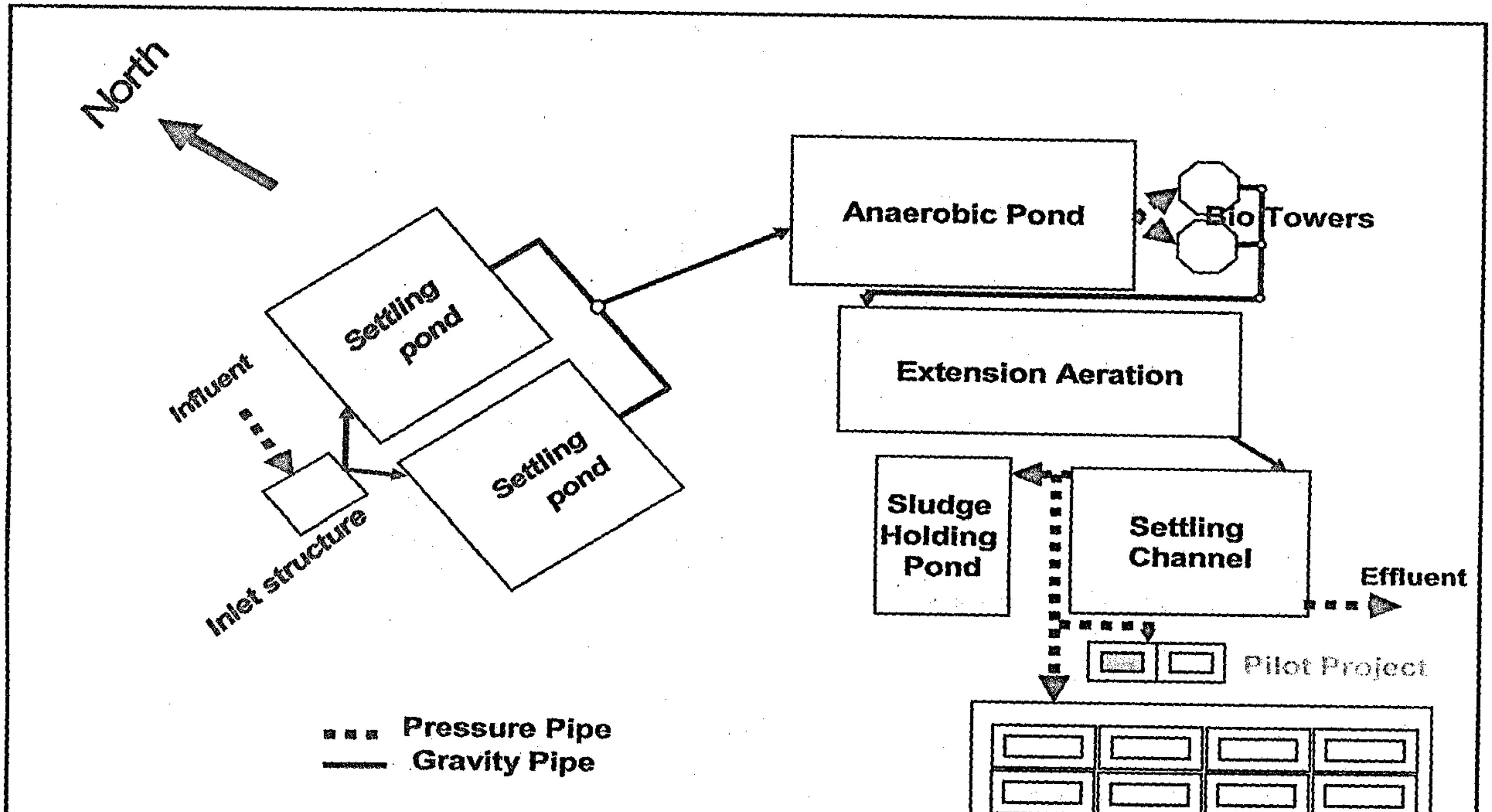


Figure 1.2: Gaza Wastewater Treatment Plant-Layout

partially, BOD removal is less than 50% while there is no significant nutrient or pathogenic removal. Generated sludge is left in the lagoon and occasionally randomly disposed of around the lagoon.

1.4 Current Sludge Management

Currently there is no real treatment or disposal of sludge generated in the existing treatment plants. The volumes of sludge are not determined, because there are no measurements of the quantities of sludge and, at the same time, the quantity is affected by the resident time of sludge in the ponds. It is estimated by the author that the anaerobic sludge, which accumulates in the ponds, is around 50,000 m^3/year with 5% solids while the aerobic sludge from bio-towers is around 400 m^3/day with 1-2% solids. See Appendix C for more details.

The sludge accumulated in the ponds receives no significant treatment expect desludging, when it is left around the ponds or in the open areas of the treatment plants. See photo 1.1 which was taken in 2002. Sometimes it is evacuated to the solid waste dump sites.

Photo 1.1: Sludge accumulation in WWTP

In general, there is no regular desludging of anaerobic sludge from ponds. The sludge is left in ponds until the ponds become full and there is no space for wastewater. The accumulated sludge has a high percent of sand, which settles in the ponds.

Photo 1.2: Sludge removal from beds

Concerning aerobic sludge generated in the Gaza wastewater treatment plant due to the bio-towers and extension aeration pond, the municipality constructed 8 sand-drying beds with a surface area of 430 m^2 each. At the beginning, sludge was daily discharged to the drying beds where it was left for weeks until dried and then evacuated to the solid waste dumpsites. Photo 1.2 which was taken in 2001 shows the method of dry sludge removal from beds.

After one year of operation, the beds are clogged and useless. The municipality stores the sludge in a holder for a few months (4-6 months), and then desludges it to the open areas within the treatment plant where the excess water infiltrates and the residual transported to the dump sites or kept as heaps in the treatment plant, see photo 1.1.

1.5 Sludge Problem- Background

As a residue of wastewater treatment, sewage sludge contains a complex mixture of pollutants originally present in the wastewater. Sewage sludge is expected to contain organic matter, i.e. nutrients that could be useful for soil, along with toxic organic elements, heavy metals and pathogens that could be toxic and dangerous if handled ***(Metcalf & Eddy, 1991)***. This by-product from wastewater treatment plants requires safe and economical disposal to protect life and environment from its potential impact on humans, soil and water. In conventional wastewater treatment plant design, a number of options are available for management and disposal of sewage sludge:

- Drying in simply constructed sludge beds.
- De-watering by centrifuge or hydraulic press
- Incineration
- Modified drying beds using Reeds

The final disposal of dried sludge or solid residue from the processes is generally to landfill or agricultural land.

Sludge drying beds occupy relatively large areas of land, and disposal of dry sludge to landfill means that useful plant nutrients are not used. In Gaza there is need to use land and resources efficiently. Drying beds incur a high operational cost due to frequent desludging of the beds and transporting dried sludge to landfill.

The second and third options incur high capital and running costs, and also place the user in a position of reliance on external bodies for supply of spare parts and expertise. Incineration also means that sludge is not used as a land additive.

In the last two decades and in many countries a great deal of attention has been paid to the reed bed option. The experiments and pilot projects carried in many countries suggest that this system has certain potential advantages over other systems ***(Keefer, 2000).*** On the one hand, the infiltration rate of a conventional drying bed is increased when planted with reeds, accelerating dewatering. At the same time, accumulated sludge becomes composted, which makes it more suitable for application to agricultural land. The system is a semi-natural system, which has local constraints and is still being studied and tested, and more research is needed to study all the design parameters for construction and operation of the system. Reed beds have not been studied in Gaza previously, where special factors apply. The research aims to develop design parameters for reed beds taking into consideration the special conditions of the Gaza situation through conducting a pilot project in the area using locally generated sludge.

1.6 Statement of the Problem

As stated before, over the past two decades three wastewater treatment plants have been constructed to serve the increasing population of the Gaza Strip. The treatment plants are located in Beit Lahia, Gaza City and Rafah.

In addition to providing less than adequate wastewater treatment, these plants also regularly produce large quantities of sludge, which at present are removed and spread on land adjacent to the treatment plants. This is causing a number of problems; including:

- Contamination of groundwater reserves; The ground water reservoir in the Gaza Strip is shallow at a depth of 30-40 m in the sludge disposal areas and the soil is sandy soil which facilitates infiltration. This means that sludge could be one of the sources of high nitrate concentration in ground water (250-300 mg/l) and a potential public health hazard. Agenda 21 adopted by the United Nations Conference on Environment and Development (Earth Summit of Rio de Janeiro, 1992) estimated that 5.2 million people, including 4 million children, die every year due to consumption of contaminated water. Improper disposal of wastes (human wastes, sludge and solid waste) are major sources of such contamination ***(Sundaravadivel et al., 2000)***
- Wind-blown distribution of dried sludge is likely to contaminate locally grown crops, grown for market and local consumption. There is a risk that dry sludge dust particles, with bacteria attached, coat the leaves of locally grown salad crops. It is noticed by the author that many crops mainly grapes are coated with sludge particles which could be contaminated with pathogenic organisms.
- Availability of land required to accommodate the dumping of sludge is decreasing, creating a logistical problem for the operators of the treatment plants. The area of the Gaza Strip is only 365 km^2 with an overall population of more than1.2 million. The high rate of population increase and demands on available land for expansion of residential areas are making land scarce and expensive.
- Many farmers in Gaza use partially treated sludge. Such illegal and unmonitored use of contaminated sludge could create environmental and health problems.
- The existing waste water treatment plants are poorly managed. This is due to lack of clear roles and responsibilities of existing Palestinian institutions ***(OUT, 1998)***. Clear roles and responsibilities regarding wastewater treatment and sludge handling should be required to manage the wastewater sector in Palestine properly.

Existing wastewater treatment plants in the Gaza Strip are waste stabilization ponds and aerated lagoons. The current focus for future wastewater treatment in Gaza is activated sludge. The activated sludge process is capable of treating domestic wastewater quickly while needing only a relatively small area of land. This process uses active bacteria culture that convert approximately half the organic pollutants present in settled sewage into new bacterial cells that can be removed, by physical separation, as sludge. Although providing efficient wastewater treatment, this system also generates large quantities of sludge as a by-product. This means that in the near future, the Gaza Strip will face a serious problem in sludge handling. The solution of such a problem has to consider the scarcity of land in the area and the limited ability of residents to pay for sludge handling besides local human skills capacity.

1.7 Summary

The recently constructed treatment plants (constructed within the last 25 years) are providing a partial solution for the treatment of wastewater in Gaza. A more comprehensive solution to the problem requires that some means of dealing with the quantity of sludge produced by these plants is quickly found before the heaps of sludge currently accumulating around the treatment plants grow to an unmanageable size and begin to impact on the environment.

This research evaluated a potential solution for sludge management which is effective in terms of reducing the volume of the sludge whilst also ameliorating any concentrations of pollutants taking into consideration the speciality of the Gaza Strip situation where land is scarce and ability of residents to pay for sophisticated systems is low, as the local human skills are limited.

CHAPTER 2

Objectives and Hypothesis

2.1 Aim

Huge amounts of sewage sludge (400 m^3/day of aerobic and 5000m^3/year of anaerobic sludge according to author calculations Appendix C) are generated in the Gaza Strip and sludge generated rates are expected to double in the near future (3,700 m^3/day by the year 2025 according to author calculations article 4.4.2). Such amounts create health and environmental problems in the area, and a practical solution is required taking into account the scarcity of land in the Gaza Strip, the bad economic situation and the limited available human skills capacity. The main purpose of this study is to find a suitable sludge management system, which circumvents the problems and provides a long-term, affordable method for the processing of sludge. Part of this investigation will focus on the production of a final material, which may be suitable for application to local land as a soil fertilizer and improver in terms of organic matter and nutrients content, and which is acceptable to local growers.

2.2 Objectives

In order to achieve the project aim, the following stages are necessary as objectives:

1. To determine the characteristics (composition and water content) of the raw sludge produced by the existing wastewater treatment plants.
2. To determine the quantity of raw sludge produced by the existing and future wastewater treatment plants.
3. To examine the quality and quantity of dried sludge produced by processing the material in drying beds planted with the common reed *Phragmites australis.*
4. To compare the efficiency of drying sludge using vegetation with conventional drying beds.

5. To establish whether there is a role for reed beds for sludge drying within the existing and future wastewater management system in the Gaza Strip.
6. To identify suitable local operation and maintenance schedules for sludge drying beds planted with reeds.
7. To identify the potential and economic value of the treated sludge for use as a soil improver for Gazan agriculture.
8. To propose a management system for sludge with short and long term solutions.

2.3 Hypothesis

In order to assess the suitability of using reed beds for sludge treatment in the Gaza Strip, this research will attempt to prove or disprove the following hypothesis:

"Reed bed technology for wastewater sludge treatment can be demonstrated to be a feasible solution based on the constraints of land area, climatic conditions, and the social, political, and economical situation in the Gaza Strip."

2.4 Methodology

The research has been carried out over three years. The methodology adopted to carry out such research was based on fieldwork, literature review, meetings and interviews. The author began by clearly identifying the sludge problem in the Gaza Strip and establishing aims and objectives for the study.

A literature review regarding sludge dewatering and treatment using reed beds was conducted, and publications analysed to clearly identify gaps in knowledge. The management systems of sludge disposal in neighbouring countries (Egypt, Jordan and Tunisia) were studied together with existing and future laws and regulations for sludge handling in the Gaza Strip.

A pilot project for a reed bed system was also constructed, and a three-year monitoring program was implemented. The author studied the composition of sludge in the Gaza Strip and assessed its current quantity and estimated likely future quantities. The quantities and costs of local produced and imported organic fertilizers were estimated, and a social survey conducted to study the attitudes and willingness of Gaza farmers to use treated sludge. Further details are summarised below.

Literature review: the author reviewed the management systems for sludge in many places. The main points of the literature review were:

Treatment systems: Various possible systems for sludge treatment and dewatering have been reviewed. Particular attention was paid to reed bed systems. The author reviewed all available documents through checking libraries in both Palestine and UK, and contacting various authors and researchers directly. The main purposes of the literature review were:

1. Finding out what other authors have done, and what is already known and documented.
2. Building on the experience of others
3. Identifying current gaps in knowledge

The reviewed material has been analysed and compared against the results obtained from the pilot project constructed in the Gaza Strip.

Laws and regulations: the laws and regulations regarding sludge treatment and disposal have been reviewed in regional and international countries. The aims were to understand the main concern of the countries having experience of using sludge for agricultural purposes. The author reviewed the Palestinian laws and regulations regarding environment and natural resource protection, and compared the Palestinian standards with others.

Institutional aspects: the institutional arrangements for sludge use in agriculture in Egypt, Jordan and Tunisia have been reviewed and studied. This review aimed to propose an appropriate institutional arrangement for sludge use in the Gaza Strip based on the experience of neighbouring countries and the existing Palestinian institutions and future plans prepared by the Palestinian Authority. To carry out such activities, the author made many meetings with Palestinian decision makers besides reviewing the available documents.

Determine the quantity and the quality of sludge: The author reviewed the available documents regarding quantity and composition of sludge in the Gaza Strip. Based on the available documents and population forecast figures sludge quantities have estimated. Studies that have been carried out by the Palestinian institutions such as the Ministry of Planning and International Cooperation (MOPIC), Palestinian Water Authority (PWA), Ministry of Local Government (MoLG), etc; and the analyses of sludge carried out in the laboratories have been reviewed. The future quantities were estimated based on the existing quantities and population forecasts, taking into account the treatment technology that is being proposed for future wastewater treatment in the Gaza Strip. The quality was predicted based on available laboratory results and expected changes in wastewater quality in the future due to social and cultural behaviour, and treatment technology.

Land use and Potential of sludge use: the author surveyed the agricultural land use in the Gaza Strip and size of each cultivated crop beside the required quantity of organic fertilizers applied to each crop yearly. The survey is based on the reports of Palestinian Ministry of Agriculture (MoA), Palestinian agricultural NGO's, meetings and site visits. The available data were collected, analysed and checked. The author tried to have many sources of data to check and confirm their validity. The estimated quantity of organic fertilizers used in Gaza was compared with the quantities produced locally and the imported quantities.

Standards and guidelines for sludge use in Agriculture: the standards of sludge use in agriculture from many regional and international countries have been collected. The main countries are Egypt, Jordan, Israel, EU-countries and USA. A comparison between the standards of these countries and the draft standards of the Palestinian Authority has been carried out, and recommendations proposed for Palestinian standards that have not yet been drafted.

Social survey: to study the acceptance and willingness to use treated sludge as an option to existing organic fertilizers, a social survey was conducted on Gaza's farmers. The survey studied the farm sizes and types of crops in the Gaza Strip, the availability and cost of existing organic fertilizers, acceptance by farmers of using treated sludge, previous experience of some Gaza farmers in using sludge, and the willingness of farmers to pay for treated sludge.

The author prepared a questionnaire that would be clearly understood by the farmers. After preparing the questionnaire, the author discussed it with staff from the public relations section of the Ministry of Agriculture. The idea was to investigate how best to approach farmers to get accurate answers taking into consideration the farmers' limited background regarding sludge use, and their levels of education. The questions were generally prepared in a way that offered yes or no answers. The author asked for information using different questions to double check and to verify the accuracy of the farmers' answers.

The author cooperated with the Ministry of Agriculture and the Palestinian Agriculture Relief Committee (PARC) in distributing the questionnaires. The farmers were selected randomly within chosen regions; the only consideration being paid to the geographical location. Groups of farmers from different areas were questioned to present the attitude of all farmers in the Gaza Strip. Over 170 farmers were chosen within certain regions. This number was based on time constraints; how many could be distributed and processed. A group of agricultural engineers and the author met each farmer individually to explain the purpose and aim of the questionnaire and then asked them to answer each question. The author spent three months distributing questionnaires and 139 farmers of those questioned replied.

Reed Bed Pilot Project: to study the efficiency of reed bed system for sludge treatment in the Gaza Strip conditions, a pilot project of two drying beds (one planted with reeds and the other unplanted) was constructed in the Gaza City wastewater treatment plant with a base area of 200 m^2 each bed. The author monitored the project for approximately three years and the main monitoring parameters were:

- Plant (reed) growth and performance
- Hydraulic loading rates and its seasonal variation
- Solid loading rates
- Evaporation and evapotranspiration rates and its seasonal variation
- Quality of raw sludge and infiltrated water
- Increase rate of accumulated sludge volume
- Quality of accumulated sludge
- Infiltration rate of leachate water vs. time

The design, operation and monitoring of the pilot project was based on the results of the literature review.

The methods and equations used to measure each monitoring parameter are presented in detail in chapter 8. The obtained results were compared with data collected from previous studies in other countries. Finally, design criteria for construction and operation of a reed bed system were modified taking into consideration the specific conditions of the Gaza Strip.

Management Plan: Based on all the mentioned activities, the author proposed a management plan for sludge treatment and disposal in the Gaza Strip using a reed bed system instead of the existing sand drying beds or any mechanical system. The plan took into consideration the possibility of using treated sludge for agricultural purposes and the most safe and technically appropriate method of sludge handling. The main elements of the plan are:

- ***Treatment system***: the author determined the design parameters for a reed bed system for sludge treatment such as the bed area and cross-section. Important operational parameters included hydraulic loading rate and solids loading rates, with seasonal variation of loading rates.

- ***Institutional aspects***: the author proposed the most appropriate institutional arrangement regarding sludge use for agriculture purposes and recommended responsibilities for relevant Palestinian institutions. The proposed arrangements are based on the experience of other regional countries, the roles and responsibilities of existing Palestinian institutions, the laws and regulations of the Palestinian Authority and the proposed standards and guidelines for wastewater reuse which were prepared by IUG in 2002. The author discussed the proposal with staff from the relevant Palestinian institutions, and other individuals, and used his personal knowledge to adapt and refine the proposal during the study.

- ***Future plans***: short and long term plans regarding a sustainable sludge management system were proposed, together with recommendations for future activities.

2.5 Scope

The scope of the research can be summarised in the following points:

- Determine the quantity and the quality of existing and future sludge generated in the Gaza Strip
- Determine the potential for sludge use on agricultural land in Gaza.
- Construct a pilot project of two beds, one planted with reeds and the other unplanted, and monitor the performance of such a pilot project for three years.
- Specify the roles of the Palestinian institutional organisations dealing with sludge handling.
- Study the social and economic aspects of sludge use for agricultural purposes.

2.6 Approach of the Thesis

The logical framework of the study is started by an introductory chapter that presents the study area and describes the existing wastewater treatment plants and defining the sludge problem.

Chapter two presents the aims, objectives and hypotheses, in addition to thesis methodology and scope of work. The chapter concluded with the thesis approach presented in Figure 2.1.

In chapter three, a literature review of using reed bed for sludge dewatering and treatment is presented showing the common and the gaps in knowledge within previous experience.

Chapter four presents the existing and the future sludge quantity and quality in the Gaza Strip based on available documents, site visits and interviews.

Chapter five concentrates on the advantages and disadvantages of sludge use as agriculture fertilizer, and explains the international and regional standards regarding sludge use in agriculture. Palestinian standards, which are proposed by the Palestinian concern institutions, are presented with final conclusions.

Chapter six introduces the land use in the Gaza Strip and the quantities of organic fertilizers needed yearly with the cost of importing fertilizers and the periods of fertilizer application

Chapter seven addresses the results of a social survey conducted to study the acceptance of using sludge as an alternative to organic fertilizers, and the willingness of farmers to pay for treated sludge

Chapter eight presents the results of a three-year pilot project using a reed bed for sludge treatment in Gaza conditions.

Chapter nine presents a management system for sludge treatment, disposal and recommends further steps towards sustainable sludge handling.

Chapter ten outlines the final conclusions and recommendations.

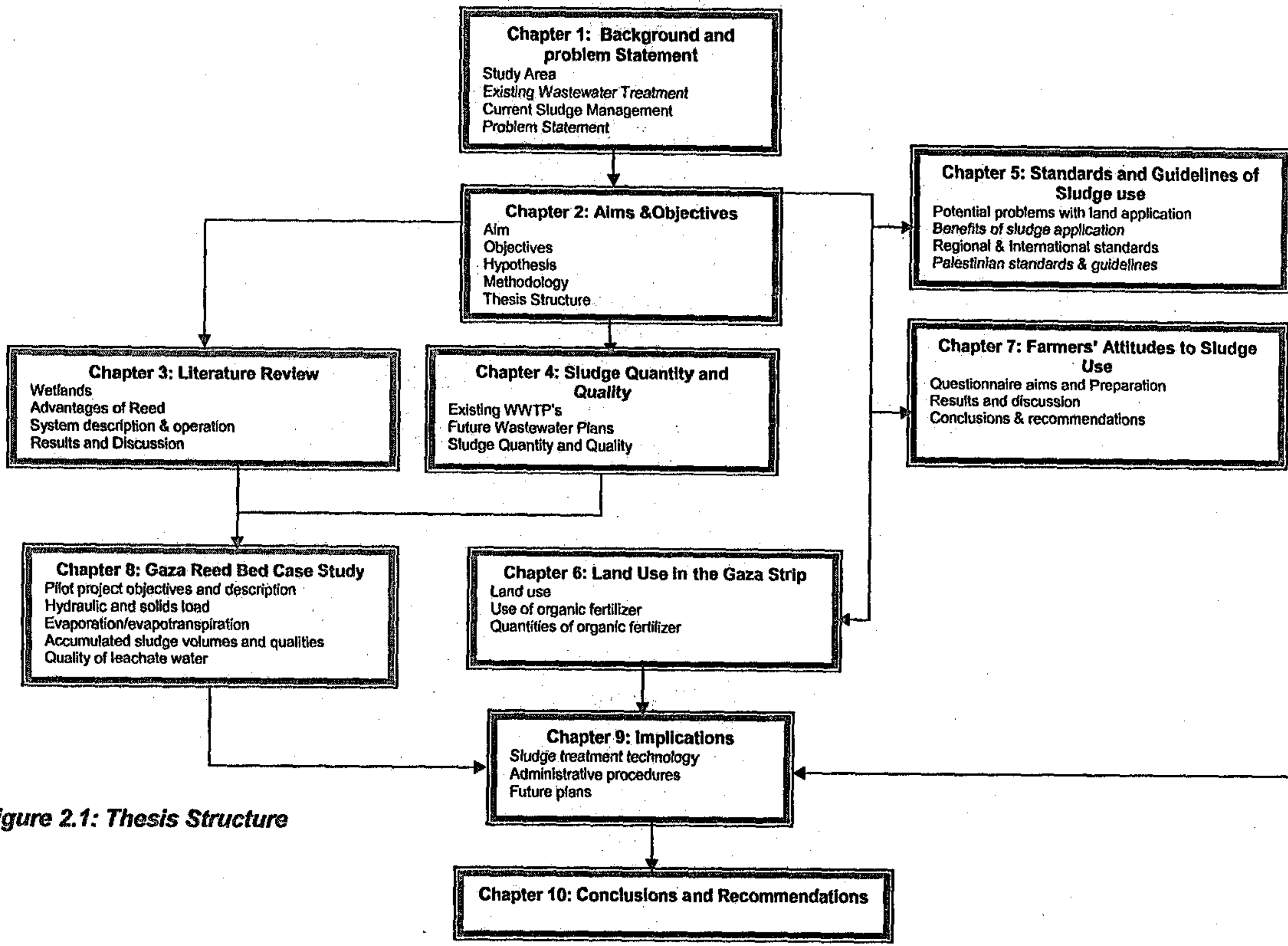


Figure 2.1: Thesis Structure

CHAPTER 3

Sludge Treatment and Disposal

Literature Review

3.1 Background

A good sludge management solution at reasonable cost is not easy to find ***(Lienard et al., 1990)***. The proper utilization and disposal of sludge is one of the most critical issues facing wastewater treatment plants. *"Nearly all wastewater treatment plant operators face the problem of storing and disposing of bio-solids. Landfill costs are increasing rapidly; incineration permits are expensive and difficult to obtain; and land application is limited by the availability of permitted land. However, constructed wetland technology such as reed beds provides long-term storage and volume reduction of bio-solids to mitigate these concerns"* ***(Keefer, 2000, P.61)***.

This chapter presents the experience of using reed bed system for sludge treatment in many areas and the management system for sludge use in agriculture in Egypt, Jordan and Tunisia.

3.2 Sludge Treatment using Reed Beds

A Reed bed system for sludge dewatering is an innovative process ***(Fox Engineering, 2003)***, being a combination of traditional sludge drying bed and natural wetland ***(Burgoon et al., 1997)*** .It is widely used throughout Europe, Asia, and Australia, and in many locations in the United States. Reed bed technology features low construction costs and minimal day-to-day operation and maintenance costs ***(Keefer, 2000)***. The system reduces water content, minimizes solids, and provides sufficient storage time for stabilization of bio-solids prior to disposal.

Reeds act in many ways to alter the character of solids and metals present in the sludge. Firstly, their root system provides oxygen, which boosts the population and activity of naturally occurring microorganisms, which, in turn, mineralize the sludge ***(Roy Consult Group, 2000)***. Secondly, the plants grow rapidly in this nutrient-rich medium and absorb some of the minerals, as well as drawing water from the sludge ***(Roy Consult Group, 2000)***. Thirdly, roots extend from the reed stems into the biosolids which create a system of channels in the bio solids, allowing for continuous drainage and preventing the formation of a semi-impervious biosolids layer, which is typical in unplanted beds ***(Mellstrom and Jager, 1994)***. Meanwhile, the processes of evaporation, drainage and plant uptake combine to transform the sludge into a stable humus-like fertilizer material, which can be used to seal sanitary landfill cells or as a soil conditioner ***(Mellstrom and Jager, 1994)***.

Although many research studies have been undertaken, there is still need for further investigation. The researcher has collected several materials about the experiences using this system from many places, using the Internet and libraries in both Palestine and the United Kingdom. In this chapter, the author summarizes the findings of the literature available. The main purposes of the literature review are to know what others have already done, where there are identifiable gaps in knowledge, and to compare results from different researchers. The author compared the findings of the literature review with the results obtained from the pilot project implemented in the Gaza Strip and monitored over a period of three years.

3.2.1 Wetland Definition

According to Gosh (1995) *"Wetlands are parts of the earth's surface between true terrestrial and aquatic systems. Thus shallow lakes, marshes, swamps, bogs, dead riverbeds, borrow pits, are all wetlands irrespective of their extent and degree of human interventions. Wetlands are generally shallow and thus differentiated from deep-water bodies. Wetlands often include three main components. These are the presence of water, unique soils differing from those of uplands and presence of vegetation adapted to wet conditions"* **(Aalbers, 1999, P.31)**.

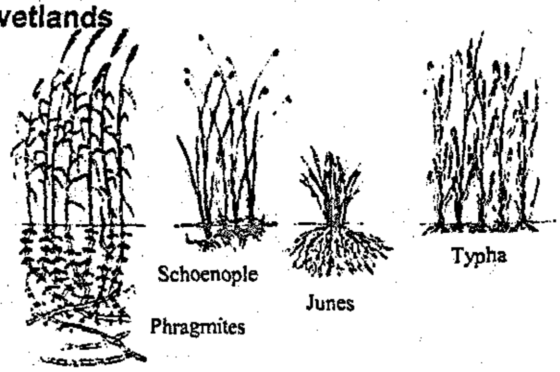
The term "constructed wetland" generally refers to the use of artificial wetlands in treating wastewater, and has recently been applied to sludge dewatering *(Kim et al., 1993)*. The interest in the aquatic wastewater treatment systems can be attributed to three factors:

- Recognition of the natural treatment capabilities of plants, particularly as nutrient sinks and buffering zones ***(Kim et al., 1993)***.
- In the case of wetlands, emergence or renewal of aesthetic wildlife and other incidental environmental benefits ***(Kim et al., 1993)***.
- Rapid increase in cost construction and operation associated with conventional treatment systems ***(USEPA, 1988)***.

3.2.2 Plants Options for Constructed Wetland

A number of aquatic plants (e.g. reeds, cattails, bulrushes, willows) can grow in water. Some common plants used in constructed wetlands are shown in Figure 3.1. Some species are very resistant to pH variation and high salinity ***(Burgoon, et al., 1997)***. The reed "Phragmites" is one of the most widespread flowering plants in the world. It is a tough adaptable plant, which can grow in polluted waters and find sustenance in sludge. This reed has a voracious appetite for water. The plant is also tolerant to low oxygen concentrations in the water and to waterlogged conditions ***(Fox Engineering, 2003)***. Phragmites Australis is an emergent aquatic macrophyte that seems to be the best choice although its initial growth rate is surpassed by broad leaved cattail (*Typha Latifolia*) ***(Burgoon et al., 1997)***.

Figure 3.1: Plant options for constructed wetlands



Source: Sasse, 1998

3.2.3 Advantages of Reeds for Constructed Wetlands

Reeds have many advantages and can meet the following demands of other candidate species:

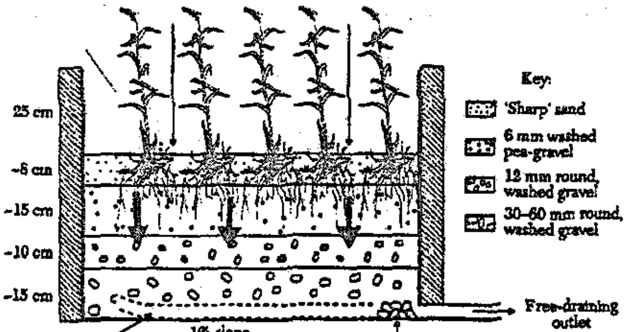
1. Fast growth even under diverse conditions ***(De Maeseneer et al., 1982)***.

2. Reeds have a high evapotranspiration rate ***(Kiendl, 1953; Nielsen, 1993; Reinhofer and Bergholz, 1994).***
3. Reeds increase solids dewatering and stabilization of the biosolids via evapotranspiration and root growth ***(Hoffman, 1990).***
4. Reeds are tolerant of different water levels, drought, low and high pH values and variations in salinity ***(De Maeseneer, 1997).***
5. Deep growth rhizome and root system ***(Lienard et al., 1995)***
6. Reeds build new roots on the nodes when they are covered by accumulated sludge. ***(De Maeseneer et al., 1982; Kampf and Nolthenius, 1993; Nielsen, 1994)***.
7. Reeds are commercially available ***(De Maeseneer, 1994; Lienard et al., 1995).***
8. Reeds are easily planted ***(De Maeseneer, 1997).***
9. Reed beds improve dewatering of sludge due to that the root excretion of reeds roots leads to flocculation of colloidal organic acids (and their subsequent polymerisation) ***(Kickuth, 1969).***
10. Reed biomass contains lignin and other phenolic sources that might improve biological stabilization. Such materials play an important role of humic acid construction ***(Duchaufour, 1983).***

3.2.4 System Description

Reed bed design may vary from installation to installation; depending on local conditions ***(Fox Engineering, 2003).*** In general, a reed bed system is a natural system consisting of a sand drying bed covered with dense vegetation consisting of reeds. The bed consists of different layers of washed gravel with a top layer of sand. The bottom is lined with an impermeable liner to prevent drainage into the underlying soil ***(Kim et al., 1993).*** Leachate water is collected through a perforated pipe installed into the

Figure 3.2: Reed bed system for sludge treatment, typical cross-section



Source: Kadlec et al., 2000

bottom. The sides could be vertical or inclined with a freeboard sufficient to contain accumulated sludge and raw sludge. The system could be vertical flow or horizontal flow, depending on the loading regime and the direction of liquid flow through the system. Figure 3.2 shows a typical vertical cross-section through vertical flow reed bed system for sludge treatment. Such a system could also be used for wastewater treatment instead of for sludge treatment.

Once the beds have been constructed, phragmites reeds are planted. The bed is then flooded with water for a period of time varying from several days to several weeks, depending on the growth rate, to facilitate reed development ***(Kim et al., 1993)***. Once the reeds are established, stabilized sludge is applied to the surface of the bed at regular intervals ***(Kim et al., 1993)***. Raw sludge is applied to the sand and dewatered by gravity flow ***(Burgoon et al., 1997)***.

3.2.5 Planting & Plant Growth

Reeds are planted usually with a density of plants or root stocks being planted at 30-cm centres ***(Kim and Smith, 1997)***. Mellstrom (1994) planted 10 plants per m^2. Roots are planted for six months in a greenhouse before being planted in the reed bed ***(Burgoon et al., 1997)***. As already explained in section 3.2.4, after initial planting, the beds are flooded with water; maintained, and allowed to enter a vigorous, normal growth phase before sludge is applied ***(Kim and Smith, 1997; Burgoon et al., 1997)***. In some plants, sludge is applied immediately after planting, and others are left for 1-2 months before sludge application. The USEPA reports that the beds are usually flooded with water to a depth of about 10 cm for several weeks to encourage plant development, and that sludge is not applied until the plants are well established ***(Kim and Smith, 1997)***.

Plant growth rates vary from one area to another based on climatic conditions and research method. The system needs two years to become fully established, which means that mineralization cannot be detected before that time ***(Nielson, 1994)***. Reeds can grow to their full height of 250 cm in one year under normal weather conditions ***(CERL, 1998)***. After one year, regrowth rates were more than 95% of the plants' full size ***(Burgoon al et., 1997)***.

The plants are more sensitive to air temperature and wind than to the moisture content of sand in the reed bed. When a reed bed is completely drained, the tops of the plant curl and turn a light green then brown only when temperatures increase above 30°C on windy days ***(Burgoon et al., 1997)***.

Experiments showed that the growth of reeds could be hindered or even fully suppressed if strongly anaerobic sludges are applied ***(Lienard et al. 1990)***. Reed beds treating sludge require a passive ventilation system to avoid anaerobic conditions developing in the root zone.

3.2.6 Results and Discussion

The author reviewed all available literature regarding the use of reed beds for sludge dewatering and treatment. The results of all available documents are summarized in Table 3.1. The main factors that control the operation of reed bed system are:

- Hydraulic and solids loading rates
- Raw sludge type and solids content
- Sludge application intervals
- Loading intervals and seasonal variation

The results summarized on Table 3.1 are only for reed bed systems that were considered successful by the authors of the publications, while some results have been omitted for schemes that considered as failures by the same authors. Some data were not published, and there are therefore some gaps in Table 3.1. Regarding the type of sludge, the author has divided sludge into aerobic and anaerobic sludge, which are the main types of raw sludge.

Table 3.1: Hydraulic and Solid Loading rates of researches experiences

Author	Hydraulic Loading Rate cm/m^2.yr	Solid Loading Rate kg/m^2.yr	Solids Content %	Raw Sludge Type	Loading intervals (in weeks) Summer	Loading intervals (in weeks) winter
Mellstrom(1994)- METHEL, ME	196	58.8	3	Aerobic Sludge	2	2
Mellstrom(1994)- CARIBOU, ME	159	47.7	3		2	2
Mellstrom (1994)-WINTER HARBOR	196	34.3	1.75		1	3
Mellstrom (1994) - BRISTOL, NH	265	39.75	1.5		2	
Mellstrom(1994)- WALLINGFORD, VT	224	22.4	1			
Lienard (1990)- USTERS-BACH	350	35	0.9		1.5	
Lienard (1990)- GEMMINGEN	200	146	7.3		1	
Lienard (1990)-DORNSTADT-1	520	23.4	0.4		1	
Lienard (1990)-DORNSTADT-2	130	19.5	1.5		2	
Lienard (1990)-REGSTRUP-1	653	49	0.75			
Maeseneer (1997)	571	40	1.4275		2.5	
Kim (1994)	400	61	3			
Lienard (1995)	225	35	1		1.7	
Bergoon at el, (1997)	571	40	0.7		2	
Nielsen S. M. (1994)	200	40	2		2	
Lienad (1990)-DORNSTADT-3	130	45.5	3.5	Anaerobic Sludge		
Lienard (1990)-WITZENHAUSEN	157	45.8	2.9			
Lienard (1990)-REGSTRUP-2	156	54.6	3.5		6	
Zwara W., (2000)	80	56	7		1.5	
Neurohr (1983)	429	50	0.858			
Kim (1994)	57	36.5	6			

Source: Author, adapted from various publications (see references in the table)

Hydraulic Loading Rate

The hydraulic loading rate (HLR) varies for different authors, see Figure 3.3. Also HLR is affected by sludge type and concentration. Many experiments show that as sludge concentrations increase, the HLR reduces. Reported sludge loading rates on average ranged from 5 to 10 cm per bed, and sludge applications ranged from weekly to bimonthly loadings ***(Kim and Smith, 1997)***. The HLR varies from 0.73 m/year to 7.3 m/year with aerobic stabilized sludge (***Kim and Smith, 1997***), while under the same conditions the HLR reduces to

Figure 3.4: Hydraulic Loading vs. Percent Solids
Aerobic Sludge

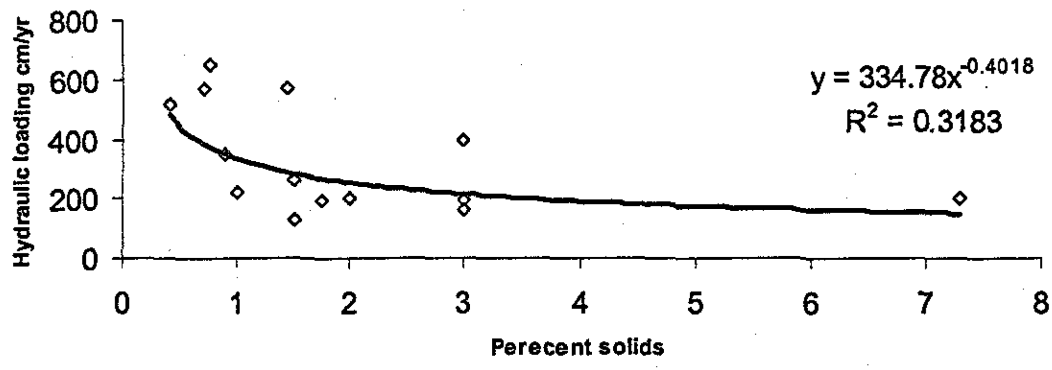
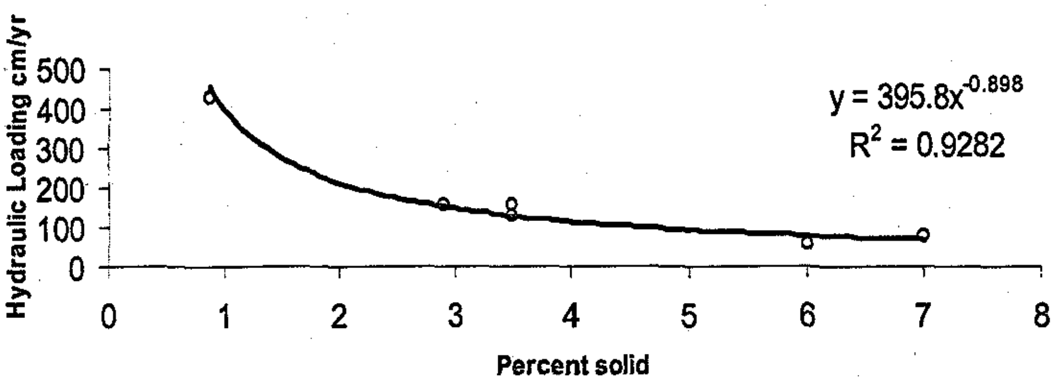


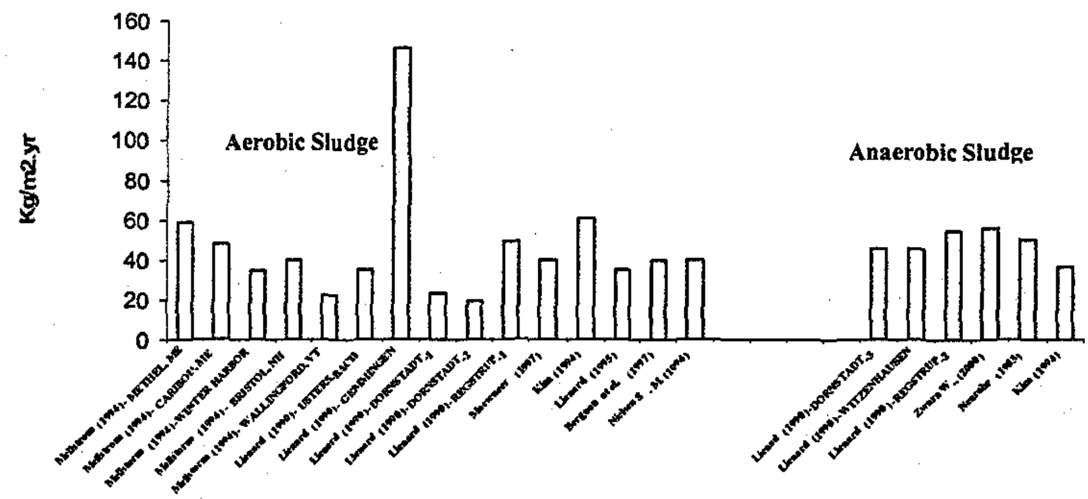
Figure 3.5: Hydraulic Loading vs. Percent Solids
Anaerobic Sludge



Solids Loading Rate

The factors that may affect solids loading rates include the weather conditions (summer/winter), type of sludge, percent solids, area of bed and hydraulic loading rate ***(Kim and Smith, 1997)***. Solids loading rates range from 16 kg/m^2.yr to 106 kg/m^2.yr (***Kim and Smith, 1997***). Another research study carried out using activated sludge shows that SLR varies from 43.8-58.4 kg/m^2.yr and can reach 78.5 kg/m^2.yr (***Lienard et al., 1995***). The loading rate recommended by Hofmann (1990) was an annual dose of 20-30 kg/m^2.year ***(Lienard et al, 1995)***. Burgoon et al. (1997) reported that 65 kg/m^2.yr of TSS can be applied. Solids loading rates ranged from 13 -60 kg/m^2.yr using anaerobic digested sludge with solids content 2-10% and increase up to 16-106 kg/m^2.yr using aerobic digested sludge with solids contents of between 1 and 5% ***(Kim and Smith, 1997).***

Figure 3.6: Solid Loading Rate



Source: Sources are shown on horizontal axis

There is a significant variation in solid loading from one site to another. It seems the main parameters affecting the solids loading rate are the type and quality of raw sludge. Experience from several authors shows that for aerobic sludge, solid loading varies from 20 kg/m^2.yr up to 145 kg/m^2.yr. This range is less for anaerobic sludge, for which solid loading rates can vary from 37 up to 55 kg/m^2.yr.

Figures 3.7 and 3.8 show the relationship between solids loading and percent solids for aerobic and anaerobic sludge respectively. The results are from the publications used as source material for Table 3.1

Figure 3.7: Solids Loading vs. Percent Solids Aerobic Sludge

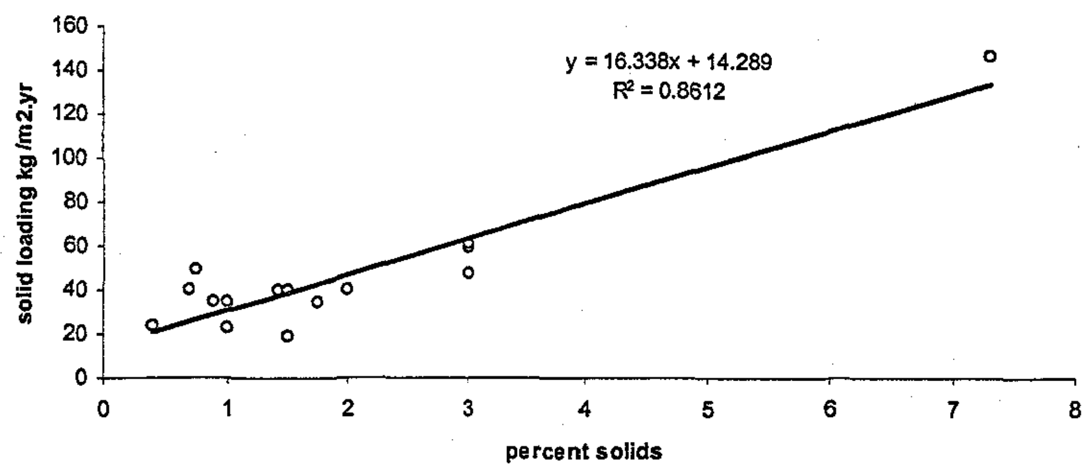
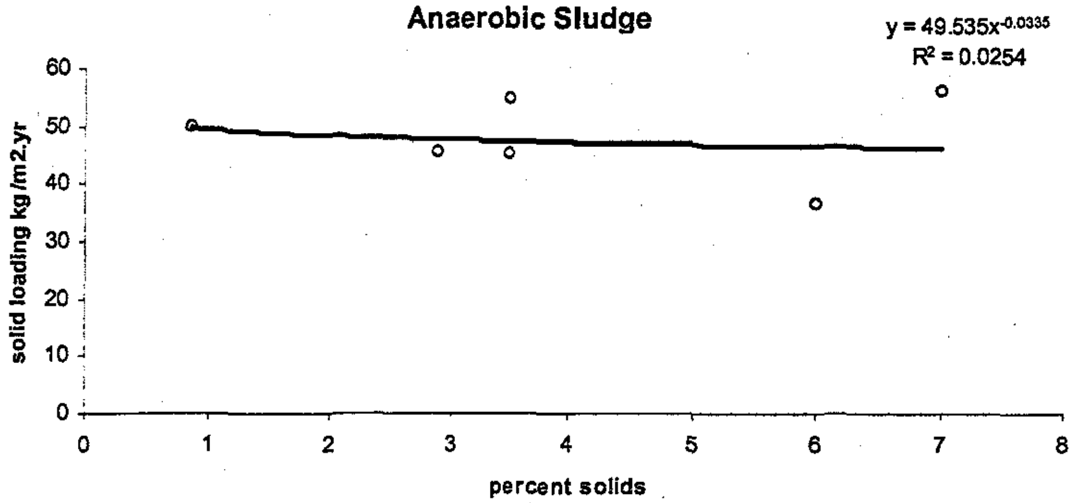


Figure 3.8: Solids Loading vs. Percent Solids Anaerobic Sludge



Based on Figures 3.7 and 3.8, solid loading rates increased while percent solids content in raw sludge increased if aerobic sludge is applied; while for anaerobic sludge, solid loading rates are not affected by the percentage solids contents. Solids loads are calculated based on hydraulic loads multiplied by percent solids. As solids load per year is constant whatever the solids content of raw anaerobic sludge, the hydraulic load is inversely proportional to. solids content. As the solids content in raw sludge increases, the hydraulic load that can be applied reduces. For aerobic sludge, the hydraulic load is not affected by the percent solids of the applied sludge. This makes aerobic sludge more favorable than anaerobic sludge for application to reed bed systems.

Evapotranspiration

The dewatering rate of sludge applied to reed bed systems depends on the infiltration rate of the bed and the evapotranspiration capacity of reeds. Phragmites is well suited to sludge dewatering because it is characterized as being extremely tolerant to variable environmental conditions and as having a high evapotranspiration rate ***(Kim and Smith, 1997)***. Most plants can take up water with osmotic pressure superior to 16 atmospheres; while this pressure in reeds can reach 20 atmospheres, which enables reeds to absorb more water even in adverse conditions. The rate of evapotranspiration from reeds can be double the evaporation rate from an open water surface ***(Lienard et al., 1993)***.

Around 70% of water from applied sludge infiltrated within the first 12 hrs of sludge loading ***(Nielson, 1994)*** and the infiltration stops after 24 hrs. Nielson (1993) stated that infiltration stops when solid contents reaches 20% or more. The rest of water has to be evapotranspirated. Burgoon (1997) estimated that around 10% of hydraulic load is lost through evapotranspiration and the other 90% infiltrates into the bed.

Comparing evaporation and evapotranspiration from reeds, Burgoon (1997) stated that the evapotranspiration rate from reeds is 6.4 mm/day while evaporation from an open water surface at the same climatic conditions is 3.8 mm/day. Reinhofer and Bergholz (1994) stated that of the total water input (sludge + precipitation) 46% leaves the system by drainage, 39% by evaporation and 15% stays in the remaining sludge.

No fixed factors should be used to estimate the water consumption of reed from open water evaporation, as transpiration was much more sensitive than evaporation to weather conditions ***(Herbst and Kappen, 1999)***. The evapotranspiration from reeds could be higher for aerobic sludge than for anaerobic sludge due to healthier growth of reeds with aerobic sludge than with anaerobic sludge ***(Kim and Smith, 1997)***.

It is concluded that the evapotranspiration capacity of reeds is high compared to evaporation rates, although it is difficult to estimate the evapotranspiration capacity of reeds. The figures mentioned by authors are based on their observations, while there are no exact figures that estimate the potential evapotranspiration capacity of reeds.

Reed Harvesting and Accumulated Sludge Removal

Unlike ordinary sand-drying beds, reed beds do not require removal of dried sludge. New sludge may be applied in layers over the previous sludge applications. The reeds are normally harvested annually; usually at the start of the plant's winter dormancy ***(Kim et al., 1993; Mellstrom and Jager, 1994)***. The full height of reeds is around 4 m, Reeds are cut to a height of 8 inches (20 cm) to prevent large plants from drying out and then requiring oxygen for decomposition, as well as to ensure that drying plants will not occupy space that could be filled with solids ***(Keefer, 2000)***.

The sludge accumulation need only be removed from the reed beds after about 10 years of continued application ***(Kim et al., 1997)***, although this figure could vary between 6 and 10 years ***(Fox Engineering, 2003; Burgoon et al., 1997; Nilson, 1993; Neurohr, 1983)***. Reed growth and health is affected by the depth of accumulated sludge. If more sludge is accumulated, more oxygen will be required for sludge mineralization. The authors estimated that the maximum depth of accumulated sludge could reach 60-70 cm, which is the main factor that necessitates removal of accumulated sludge.

Drying Periods

After sludge application, beds are allowed to rest before complete removal of accumulated sludge. The rest period varies from six months ***(Zwara and Obaraska, 2000)*** up to a full year ***(Mellstrom and Jager, 1994)***. Such a period is required to make the accumulated solids drier and to get rid of pathogenic organisms. At the same time mineralization of organic matter can be achieved. Solids content may be between 25 and 50% based on the climatic conditions and the duration of the resting period *(Kim, 1994; Lienard et al., 1990; Nielson, 1994)*.

Cost Analyses

The cost of any sludge treatment system can be categorized into three main items. The initial or capital cost which is the cost of construction of the system. Operational and maintenance cost which is the cost of equipment, manpower and maintenance of the system during operation. The third is the cost of disposal for treated sludge. Comparing reed bed with drying beds, the following points should be noted:

- Construction costs for reed beds are the same as the drying beds. Only the freeboard for a reed bed needs to be greater than for a drying bed to contain the accumulated sludge *(Kim, 1994)*.
- Drying bed systems need regular, intensive manual labour to remove the dewatered sludge *(Kim et al., 1993)*.
- Disposal costs of sludge from reed beds are less than those for drying beds. Composting and mineralization of accumulated sludge reduces its volume *(Neurohr, 1983)*, which has a direct impact on disposal costs.
- The operational cost of a reed bed is 27% that of a drying bed while disposal costs are 50% less for the same quantities of sludge *(Kim and Smith, 1997)*.
- In Pennsylvania, it has been found that significant cost-saving occurs by replacing sludge drying beds with reed beds (*Peter et al., 1997)*.

Quality of Leachate Water

High removal rates for organic pollutants can be achieved in beds planted with reeds. The quality of filtrate depends of the source of raw sludge, hydraulic loading rate and seasonal variation. With a solids loading of 40 kg/m^2.yr and a hydraulic load of 571 cm/yr, the removal rates of COD and TSS can reach 95 and 99% respectively, while a 90% reduction of TKN can be achieved *(Burgoon et al., 1997)* (see Table 3.2). Burgoon et al.(1997) stated that the quality (COD, TKN, TSS) of the filtrate from the reed beds is not influenced by the range of solids loading the bed.

Table 3.2: Water quality in biosolids and filtrate from the Reed Beds in Quincy, WA

Parameter	COD mg/l	TSS mg/l	TKN mg/l	NH_4-N mg/l	NO_3-N mg/l	pH
Biosolids	14,131 ± 5821	14,567 ± 16,647	974 ± 376	126 ± 63	1.0 ± 0.5	7.0 ± 0.2
Filtrate	713 ± 291	75 ± 27	95 ± 22	73 ± 29	6.0 ± 5.9	7.0 ± 0.1
% Removal	95	99	90	42		

Source: (Burgoon et al., 1997).

Experience with planted and unplanted drying beds used for treatment of activated sludge indicates that varying degrees of nitrification are taking place during the passage of the liquid through the bed ***(Lienard et al., 1995; Heinss et al., 1998)***. Ammonium nitrogen (NH_4-N) reductions are particularly high in planted beds. Denitrification was considerably higher in the planted bed than in the unplanted one (237.1 versus 14.1 g N/ m^2.year) ***(De Maeseneer, 1997)***. Begg et al. (2001) stated that effluent quality and removal efficiency of drained water are highly satisfactory in the removal and effluent concentration of suspended solids, organic matter, and nutrients. Reed bed systems show positive removal capacities for nitrogen and phosphorus with the removal mechanisms ascribed to plant adsorption, plant uptake, or chemical transformation and precipitation ***(Revitt et al., 1997)***. The results obtained by Begg et al. (2001) show a 90% reduction in nitrate-nitrogen and an 80% reduction in total phosphorus. The effluent quality of drained water (for BOD and SS) complies with regulatory standards and no further treatment is required; effluent could be discharged directly to waterways ***(Begg et al., 2001)***.

Quality of Accumulated Sludge

Many authors have paid attention to the quality of accumulated sludge to investigate its suitability for land application. Based on the author's conclusions, the following points can be noted:

- Accumulated sludge has 40-50% solids, while metal concentrations increase by between 50% and 150% for dry mass compared with raw sludge ***(Kadlec et al., 2000).***

- Accumulated sludge is mainly biomass and low grade compost ***(Neurohr, 1983).***

- Analyses carried for 3-year accumulated aerobic sludge indicated that the bottom 30 cm of the residue was composted brown matter with a fresh smell. It was well dewatered (over 40% solids), but volatile solids had not mineralized as expected, and there had been only a 5% volatile solids reduction in 4 years ***(Kim and Smith, 1997).***

- Hofmann (1990, 1995) shows several positive effects of the planting of reeds in wastewater sludge such as higher dry weight contents of the residual sludge, enhanced decomposition of the organic matter, and better quality of the percolated water. In the deeper layers of the sludge the numbers of different bacteria groups are roughly ten times as many in the sludge from planted beds as in that from the unplanted beds, whereas it is the reverse in the filtrate (percolated water) ***(De Maeseneer, 1997).***

Pempkowiak and Obaraska (2002) analysed sludge accumulated in a reed bed system for 7-21 years (see Table 3.3). The main concern was the moisture content, organic matter nitrogen, phosphorus and heavy metals. The system was loaded with a hydraulic loading rate of 17.5 mm/m^2.day in summer, 4.7 mm/m^2.day for the rest of the year and a solids loading of 21.25 kg/m^2.year

Pempkowiak and Obaraska (2002) concluded that a 21 year storage period leads to distinct changes in the chemical composition of aerobic sewage sludge. This is best manifested by a decrease in moisture from 46 to 41%, organic matter from 49 to37%, N_{total} from 3.86 to2.5%, P_{total} from 0.51 to 0.23% increasing ratio OM/P 149±2, N_{total}/P_{total} 20±4, and OM/N_{total} 15.0±0.9.

Table 3.3: Contents of water, organic matter, nutrients in stratified sewage sludge stored in Jastarnia

Depth (cm)	Organic matter (% d.m.)	Moisture (%)	N_{total} (% d.m.)	P_{total} (% d.m.)
0-2	40.6	46.7	3.05	0.35
2-4	40.1	48.5	3.1	0.34
4-6	48.5	49.7	3.81	0.55
6-8	50.2	48.6	3.86	0.51
8-10	45.8	44.8	3.25	0.34
10-12	41.9	44.1	2.85	0.28
12-14	38.6	40.2	2.54	0.26
14-16	37	38.7	2.52	0.24
16-18	36.6	39.6	2.44	0.23
18-20	36.8	40.9	2.6	0.24
20-21	32.5	36.1	2.52	0.22
21-22	18.2	28	1.94	0.16
22-23	14.3	26.3	1.7	0.14
23-24	16.4	30.1	1.72	0.12
d.m., dry matter				

Source: Pempkowiak and Obaraska, 2002

3.3 Sludge Management

Sludge is widely used in agricultural purposes in many places around the world. Therefore in this research, the management system regarding sludge treatment methods, laws and regulations, institutional and social aspects of sludge use in agriculture is reviewed in some regional countries and in Palestine.

3.3.1 Sludge Management in Neighbouring Countries

Sludge management system in Egypt, Jordan and Tunisia has been reviewed and analyzed. Table 3.4 summarized sludge management in the three countries regarding sludge treatment methods, sludge disposal, laws and regulations, and institutional aspects.

Table 3.4: Experience of Sludge treatment and disposal in Egypt, Tunisia and Jordan

	Egypt	Jordan	Tunisia
Sludge Disposal	Most of the produced sludge is utilized in agriculture and as soil conditioner	Sludge is only disposed to landfills; no sludge is utilized in agriculture.	Currently, sewage sludge is mainly used for agricultural purposes. Until now, sludge market is not organized. Sludge is supplied to the farmers at low cost compared with other organic fertilizers. Sludge is given to the farmers at the treatment plants, where dried sludge is hauled by the farmers who use it for their agricultural land.
Laws and Regulations	Until now, there have been no strict regulations for sludge utilization. Although, the Egyptian Environmental Agency and Ministry of Agriculture recently issued informal regulations regarding the handling and disposal of sludge	The Jordanian Standards JS 1145/1996 is adopted regarding sludge reuse in agriculture. The main elements of the standards are: Treatment method. Quality inspection Heavy metals concentrations and Pathogenic pollution limits. See appendix F for more details.	Up to now, official control and regulation of sludge quality and use does not exist.
Institutional Aspects	Responsibilities for Water quality management including sludge treatment and disposal are shared by a wide range of governmental institutions at the national, regional and local levels of the government of Egypt supported by a number of NGOs such as scientific Institutions, Universities and others which play a role in policy formation and implementation. See appendix F for more details	Reuse of sludge in agriculture is regulated by the Jordanian Standard JS 1145/1996. The legislation appoints the Water Authority of Jordan and the Department of Environment and Health to monitor the compliance to the law.	The responsibility of wastewater and reuse in agriculture is shared by many Ministries: the Ministry of Environment and Land Management, the Ministry of Agriculture, the Ministry of Public Health and the Ministry of Tourism. More details about the responsibility of each Ministry are presented in Appendix F.

Source: Adopted from DAC/DAPE, 2000

Based on the literature and Table 3.4 the following points are addressed:

Sludge Treatment: the main treatment technologies which are used are aerobic and anaerobic digestion, thickening and conventional sludge drying beds. It seems that the three countries (Egypt, Jordan and Tunisia) are interested in low cost systems which do not require high levels of skill.

Sludge Disposal: In Tunisia and Egypt, most sludge is utilized for agricultural purposes while in Jordan; sludge is only disposed to landfills. It is intended in all countries to utilize sludge in agriculture and to benefit from the nutrients available.

Laws and regulations: The legislation on sludge use in different countries varies greatly. For example, in Egypt the Ministry of Agriculture limits the use of the sludge as a fertilizer in restricted cultivation of uncooked crops, citrus, mango, cotton, green beans, provided that the quantities used not exceed 5 tonnes/acre/year with official and valid permission from the Ministry according to farm size. In Jordan, there are clear laws and regulations that control the treatment and disposal of sludge. In other countries such as in Europe, legislation is much stricter.

Institutional Aspects: the three countries pay attention to reuse of treated wastewater in agriculture where laws and regulations are clear and well defined. The types and numbers of institutions involved in wastewater treatment and reuse differ from one country to another. In Egypt and Tunisia there are many Governmental and Non governmental institutions which are involved in the wastewater sector. The institutions vary from national to regional and local levels. Such arrangements could depend on the size and population of the country. They may also depend on political decisions about the number and responsibilities of different ministries. In Jordan two governmental institutions are responsible for the wastewater sector.

Social Aspects: Farmers attitudes and their acceptance of sludge use in agriculture are not covered in the literature reviewed. This could be due to limited experience and random use of sludge. Only Tunisia promotes the use of sludge and supplies it to the farmers at low cost compared with other organic fertilizers. In other places such as Stockholm (Sweden) the agricultural use of sludge has not been accepted by the food industry, some members of the public and certain interested organizations, even if the quality of sludge is better than the stringent requirements from authorities ***(Mossakowska et al., 1998).***

3.3.2 Current Sludge Management in Palestine

In Palestine, as in numerous other countries where water is scarce, sewage is often discharged as a waste product, leaving most of the attention to focus on emergency measures to solve water supply problems. Therefore, generally speaking, one finds no specific institutional or legal references to sewage management and the tasks and duties of administrative bodies are defined case-by-case on an ad-hoc basis according to the problems and opportunities linked to local skills and resources at the time.

Since 1995, specific requests for action from the PA, and increased difficulties due to general malfunction of sewage treatment facilities, have provided justification for new investment in sewage management facilities.

Current programmes are aimed at increasing the volume of wastewater treated, both as a result of increased urban water consumption and because of a shortcoming in old sewer networks; some networks, for example, collected wastewater, but discharged it without treatment. Between 1995 and 1997, from the author's personal knowledge, eleven such networks in the Gaza Strip were connected to wastewater treatment plants. Programmes are also aimed at reuse of wastewater and sludge for agricultural purposes, because of general public concern about conserving water resources, and protecting the environment.

Existing laws and legislations

The most frequently quoted relevant legislation is Water Law No.3/2002 ***(PNA, 2002)***, (see appendix C) explaining the basis for establishment of the Palestinian Water Authority (PWA). It should be noted that Water Law No.3/2002 is a modified version of Law No. 18, published in 1996. The PWA was officially established in 1996 but existed before the PA. Section 9.3 explains the contents of this law in terms of the functions to be performed by the PWA.

At the same time as the principles for establishing an institutional framework for water management and service delivery for the Palestinian National Authority (PNA), other aspects are discussed in Water Law No.3/2002, in particular the environment and the protection of natural resources.

The "Palestinian Environmental Protection Law No.7/1999 ***(PNA, 1999)***, *(see appendix D*), more commonly known as the Environmental Law, has been approved. It defines how in environmental terms, to locate environmentally sensitive areas, define acceptable levels of pollution, identify the environmental nuisances and conduct environmental assessments.

Its aim is to foster environmental protection in order to guarantee sustainable development of the natural resources available, and to preserve them for future generations. The law is based on several principles which are briefly summarized below:

- Precautionary principle: certain measures shall be taken beforehand to reduce or minimize any risk of danger to the environment.
- Preferential principle: the project with the least negative impact on the environment shall take preference over projects likely to have a larger impact.
- Preservation of natural resources: the good quality of natural resources such as water shall be preserved.
- Polluters pay.

- The public has rights to information, knowledge and participation.
- Cooperation: the public authorities, associations and individuals shall cooperate at all possible levels to protect the environment.

Institutional Aspects

This section provides information about the various organizations associated with the water sector in Palestine. Several organizations are involved and these have legal obligations to cooperate with one another. Much of the information in this section dealing with institutional aspects is based on the author's personal knowledge, informal interviews with local people, and reports from SOGREAH (1998), IUG (2002) and Jamal & Shoblak (2000).

Palestinian Water Authority

The duties and responsibilities of the Palestinian water authority (PWA) were derived from Water law No. 3/2002 ***(PNA, 2002)***. It is recognized as a key organization in the management of water resources throughout Palestine.

Article 7 of the Water Law stipulates that the PWA has responsibility for managing water resources, implementing water policy, and administration as follows:

"*Water resources: the water located within the boundaries of Palestine, whether surface or groundwater, and the regional water, including brackish and wastewater.*

Water policy approved by the Palestinian National Authority, to protect natural and political rights in water resources, its utilization and projects in Palestine.

Administration: monitoring and development of water resources, through guidance, data, studies and comprehensive plans for water utilization, and issuing permits and licenses to use water" ***(PNA, 2002)***.

The creation of the PWA was an important, long-awaited step providing a guarantee of efficient management of available resources, the establishment of water projects and full supervision of their implementation through government bodies, municipal councils or individuals.

In wastewater management, the major responsibilities of the PWA are:

- Legislation :
    - Drafting of legislation on water resources,
    - Drafting of waste water regulations
- Wastewater planning :
    - preparation of master plans
    - planning, design and ensuring technical standards are achieved
- Effluent standards and sludge handling:
    - discharge of effluents for re-infiltration (groundwater recharge),
    - managing, approving and monitoring discharge for agricultural reuse,

The PWA comprises 4 departments:

1. Water resources and planning department, which is mainly in charge of policy strategy, maintaining a water data bank, and hydrological analysis,
2. Regulation department, which is in charge of license fees and tariffs, control of tariff collection, and consumer affairs,
3. Technical department, which is in charge of quality assurance and standards, personnel training, and research,
4. Administrative department, dealing with economics, personnel management and personal services.

The main aim pursued by the PWA is to control knowledge and utilization of local resources whilst facilitating positive initiatives taken by various public and private promoters.

By granting licenses, permits and concessions for any type of water utilization or wastewater end use, the PWA is an important partner in the master plan for sewerage in the Gaza strip. The PWA supervises and monitors individual water projects as well as preparing the national water plan.

Palestinian Environmental Quality Authority (EQA)

Following a decree from the chairman of the Palestinian National Authority, Palestinian Environmental Authority was established on 10^{th} December 1996. This later changed its name to the Ministry of Environmental Affairs and more recently to the Palestinian Environmental Quality Authority. The Authority is improving its performance, but the changes in name do not affect the status, roles and responsibility of the Authority. The structure of the Authority took shape in early 1998 and comprises a multi-skilled staff split into 7 directorates:

- The Inspection and Monitoring Directorate, with district environment offices in Gaza City, Ramallah, Nablus and Hebron. This directorate is in charge of environmental control, and is responsible for follow-up on licensed factories and companies to ensure compliance with the terms agreed when licensed.

- The Natural Resources Conservation Directorate, which is divided into five sub-departments dealing with soil, wildlife, natural reserve, bio-diversity and public park preservation.

- The Environmental Studies, Research and Planning Directorate. This directorate is mainly involved in the establishment of strategy and environmental planning. It works on the basis of statistical tools and data processing, and is also in charge of the central laboratory unit, which allows it to extend the Authority's environmental research activities.

- The Environmental Impact Assessment, Licensing and Pollution control Directorate. This directorate works in conjunction with companies and small, local factories on pollution control and on environmental impact assessments related to business development. It is also involved in finalizing and approving waste treatment processes, both public and commercial.

- The Managerial and Finance Directorate, dealing with EQA staff, recruitment of personnel, and administrative and financial management.

- The Public Relations and International Directorate to ensure the awareness of activities of EQA in the West Bank, the Gaza Governates, and abroad.

- The Project Implementation and International Directorate, is the executive unit for all on-going and proposed projects, negotiating with donors and investors.

Since its creation, EQA has been working on an Environmental Law. The final amendments of this law received approval in 1999. It empowers EQA to enact regulations and decisions under this law in all municipalities and companies.

At least one of the major concerns of EQA is to preserve the consensus between the various authorities and stakeholders involved and to supervise various projects managed by other organizations. EQA therefore works closely with the PWA, with the Regional Utilities and Village Councils, and with MOPIC.

Ministry of Planning and International Cooperation (MOPIC)

The Ministry of Planning and International Co-operation has an important role to play at macro-economic level in integrated planning within the Palestinian Territories, while sectoral planning is the basic responsibility of operating ministries, having responsibility for implementing developments.

The infrastructure projects initially managed by MOPIC are highly demanding, and the various development activities need many different human, financial and material resources. MOPIC has therefore been given a mandate to work in liaison with all PNA operating ministries for medium and long term results.

MOPIC's liaison with operating ministries will enable the integration of all sectoral plans and programmes in the National Development Plan. Monitoring progress is an essential role of MOPIC in the implementation of sectoral policy, projects and programmes.

The human resources of MOPIC are substantial: approximately 215 persons were employed in 2003. MOPIC consists of two main directorates under the Minister. These two general directorates (International Co-operation and Planning) have specific functions and operational duties, and they report to the Minister. Each of these main directorates comprises of a number of other directorates. In addition two smaller directorates (administration and co-operation) manage relations within MOPIC.

Only the directorates within the General Directorate of planning are listed below, because this Directorate has responsibility for infrastructure projects, including sludge management, within the directorate of Water, Sewerage and Storm Water Drainage Planning.

The General Directorate of Planning Sector with:

- The Directorate of Urban and Rural planning, DURP
- The Directorate of project planning & Monitoring,
- The Strategic planning Directorate,
- The Technology & Scientific planning Directorate,
- The Directorate of Roads, Rail & Marine Transportation planning,
- The Directorate of water , Sewerage & Storm water Drainage planning,

- The information & Mapping Center Directorate,
- The Directorate of Human Resource planning & Development.

Ministry of Local Governmental Affairs (MoLG)

This Ministry is responsible for coordinating the provision of services by regional utilities. Its role is to control technical and financial operations. It is in charge of pricing policy in each municipality.

The Ministry comprises 4 departments:

1. Department of Engineering, including a planning unit working on land use,
2. Department of Projects, having responsibilities for implementing and maintaining infrastructure projects.
3. Financial, Management, and Administration Department,
4. Inspection and Control Department.

Municipalities and Village Councils

There are 16 Municipalities in the Gaza strip, each municipality having more than 5000 inhabitants. In addition there are 7 local village councils, consisting of villages with a population of up to 5000 inhabitants. Some of these villages have very small population.

Responsibilities for village councils and municipalities differ on some issues. The Municipality and village councils are responsible for providing water and sewerage services. The legal basis is very complex since laws and regulations from the Ottoman Empire, the British mandate, the Jordanian Government and the Israeli occupation all appear to play a significant role. However, individuals and municipalities can hold water rights.

Finance for operation and maintenance of water supply and sewerage systems is the responsibility of the municipalities and village councils. The recurrent expenses associated with these systems are mainly wages, raw materials, power, and supply of spare parts.

The councils are responsible for the collection of water revenues and taxes. Revenue collection is regulated by the guidelines established by the Ministry of Local Government Affairs.

3.4 Conclusions and Recommendations

Based on the literature review of using reed bed for sludge treatment and the experience of using sludge in agricultural purposes, the following conclusions and recommendations can be identified.

3.4.1 Sludge Treatment

Great attention has been paid to sludge treatment and dewatering using reed bed systems. The start was a modification of traditional drying bed systems, which is to retrofit sludge drying beds by planting it with reeds. Based on the review of the experience from USA, UK, West and East Europe the following points can be addressed.

System design: most constructed reed bed systems are very similar. The beds are similar to drying beds with planted reeds. Some modifications are made to traditional drying bed systems by providing ventilation pipes to maintain the root of the reed in aerobic conditions.

Raw Sludge: secondary sludge was applied in reed bed systems. Aerobic and anaerobic sludge have both been tried. The solid content of sludge varies from 1-5% in aerobic sludge and up to 10% in anaerobic digested sludge. This wide range of sludge quality provides evidence that reed beds can cope with different sludge qualities.

Hydraulic Loading Rate: review of other experience on this field shows a wide range of hydraulic loadings applied to reed bed systems. The main effect of the hydraulic load is the raw sludge type (aerobic & anaerobic), solid content and climatic conditions. Based on data collected from different experiences, it is concluded that the hydraulic loading rate can be higher for aerobic sludge than for anaerobic sludge.

Solids Loading Rate: reed bed systems can cope with different quantities of solids loading rates. The main parameters affecting the capacity of reed bed systems are the quality of raw sludge and the climatic conditions.

Based on the review of several studies of using reed bed system for sludge treatment, the following points can be addressed:

- A number of reed beds treating sewage sludge have been operating successfully in Europe and in North America over periods of up to eight years without sludge removal ***(Lienard et al. 1990; Kim and Smith, 1997).*** As an example, a survey of operators from 17 treatment plants in New England reported that 12 prefer reed bed, 2 do not have an opinion while only three do not prefer reed bed ***(Mellstrom and Jager, 1994).***

- Previous experience reveals that good permeability is maintained despite an increasing sludge height on the bed. This may be attributed to the permanent root growth, which prevents clogging of the soil/sludge filter.

- The main parameters that control the system performances are: hydraulic & solids loading rate, raw sludge quality and climatic conditions.

- Health conditions of reeds are influenced by air temperature and wind more than moisture content of the sand in the reed bed. The biological activities inside the accumulated sludge are affected by weather conditions, which influence the mineralization rate of accumulated sludge. Also in many places, hydraulic loading stopped for a certain period of the year due to freezing or the dryness of the reeds.

- Raw sludge is applied every one to two weeks, and in some research programmes it is applied every six weeks.

- Hydraulic loading rates are affected with sludge type. Higher rate of hydraulic load could be applied for aerobic sludge.

- Sludge loading could be stopped when the depth of accumulated sludge reaches 60-70 cm. A drying period from 2 months up to one year is required to dry accumulated sludge before removal and disposal.

- Accumulated sludge receives a significant improvement due to mineralization and dewatering where the solids content could reach 25-50%. The mineralization and composting ratio of accumulated sludge depends on accumulation duration, type of raw sludge and solid loading rate.

Although experience of reed bed system is promising, the following gaps have been identified:

- The system is weather-dependent and the available experience is limited to locations in the USA and Europe. No research studies have been carried out in arid or semi-arid regions, which are expected to show better results due to warmer and more favourable climatic conditions than in Europe.

- The available literature describes results not design parameters. Operational parameters such as HLR, SLR and seasonal variations vary from one author to another. This makes it difficult to make a design for a reed bed system based on available figures.

- Design of reed beds is empirical and most results are based on certain climatic conditions. No clear design criteria have been developed to design reed bed systems.

- It is recommended that: further research is required to investigate the performance of reed bed technology in other places with different environmental conditions.

3.4.2 Sludge Disposal

Based on the literature review regarding sludge handling in Egypt, Jordan and Tunisia, the following points are addressed:

- Sludge use for agricultural purposes is the most preferred and main alternative for the use of sludge as a resource of fertilizers. To use sludge for agricultural purposes, sludge quality must be guaranteed by use of a well defined control programme for sludge quality.

- In many countries attention is paid to wastewater reuse and institutional arrangements are well clarified. Regarding sludge reuse, the same institutions can handle such issues but there is still a need for determining the responsibility of the existing institutions with regard to sludge use in agriculture.

- The socio-economical aspects of sludge use require more investigation, and each country should study such important factors with respect to the behavior of farmers and the needs of each country.

- Many institutions in Palestine are involved in the water and wastewater management sector. The current roles of such institutions are not clear.

- The recently established water and environmental laws outline the general responsibilities of the Palestinian institutions, mainly the Palestinian Water Authority and the Environmental Quality Authority.

- The roles and responsibilities of different Palestinian institutions regarding sludge handling have yet to be specified and clearly defined.

CHAPTER 4

The Gaza Strip Sludge Quantity and Quality

4.1 Introduction

In the Gaza Strip, there is a desperate need for rehabilitation of the current wastewater collection, treatment, and disposal systems. Treatment systems, if they exist, are under-designed and rely on old technologies that have proved to be unable to solve the existing problems. Partially treated wastewater is disposed of either into the Mediterranean Sea or by flooding agricultural land, both of which were banned as a practice in most European countries and in the United States years ago due to their proven health risks for fish, biota and humans ***(SOGREAH, 1998)***.

The sludge management challenges are not currently considered in detail in Palestine due to the lack of proper treatment systems. However residents of the Gaza Strip will face challenges after the construction of such ongoing and future projects related to the wastewater management sector in the Gaza Strip.

Planning and design of any sludge treatment and disposal system requires determining the quantity and the composition of existing and future sludge generated in the area. The author therefore determined the quantity and quality of existing and future sludge in the Gaza Strip based on the available literature, current and planned wastewater treatment systems, present population data, and future population forecasts for the Gaza Strip.

4.2 Existing Wastewater Treatment in the Gaza Strip

There are three wastewater treatment plants in operation in the Gaza Strip: Jabalia WWTP in the North, Gaza WWTP in Gaza City and Rafah WWTP in the South. The type of treatment, quantity and final disposal of each plant is summarized in Table 4.1; note that the WWTP at Beit Lahia is often referred to as Jabalia WWTP.

Table 4.1: Existing Treatment plants in the Gaza Strip

Location	Treatment method	Quantity of wastewater treated m^3/day	Final disposal	Remarks
Beit Lahia (Jabalia)	Stabilization ponds and aerated lagoons	8,000-1,0000	Surrounding sand dunes	The treatment plant is overloaded, and poorly managed
Gaza	Anaerobic ponds followed with bio-towers	40,000 – 45,000	75% to the sea and 25% infiltrated to the ground aquifer	The treatment plant was rehabilitated in 1999 to treat a max design flow of 32,000 m^3/day.
Rafah	One aerated lagoon	3,000 – 4,0000	To the sea	The plant is overloaded, and poorly managed

Source: Data compiled by author, 2001

In general three existing treatment plants provide only partial treatment of the wastewater. Table 4.2 presents analyses carried in the Gaza laboratory for both influent and effluent of the three treatment plants. Concerning organic matter, Gaza treatment plant achieves more than 90% removal of BOD and COD. The percentage nitrogen removal in all plants is very low and in some plants there is no difference between influent and effluent concentrations. No treatment processes are provided for pathogen removal. Sometimes, numbers of Faecal Coliforms in the effluent are higher than the influent. This is due to the evaporation from ponds, which increase the concentration. Septage from unsewered areas is disposed direct into the ponds. The quality of the influent does not include septage while in the effluent it does. Facilities have been provided for disinfection of effluents at Gaza, but currently no treated effluents are disinfected. The facilities at Gaza are not operational because they have not been maintained. Also, disinfectants are expensive, and Israel does not permit import of chlorine-based products.

Table 4.2: Quality of Inf. & Eff. of wastewater in the Gaza Strip

Parameter	Beit Lahia			Gaza			Rafah		
	No of Tests	Influent	Effluent.	No of Tests	Influent	Effluent.	No of Tests	Influent	Effluent.
pH	2	7.84	7.2	50	7.4-7.85	7.6-7.83	2	7.38	7.48
Temperature °C	2	16.1	15	50	14-20.7	16-19	2	23.5	22.2
Sett. Solids mgl/l	2	6	TR	42	3.5-38	TR-0.7	2	13	0.1
TS mg/l	2	1888	1480	28	1472-3960	1024-1536	2	2140	1610
TDS mg/l	2	1471	1445	28	1094-2267	905-1503	2	1518	1484
TSS mg/l	2	417	35	40	244-1693	31-79	2	622	126
TVSS mg/l	2	370	30	40	212-1397	24-57	2	550	110
NO_3-N mg/l	2	0	0	4	0	1.6-2.37			
NH_3-N mg/l	2	61.6	54.6	4	51-70	41-47.6	2	88	63.6
TKN-N mg/l	2	102.7	75.6	2	74	57	2	128.8	88.2
Cl mg/l				2	-	340-400			
PO_4 mg/l				2	-	6.89-9			
BOD_5 mg/l	2	420	40	10	360-1600	35-41	2	760	240
COD mg/l	2	1078	120	15	608-3100	114-162	2	1298	556
F.Coliform CFU/100ml	2	$4.4x10^8$	$8.3x\ 0^5$	10	$2.5x10^8$ $-5x10^9$	$3.4x10^6$ $-3x10^7$	2	$2x10^9$	$7.5x10^7$

Source: Gaza Municipality Lab, 2001 TR: Trace

A monitoring program for wastewater quality was carried out in the Gaza Strip in July 2001 *(IUG, 2002)*. Six different locations around the Gaza Strip were monitored for one week, and composite samples were taken every 15 minutes over a 48 hour period consisting of one working day and a holiday. Around 40-50 houses were monitored per area to have the same quantities of flow during monitoring. The samples were tested for a range of physical, chemical and microbiological quality parameters. The main concern was assumed to be associated with heavy metal pollution, but results (see Table 4.3) show that all samples contained no significant heavy metal concentrations. Comparing

Gaza figures with international figures shows that heavy metal average concentration in wastewater in the Gaza Strip is less than the concentration of international figures. Heavy metals concentration in the Gaza wastewater varies from 4% for Cd up to 34% for Zn compared with international figures.

Table 4.3: Heavy metal concentrations in raw sewage at different locations in the Gaza Strip

Parameter	Shejaia	Shaboura	Radwan	Jabalia	Remal	Tel Sultan	Average mg/l	Max mg/l	Typical* International figures mg/l
Pb (mg/l)	0.00	0.00	0.00	0.14	0.01	0.00	0.03	0.14	0.1
Fe (mg/l)	1.46	1.78	0.53	6.06	2.12	1.45	2.23	6.06	
Co (mg/l)	0.00	0.03	0.13	0.16	0.13	0.09	0.09	0.16	
Cu (mg/l)l	1.35	0.00	0.00	0.13	0.00	0.00	0.25	1.35	1.0
Hg (mg/l)	0.02	0.26	0.03	0.28	0.02	0.16	0.13	0.28	0.1
Zn (mg/l)	0.08	0.21	0.03	0.34	0.07	1.27	0.34	1.27	1.0
Cd (mg/l)	0.00	0.01	0.04	0.13	0.00	0.03	0.04	0.13	1.0

Source: IUG, 2002

****: Crites & Techobanoglous, 1998***

In summary, raw wastewater in the Gaza Strip is strong regarding organic load. The estimated organic load is 45-55 g/c/d ***(SOGREAH, 1998)***. Water use (100 l/c/d) in the area is low compared with international figures (> 150 l/c/d). This is due to the scarcity of water, its salinity and its high concentration of nitrates. Water use is around 100 l/c/d and approximately 80% of the water used is returned as wastewater ***(IUG, 2002)***. The combination of organic load and low water use means that the organic concentration of the wastewater is high. Wastewater in the Gaza Strip is relatively free of contamination by heavy metals. This is due to the limited number of industries, and the fact that most wastewater is from domestic sources. This suggests that the treated wastewater and sludge could be applied to crops with minimal risk of heavy metal accumulation.

4.3 Future Wastewater Plans

After the establishment of a Palestinian Authority in 1994, attention has been paid to improving environmental conditions in Palestine. New plans were prepared to construct new wastewater treatment plants. The Palestinian

Authority intends to construct three treatment plants to serve the entire Gaza Strip. One will be in the Northern Area to serve the northern part of the Gaza Strip (Jabalia, Beit Lahia and Beit Hanon). A second, and the largest of the three, will be in the middle to serve Gaza City and the Middle Area of the Gaza Strip. One more is planned in the south to serve the Khanyounis and Rafah areas

The development plans of MOPIC estimates that the standard of living in Palestine will be improved and the Palestinian water demand will raise from 100 l/c/d nowadays up to 140 l/c/d by 2010. The estimated wastewater generation in 2010 is predicted to be 112 l/c/day. This means that 123,535 m^3/day of wastewater will be generated in the Gaza Strip by the year 2005, and flows will increase up to approximately 325,968 m^3/day by 2025 which is the end of the design period for the planned treatment plants. Table 4.4 illustrates population forecasts, water use and wastewater generation in the Gaza Strip up to 2025. Calculations are based on population estimated from MOPIC (1998), water use of 115 l/c/day for the year 2005 and 140 for years 2015 & 2025 where 80% returns as wastewater.

Table 4.4: wastewater forecast in the Gaza Strip

	2005		2015		2025	
Area	Population Inhabitants	Wastewater m^3/day	Population Inhabitants	Wastewater m^3/day	Population Inhabitants	Wastewater m^3/day
Northern Area	198234	18238	258495	28951	318892	35716
Gaza and Middle Area	694583	63902	1091504	122248	1385860	155216
Khan younis and Rafah	449954	41396	937466	104996	1205676	135036
Total	134,277,1	123,535	2,287,465	256,196	2,910,428	325,968

Source: Author Calculation based on population estimated from SOGREAH (1998)

4.4 Sludge Quantity

The quantity and the composition of wastewater sludge produced is difficult to determine. The quantity and nature of sludge is based on the type of treatment system (aerobic & anaerobic), quality of raw wastewater and the efficiency of treatment plant.

4.4.1 Current Sludge Quantities

Sludge currently generated in the Gaza Strip is difficult to quantify. No measurements are taken and there are no previous estimates of sludge quantities removed from ponds. The sludge produced in Jabalia and Rafah treatment plants is kept in the ponds for several years and when desludged, it is kept in the sand dunes around the treatment plant without any treatment. Such dispose could pollute the groundwater in the area through increasing the concentration of Nitrate. In the Gaza treatment plant, 8 sand drying beds were constructed with a surface area of 430 m^2 each. Due to the large quantities of sludge and the unsatisfactory operation of drying beds, the sludge is disposed of in the unused areas of the treatment plant. After partial drying, the sludge is transported to solid waste dumpsites within the Gaza Strip. Due to the high cost of transporting and land filling of dry sludge, it is kept in the treatment plants where it mixed with sand or fly due to wind into the adjacent agriculture areas. Estimates suggest that around 400 m^3 of sludge is produced daily in the Gaza treatment plant excluding the quantities accumulated in the ponds, which is estimated to be 50,000 m^3/year from the three treatment plants. The estimates are based on the measurement taken by the author using flow measurement and the theoretical calculations carried by the author depending on the treatment process, quantity and quality of the influent and the effluent of wastewater, see Appendix C for more details.

4.4.2 Future Sludge Quantities in the Gaza Strip

The master plan carried in by SOGREAH (1998) for sewerage and storm water drainage in the Gaza Strip Governorates made estimates for future population numbers and wastewater generation rates. As described in section 4.3, according to the master plan, three wastewater treatment plants will serve the whole population of the Gaza Strip. Table 4.6 presents forecasts for the population, expected wastewater flows and sludge quantities by year 2025. The study proposed that oxidation ditches (an extended aeration version of the activated sludge system) would be used for wastewater treatment in all three treatment plants with an F/M ratio of 0.1 – 0.2 gram BOD per day per gram MLSS. The quantity of solids as dry matter was calculated based on the following formula ***(Hammer, 1986)***:

$$Ms = K \times BOD$$

Where;

Ms = Biological sludge solids, grams of dry mass per day

K = Fraction of applied BOD that appears as excess solids

BOD = BOD in applied wastewater, gram per day

Based on an F/M ratio of 0.15 and according to Hammer (1986), K= 0.38. The quantities of sludge estimated by the year 2025 is presented in table 4.5

Table 4.5: Wastewater and sludge quantities in the Gaza Strip by 2025

	Northern Area	Gaza and Middle Area	KhanYounis and Rafah	Total
Population	318,892	1,385,860	1,205,676	2,910,428
Wastewater m^3/d	35,716	155,216	135,036	325,968
Sludge kg dry solids/day	6,107	26,542	23,091	55,740

Source: Author calculations based on SOGREAH population forecast (1998)

The sludge is expected to consist of 1-2% dry solids which means that 3,716 m^3 of sludge will be generated in the Gaza Strip by the year 2025.

4.5 Sludge Composition

The sludge resulting from wastewater treatment plants is usually in the form of a liquid or semi-solid liquid that typically contains from 0.25 to 12 percent solids by weight ***(Metcalf & Eddy, 1991)***. The solid phase consists principally of organic matter, derived from human, animal and food wastes. Other constituents are trace contaminants (metals and persistent organic compounds) mainly from industrial waste and bacteria, some of which may be pathogenic. Nutrients like nitrogen, phosphorus, potassium and some trace metals are present in sludge and the nutrient content of sludge makes it potentially useful as a fertilizer.

The characteristics and amounts of sludge generated depend on the characteristics of the raw wastewater and the treatment plant process. Sludge can contain not only organic and inorganic matter, but also bacteria and viruses, oil and grease, nutrients such as nitrogen and phosphorus, and heavy metals ***(Metcalf & Eddy, 1991)***.

Of the constituents removed from wastewater by treatment, sludge is by far the largest in volume, and it's processing and disposal is perhaps the most complex problem facing the engineer in the field of wastewater treatment ***(Metcalf & Eddy, 1991)***. Table 4.6 illustrates typical chemical composition and properties of untreated and digested sludge.

Table 4.6: Typical chemical composition and properties of untreated and digested sludge

Item	Untreated primary sludge		Digested primary sludge		Activated sludge range
	Range	Typical	Range	Typical	
Total dry solids (TS), %	2.0-8.0	5.0	6.0-12.0	10.0	0.83-1.16
Volatile solids (% of TS)	60-8-	65	30-60	40	59-88
Protein (% of TS)	20-30	25	15-20	18	32-41
Nitrogen (N, % of TS)	1.5-4	2.5	1.6-6.0	3.0	2.4-5.0
Phosphorus (P_2O_5, % of TS)	0.8-2.8	1.6	1.5-4.0	2.5	2.8-11.0
Potash (K_2O, % of TS)	0-1	0.4	0.0-3.0	1.0	0.5-0.7
Cellulose (% of TS)	8.0-15.0	10.0	8.0-15.0	10.0	
Iron (not as sulphide)	2.0-4.0	2.5	3.0-8.0	4.0	
Silica (SiO_2, % of TS)	15.0-20.0		10.0-20.0		
pH	5.0-8.0	6.0	6.5-7.5	7.0	6.5-8.0
Alkalinity (mg/l as $CaCO_3$)	500-1,500	600	2,500-3,500	3000	580-1,100

Source: Metcalf & Eddy, 1991

4.6 Composition of Sludge from the Gaza Strip

To treat and dispose of sludge produced from wastewater treatment plants in effective manner, it is important to know the characteristics (both quantity and composition) of the sludge to be processed. The characteristics vary depending on the origin of the sludge, and the type of treatment processing to which the sludge been subjected.

Attention has only recently (since 1996) been paid to sludge quality in the Gaza Strip. Previously, the concern of Palestinians was concentrated on how to dispose of the sludge from treatment plants. First analyses of sludge composition were carried out in 1996 within the framework of the project "*Feasibility Study and master plan for Khanyounis Sewerage System*" ***(Pacific Consult, 1996)***. Samples of sludge accumulated in both Gaza and Rafah treatment plants were collected and analysed to establish their physical and chemical composition. A summary of the results is shown in Table 4.7.

Table 4.7: Quality of sludge in Gaza & Rafah Treatment Plants

Location	Rafah Wastewater Treatment plant			Gaza Wastewater treatment Plant		
Item	Sample C-1	Sample C-2	Sample C-3	Sample C-4	Sample C-5	Sample C-6
BOD5,mg/l	9861	4243	6711	6858	11022	10135
COD mg/l	26656	7278	13176	27300	26014	381107
T-N, mg/l	319.2	210.4	238.8	211.8	245.5	501.4
T-P, mg/l	124	175	198	215	266	228
Specific Gravity kg/l	1.479	1.372	1.249	1.149	1.52	1.263
Water Content,%	30.3	23.9	27.2	24.1	52.9	72.1
Volatile Solids, mg/kg dry basis	588,700	107,280	141,440	143,026	256,800	641,232
Potassium (K), mg/l	211.30	134.7	14.55	92.60	114.47	187.70
Copper (Cu) mg/l	26.52	4.07	15.32	11.67	18.55	15.90
Zinc (Zn), mg/l	108.67	37.50	91.12	63.90	73.92	190.77
Cadmium (Cd), Mg/l	0.03	0.00	0	0	0	0
Lead (Pb), mg/l	11.37	5.05	6.52	8.22	10.75	15.40
Iron (Fe),mg/l	2805.8	1870.8	2516.60	1184.6	1325.42	1281.9
Manganese (Mn), mg/l	20.37	19.97	14.55	10.87	9.55	20.17
Total Chromium (Cr),mg/l	12.82	2.82	8.82	2.70	2.75	6.57
Arsenic(As),mg/l	0.00	0	0	0	0	0
Mercury (Hg),mg/l	0.00	0	0	0	0	0

Source: Pacific Consult (1996)

The analyses show that sludge is almost free of heavy metals and rich in nutrients such as nitrogen and phosphorus. Compared with international figures (see Table 4.8), sludge in the Gaza Strip is almost free from heavy metals; this is due to the limited industrial activities in the area.

Table 4.8: Heavy metal concentration in sludge mg/kg in international figures and the Gaza Strip

Constituent	Typical International	EPA median	Gaza Strip*
Arsenic	10	10	0
Boron	33		
Cadmium	16	10	0.006
Cobalt	4	30	
Chromium	890	500	
Copper	850	800	18.7
Mercury	5	6	0
Manganese	260	260	19.4
Molybdenum	30	4	
Nickel	82	80	
Lead	500	500	11.6
Zinc	1740	1700	114.9

Source: Crites & Techobanoglous (1998)

****: The Author calculations based on table 4.7***

4.7 Conclusions

- The existing treatment plants in the Gaza Strip provide limited treatment. This is due to overloading, poor management and limited resources.
- Existing sludge management and handling is unsatisfactory and improved management is required to protect the degraded environment in the Gaza Strip.
- Constructing new treatment plants using oxidation ditches based on activated sludge will generate more sludge. More than 3,716 m^3/day of raw sludge will be generated in the Gaza Strip by the year 2025. This will increase the current sludge problem and make it more important

that safe and healthy sludge management practices and policies are followed.

- Analyses of sludge indicate that it is free from heavy metals and other chemical pollutants, which mean that sludge could be safe if it is used as a soil fertilizer.

4.8 Recommendations

It is recommended that practical steps towards sludge management need to be started. Any management plan has to take into consideration the potential of sludge to be used as a soil fertilizer.

CHAPTER 5

Standards and Guidelines of Sludge Use for Land Application

5.1 Introduction

Handling and disposal of sludge in Palestine, as elsewhere, needs to be in accordance with standards and guidelines to protect the environment and health from possible accident or disaster due to mishandling of such material. Many international and regional countries had established their own standards and guidelines for sludge application for agriculture purposes. The Palestinian Environmental Quality Authority (EQA) is in the process of establishing Palestinian standards taking into consideration the Palestinian needs.

In this chapter, the author discusses the impacts on health, soil and the environment of land application of sludge, and the standards and regulations adopted by regional and international countries, which apply sludge for agriculture purposes. Finally, the Palestinian draft standards are presented and discussed, together with conclusions and recommendations.

5.2 Potential Problems with Land Application of Sewage Sludge

Application of sludge as a fertilizer on agricultural land, could potentially cause many environmental and health problems to soil, water, plants and human. The following points present the possible impacts of sludge application in agriculture.

Disease-Causing Organisms (Pathogens)

Raw sludge could be contaminated with various pathogenic organisms such as bacteria and viruses. Only treated (stabilized) sludge with few or no disease-causing organisms should be applied to land.

Water Quality

Sludge could be a source of groundwater and surface water contamination. Excess nitrogen and potassium applied as plant nutrients have a tendency to *seep into groundwater, and excess phosphorus and nitrogen may flow into* surface water supplies with eroded sediment ***(Muse et al., 1991).***

Nuisances: Insects and Odours

Fresh sludge smells unpleasant and attracts insects, which may create nuisance, and may spread pathogens from sludge to food. Sludge treatment greatly reduces odours. Instead of the familiar smell of raw sewage, treated sludge has neither the odour nor insect problems usually associated with raw sewage.

Heavy Metals

Sludge could contain heavy metals such as cadmium, zinc, nickel, copper, chromium, lead, and mercury. Heavy metals accumulated in plants and animals. Some heavy metals, including zinc and copper, are micronutrients that are necessary for plant growth. Excessive amounts of some heavy metals (zinc, copper, nickel, etc.) can be damaging to plants, resulting in reduced yield or even plant death ***(Muse et al., 1991).*** Table 5.1 shows possible sludge contaminants and the potential concern of each contaminant..

Table 5.1: Contaminants and potential concern in sludge

Contaminant	Potential Concern
Pathogens: bacteria and virus diseases	Human health
Nitrates	Applying in excess of plant needs; excess application entering groundwater
Copper, Zinc, and Nickel	Accumulation in topsoil; toxic to plants at high levels
Cadmium	Accumulation in topsoil; taken up by plant and accumulates in leafy material; accumulates in animal organs; human health
Lead	Accumulation in topsoil: Potentially harmful if excessive amounts are ingested with soil particles by animals
Mercury, Chromium, Selenium, Arsenic, and Antimony	Little concern unless present in extremely high amounts

Source: (Muse et al., 1991)

5.3 Benefits of Sludge Applied to Land

Sludge contains many constituents such as organic matter and nutrients, which improve soil and are necessary for plant growth. Wastewater sludge can be used as an alternative to animal manure as a fertilizer. Table 5.2 provides a comparison of the chemical compositions of sewage sludge and animal manure.

Table 5.2: Chemical composition of sewage sludge and animal manure

Constituent (Unit)	Animal Manure[a] Range	Sewage Sludge Range	Sewage Sludge Typical
Nitrogen (% dry Weight)	1.7- 7.8	< 0.1 – 17.6[b]	3.0
Total Phosphorus (% dry weight)	0.3 – 2.3	< 0.1 – 14.3[b]	1.5
Total Sulphur (% dry weight)	0.26 – 0.68	0.6 – 1.5[b]	1.0
Calcium (% dry weight)	0.3 – 8.1	0.1 – 25[b]	4.0
Magnesium (% dry weight)	0.29 – 0.63	0.03 – 2.0[b]	0.4
Potassium (% dry weight)	0.8 – 4.8	0.02 – 2.6[b]	0.3
Sodium (% dry weight)	0.07 – 0.85	0.001 – 3.1[b]	-
Aluminium (% dry weight)	0.03 – 0.09	0.1 – 13.5[b]	0.5
Iron (% dry weight)	0.02 – 0.13	< 0.1 – 15.3[b]	1.7
Zinc (mg/kg dry weight)	56 – 215	101 -27,800[b]	1200
Copper (mg/kg dry weight)	16 – 105	6.8 – 3120[c]	750
Manganese (mg/kg dry weight)	23 – 333	18 – 7,100[b]	250
Boron (mg/kg dry weight)	20 – 143	4 – 757[b]	25
Molybdenum (mg/kg dry weight)	2 – 14	2 – 976[b]	10
Cobalt (mg/kg dry weight)	1	1 – 18[b]	10
Arsenic (mg/kg dry weight)	12 – 31	0.3 -316[c]	10
Barium (mg/kg dry weight)	26	21-8,980[b]	-

[a] Data summarized from Azevado and Stout, 1974

[b] Data summarized from Dowdy et al., 1976

[c] Data summarized from Azevado Kuchenrither and Carr, 1991

Source: (Dessau-Soprin , 1999)

The composition of both animal manure and sewage sludge is variable depending on a number of factors. For animal manure factors could includes the type of animal and the diet. For sewage sludge, eating habits, treatment methods and the nature of local industries are significant. As can be seen from Table 5.2, sludge has higher metal contents for all constituents except for potassium. In the Gaza Strip, there is little industry, and sludge is mostly free of heavy metals. This makes sludge more favourable than animal manure for use as a fertilizer if treated well.

5.4 Regional and International Sludge Standards and Guidelines

Finding ways to reuse sewage sludge is an interesting avenue to pursue. Sludge from both water treatment and wastewater treatment can be used as a fertilizer subject to suitable treatment and management. Sludges can also be used to improve soils that are very sandy or have a low organic matter content.

The author reviewed the standards and guidelines for land application of sludge adopted by regional countries as Egypt, Israel and Jordan. Also International standards are reviewed and analysed to make a comparison between regional and international standards.

5.4.1 Regional Standards

The neighbouring countries (Egypt, Israel, Jordan) have established some regulations and guidelines for sludge application. Table 5.3 summarizes the standards of Egypt, Jordan and Israel. Gaps in the table are because the author did not find some values within the Jordan and Israel standards.

The Egyptian standards pay attention to the physical quality of sludge in terms of its density, moisture content, organic matter and nitrogen content. The standards for all three countries consider the concentration of heavy metals and stipulate limitations for heavy metal concentrations as percentage of dry weight.

Table 5.3: Egyptian, Jordanian and Israeli Standards for Sludge use in agriculture, heavy metals are calculated as mg/kg dry matter

Parameters	Egyptian	Jordan	Israeli
Organic matter	>40%		
NaCl	<5%		
Total nitrogen	>2%		
Density	>400kg/m3		
% Dried Solids	>30%		
Fe	1.61%		0.58-2.6
Cu	205-375	4300	1000
Ni	130-240	420	200
Zn	1200-1550	7500	2500
As	1.45-2.47	75	2.47
Hg	3-4	57	5
Cd	20	85	20
Cr	1000	3000	700
Pb	250-275l	840	300
Se	-	100	30
Mo	10	75	10

Source: OTU, 1998 and EQA, 2003

5.4.2 Sludge Application in Europe

Sewage sludge application to land in EU countries is governed by Council Directive No. 86/278/EEC (Council of the European Communities 1986) *(Pescod, 1992)*. This Directive prevents use of sludge in agriculture unless specified requirements are satisfied, including sludge and soil testing. Parameters subject to the provisions of the Directive include the following:

- Dry matter (%)
- Organic matter (% dry solids)
- Copper (mg/kg dry solids)
- Nickel (mg/kg dry solids)
- pH
- Nitrogen, total and ammoniacal (% dry solids)
- Phosphorus, total (% dry solids)
- Zinc (mg/kg dry solids)

- Cadmium (mg/kg dry solids)
- Lead (mg/kg dry solids)
- Mercury (mg/kg dry solids)
- Chromium (mg/kg dry solids)

Sludge has to be tested for the Directive parameters once every 6 months and at any time that significant changes occur in the treated sludge quality *(Pescod, 1992)*. Beside the general standard finalised by the Council Directive No. 86/278/EEC, some EU countries have their own national standards which are sometimes more demanding than the general standards. Table 5.4 illustrates the standards of EU and some European countries for heavy metal concentrations in sludge for land application.

5.4: Maximum Content of Metallic Trace Elements for treated Sludge for Land **Application in Europe and USA (mg/kg dried solids)**

Parameter	USA	France	Germany	EU	Holland	Switzerland
Cd	85	15	20	10	10	25
Cr	3000	200	1200	1000	500	500
Cu	4300	1500	1200	1000	500	3000
Hg	57	8	25	10	10	25
Ni	420	100	200	300	100	-
Pb	840	300	1200	750	500	1000
Se	100	-	-	-	-	-
Zn	7500	3000	3000	2500	2000	10000
As	75	-	-	-	-	-
Mn	-	500	-	-	-	-
Mo	75	-	-	-	-	-
B	-	-	-	-	-	-

Source: (EQA, 2003)

It can be seen that in general, EU maximum concentrations regarding heavy metals are stricter than maximum concentrations for the USA. Greatest attention is paid to Cd, Cr, Cu, Hg, Ni, Pb and Zn.

European countries pay great attention to the biological quality of sludge because of the potential direct health impact. Tables 5.5, 5.6 summarize maximum numbers of pathogens in sludge from some European countries and the USA.

Table 5.5: European Limits Values for Pathogens Concentration in Biosolids

Country	Salmonella	Other Pathogens
France	8 MPN/ 10 g of DM	Enterovirus: 3MPCN/10 g of DM Helminths eggs: 3/10 g of DM
Italy	1,000 MPN/g of DM	
Luxembourg		Enterobacteria: 100/g No egg of worm likely to be contagious
Poland	Biosolids can not be used in agriculture if it contains Salmonella	Parasites: 10/g of DM
DM: dry matter *MPN: most probable number* MPCN: most probable cytophatic number		

Source: EU, 2001 (adapted)

Table 5.6: Pathogenic limits for sludge use in agriculture

Pathogenic	*Concentration*
Shigella (MPN)	$1X10^3$/g
Salmonella (MPN)	< 3 /4g DM
Helminth eggs	< 1 egg/4g DM
Viruses/ enteroviruses	< 1/4g DM

Source: Information in this table has been compiled from:
(USEPA ,1992b; USEPA ,1992c; Pescod, 1992)

5.5 Palestinian Standards and Guidelines

The Palestinian Environment Quality Authority has established a committee to draft certain standards for sludge reuse. The committee consists of many Palestinian institutions mainly:

1. Ministry of Agriculture
2. Ministry of Health
3. Palestinian Water Authority
4. Palestinian Universities
5. Ministry of Trade, Industry and Economy
6. Gaza Municipality

7. Industrial Cities Authority
8. Palestinian Standards Authority

The committee is headed and hosted by the Environmental Quality Authority. The purpose of the committee is to establish Palestinian standards concerning sludge use for land application and land filling. The committee had conversed many meetings and made a lot of progress regarding general guidelines and maximum concentrations of heavy metal. Draft guidelines for biological quality are being prepared. The next target of the committee is to determine guidelines for physical quality and nutrient concentration.

5.5.1 Palestinian General Conditions of Applying Sludge in Agriculture Land

The committee which has been established by the EQA (Jan., 2003) drafted the general conditions regarding sludge use in agricultural purposes, these conditions are not published and are summarized below:

1. The use of untreated sludge in agriculture is prohibited.
2. Certificate stating the source of the product and providing details of composition and quality has to be provided for treated sludge to be used in agriculture.
3. Protection to labourers, farmers and consumers has to be provided by informing them of the dangers associated with the unsafe use of sludge when applied as a fertilizer.
4. Treatment, selling or storage of sludge intended for agricultural purposes require a permit issued by the supervising institutions (possibly the PWA).
5. Treated sludge can be used as a soil conditioner for land that has not been used for agricultural purposes.
6. Sludge has to be applied once a year with a maximum of one tonne (dry matter) per dunum and the nitrogen content shall not be more than 30 kg pure nitrogen per dunum.
7. Sludge can be used when land is under preparation for planting productive trees and field crops.
8. Sludge can be used as an organic fertilizer for crops which will be thermally treated or dried (as seeds) before human consumption.

9. Sludge can be used as an organic fertilizer for field crops which will be harvested and dried naturally before use as animal feed.
10. Using sludge as a fertilizer on land used for growing vegetables or home flowers is forbidden.
11. Sludge is prohibited from use for land cultivated with productive trees, with vegetables planted between the trees.
12. Sludge is forbidden from use as a fertilizer for domestic gardens, and for recreational and open areas used by residents.
13. The possible environmental impacts, including the possibility of water body contamination, are to be considered when sludge is applied. The distance of land to be fertilized by sludge from a Wadi, surface water and water-harvesting projects has to be considered.

5.5.2 Measurable Conditions

According to the drafted and unpublished guidelines *(EQA, 2003)*, the following measurable conditions have to be satisfied in treated sludge used for agricultural purposes in Palestine.

1. The maximum concentrations of heavy metals in treated sludge have to be within the limits shown in Table 5.7.
2. The concentrations of nutrients in treated sludge used in agricultural land have to be within the limits specified (maximum concentrations have yet to be agreed).
3. The maximum concentrations of biological contaminants in treated sludge have to be within the limits specified (maximum concentrations have yet to be agreed).
4. Treated sludge intended to be used for agricultural purposes has to be examined by the producer once every six months to determine chemical, *physical and biological characteristics including nutrient properties*, chemical characteristics, and biological contaminants.
5. The tested sample has to be a composition sample, from 25 collected samples, mixed together until homogeneous. The test also has to be according to the book "Standard Methods for Examination of Water and Wastewater" in a certified laboratory recognised by the Environmental Quality Authority, and the producer will pay the costs for analysis.

6. The Environmental Quality Authority should be provided with a copy of the test results.
7. Sludge with heavy metal concentrations of 20% more than those permitted by Table 5.7 must be disposed of safely with the approval of the concerned institutions.
8. The applied sludge quantities added to soil per year are calculated according to the minimum chemical element concentration based on the following formula, which can be applied to individual elements and compounds

$$RSA = \frac{AER}{ECiS \times 0.001}$$

Where;

RSA = Rate of sludge applied yearly (tonne/Hectare/365 days)

AER = Added elements rate (kg/hectare/365 days)

$ECiS$ = Elements concentration in sludge (mg/kg dry matter)

Table 5.7: Maximum Content of Metallic Trace Elements for treated Sludge for Land Application in Palestine (mg/kg dried solids)

Parameter	Max. Concentration
Cd	10
Cr	500
Cu	1000
Hg	5
Ni	200
Pb	300
Se	30
Zn	2500
As	2
Mn	-
Mo	10
B	-

Source: EQA, 2003

5.5.3 Methods of Using Treated Sludge

In accordance with the drafted guidelines (EQA, 2003), treated sludge can be added to ploughed land directly using the following methods appropriate to the type of crop and cultivation method.

Field Crops: treated sludge can be applied to the soil surface then mixed with soil by ploughing until the sludge is buried under the soil surface.

Trees: Two or three holes can be dug close to trees. The holes can then be filled with sludge and covered with soil.

Agriculture in trenches: Trenches can be dug close and parallel to agricultural trenches. The new trenches can then be filled with sludge and covered with soil.

In all cases, it is required to consider all safety conditions to protect labourers when handling sludge and while applying sludge to soil. This is done by providing them with gloves and shoes to prevent any direct contact between sludge and their bodies.

Table 5.8 illustrates the type of crops cultivated in Palestine based on possibility of using or not using sludge as soil fertilizer.

Table 5.8: Field crops, vegetables and fruits in Palestine

Field Crops**	Vegetables*	Fruits**
wheat- barley-corn-clover-lentil-sesame-chick pea	watermelon- muskmelon- strawberry-cucumber- parsley- rocket- jew's mallow-tomato- lettuce- potatoes- pepper- eggplant-calabash- carrot- cabbage- cauliflower- turnip-radish- chard- spinach- onion- garlic- taro-green pea- kidney bean- favo bean- cowpea.	olive- citrus-palm-almonds- guava-banana-apple- pear-mango-grapes*

Source: EQA, 2003

****: sludge should not be used***

*****: sludge can be used***

Sludge is prohibited from use for grapes if vines are grown traditionally, with low support so that the fruits may come into contact with the ground. If higher supports are provided, preventing possible contact between grapes and ground, sludge may be used.

5.6 Conclusions

Sludge application as a soil fertilizer is promoted by many countries, both regionally (Middle East) and internationally. Reuse of sludge is prohibited unless the sludge quality satisfies requirements to protect the environment and humans. Most standards in the documents reviewed are very similar regarding heavy metal concentrations, nutrients, and physical and chemical quality of sludge.

Palestinian Standards do not specify the treatment method for wastewater sludge and the final quality of the sludge after treatment is the most important factor determining whether sludge can be used for land application.

The Palestinian standards are based on regional and international standards, and take into consideration the specific local Palestinian circumstances and needs mainly in focussing on the types of crops to be fertilizered by treated sludge and determining the application quantity and the periods between applications of sludge.

The Palestinian draft guidelines consider how farmers can apply sludge and specify conditions requires for sludge application.

Standards concerning biological quality and nutrient limits have not been drafted yet. The author recommends that the Egyptian standards should be adopted as draft limits, in the absence of other values used in the Middle East region.

CHAPTER 6

Agricultural Land Use and Fertilizer Application in the Gaza Strip

6.1 Introduction

The Gaza Strip is one of the most densely populated areas in the world. Agricultural land comprises nearly 50% of the total area (365 km^2) of the Gaza Strip *(MOPIC, 1997)*. Quantities of organic fertilizer produced within the Gaza Strip are limited, and Palestinian farmers therefore have to import fertilizer. One of the aims of wastewater sludge treatment is to use sludge as an agricultural fertilizer.

In this chapter, the author investigated the areas of land available for agricultural purposes in the Gaza Strip and the size of each crop that is cultivated there. The quantity of fertilizer required and the application times are determined based on the crop type and area cultivated.

6.2 Land Use

The total area of the Gaza Strip is around 365 km^2. Palestinian residential areas comprise 32% of the total area, while Palestinian agricultural land is over 46.5% *(MOPIC, 1997)*. Israeli settlements occupy around 15.6% of the land area. Table 6.1 summarises areas of land for different uses.
Note that 1 dunum = 1000 m^2.

Table 6.1: Land Use in the Gaza Strip

Type of Use	Area in dunums	Area in %
Cities, Villages, residential area	117,000	32
Israeli settlements and "yellow area" (agriculture land around settlements administered by Israelis).	57,000	15.6
Main and secondary roads	5,000	1.4
Agricultural land	170,000	46.5
Reserved area for future plans	16,000	4.5
Total	365,000	100

Source: (MOPIC, 1997)

The Israeli settlements were constructed on agricultural land, previously farmed by Palestinian farmers. This means that if or when these settlements are evacuated and the land is returned to agricultural production, the total agricultural area of the Gaza Strip will be 227,000 dunums instead of the present 170,000 dunums.

Within the Gaza Strip many types of fruits, vegetables and other plants are cultivated. For some vegetables, the farmers use greenhouses, which means that more than one crop can be raised each year. The Ministry of Agriculture (MoA) compiles yearly statistics for the crops and areas under cultivation in each district in the area. Table 6.2 summarizes recent data about the agricultural land use for the main crops.

Table 6.2: Agricultural land areas in the Gaza Strip in Dunums

Crop type	North area	Gaza	Middle Area	Khan younis	Rafah	Total
Citrus	11847	11950	5917	955	1400	32070
Olive	1022	9500	5400	7920	3050	26892
Date Palm	0	150	1650	645	190	2635
Almonds	37	150	1000	1665	1650	4502
Guava	330	0	500	3170	500	4500
Grapes	400	2600	934	4	20	3958
Other fruits	621	600	88	158	360	1827
Vegetables in green houses	1029	531	3338	3491	6584	14973
Vegetables	4498	5895	6769	5302	8351.5	30815.5
Strawberries	1611	0	0	24	31	1666
Field Crops (cereals)	4605	4010	5530	28970	9850	52965
Total	26000	35386	31126	52304	31987	**176803**

Source: Ministry of Agriculture, 2001

From table 6.2 it can be seen that field crops (cereals) occupy the greatest area of land, with nearly 53,000 dunums under cultivation. Other major crops are citrus fruits (approx. 32,000 dunums), vegetables (approx. 31,000 dunums), olives (approx. 27,000 dunums) and green houses vegetables (approx. 15,000 dunums). Less than 5,000 dunums is used for cultivation of each of the other crops grown within the Gaza Strip.

6.3 Use of Organic Fertilizers

Both organic and chemical fertilizers are used in the Gaza Strip. Farmers may apply each type of fertilizer to their crops. Organic fertilizers are used most extensively because they are cheaper and more easily available than chemical fertilizers, and because they release nutrients gradually over a long period. Chemical fertilizers are used as supplements, when possible, but they are not so easily available.

In the Gaza Strip organic fertilizers are extensively used on agricultural land. Some of these fertilizers are produced locally, while the majority are imported from outside the Gaza Strip. For trees, the farmers apply organic fertilizers once every three years or, if possible, once every two years. For vegetables and field crops, the fertilizers are applied for each growing season. The amount of organic fertilizer used for the various crops and application periods and frequencies are summarised in Table 6.3. Most of organic fertilizers are required in the periods of September until November each year.

Table 6.3: Organic fertilizers applied rate and time in the Gaza Strip

Crop type	Application rate m^3/dunum	Application period	Application frequency
Citrus	10	September to November	Once every three years
Olive	7	September to November	Once every three years
Almonds	6	September to November	Once every three years
Guava	8	September to November	Once every three years
Grapes	5-6	October	Once every three years
Vegetables in green houses	8-10	August to September	Each growing season
Vegetables	5-6	April to May	Yearly
Strawberries	6	August	Yearly
Field Crops	6	October	Yearly

Source: Ministry of Agriculture (2001)

6.4 Quantities of Organic Fertilizer Required

The amount of organic fertilizers applied in agricultural areas in the Gaza Strip can be calculated based on the cultivated area, quantity of fertilizers required and application frequency, see Table 6.4.

Table 6.4: Organic Fertilizers applied in the Gaza Strip per Year

Crop type	Cultivated area (Dunum)	Fertilizer application rate m^3/dunum	Number of years between applications	Amount of fertilizer m^3/year
Citrus	32070	10	3	106900
Olive	26892	7	3	62748
Date Palm	2635	0	0	0
Almonds	4502	6	3	9004
Guava	4500	8	3	12000
Grapes	3958	5	3	6597
Other fruits	1827	5	3	3045
Vegetables in greenhouses	14973	9	1	134757
Vegetables	30815.5	6	1	184893
Strawberries	1666	6	1	9996
Field Crops	52965	5	1	264825
Total	176803.8			794765

Source: Author's calculations based on MoA figures

The amount of organic fertilizer required in the Gaza Strip is currently around 795,500 m^3 per year. This huge amount of organic fertilizer cannot be supplied locally and the majority has been imported. According to Palestinian figures, 91.5% (728,000 m^3/year) of required organic fertilizers are imported.

Several farmers in the Gaza Strip produce a limited amount of organic fertilizer daily. The main sources are animals (cows and sheep) and poultry. According to estimates made by the Agriculture Relief Association in the Gaza Strip (2002), 85 tonnes of organic fertilizers are produced daily. This is equivalent to a volume of 183 m^3/day, or 66,800 m^3/year. The quantity of organic fertilizer produced locally covers only 8.5% of local needs, and the rest (91.5%) has to be imported.

The cost of one cubic meter of organic fertilizer is typically around 10 JD (14 US $) based on information supplied by farmers (see chapter 7). This means that in the Gaza Strip around 10,200,000 US $ may be spent annually for organic fertilizer. This does not include the costs of importing chemical fertilizers, which are used in addition, but not as an alternative, to organic fertilizers.

The calculated figure of 795,000 m^3/year is based on recommended fertilizer application rates and frequencies. As has already been mentioned, farmers apply fertilizer to fruit trees every three years or, if possible, every two years. The demand for fertilizer is not always met for various reasons, and the quantity of fertilizers imported is generally less than the demand figure of 728,000 m^3/year. Current demand may not therefore be completely satisfied. Chapter 7 considers issues of fertilizer availability in more detail.

6.5 Conclusion and Recommendations

The Gaza Strip is the main producer of vegetables, citrus fruits and other fruits for Palestinians living in the West Bank and Gaza Strip. Olive production is mainly for the local market within the Gaza Strip. Crops grown in the Gaza Strip are also exported to Israel and Europe. The total cultivated land in the Gaza Strip is 177,000 dunums, which requires 795,000 m^3 of organic fertilizer per year. The local production of organic fertilizer in the Gaza Strip is 66,800 m^3/year, which is only 8.5% of the required quantities. This means that farmers have to import 728,000 m^3 of organic fertilizer per year. This costs around 10,200,000 US $ per year.

The demand for organic fertilizer is not constant through the year. Local fertilizers are used quickly, and imported fertilizers are generally bought when they are needed. The greatest demand for fertilizers is between September and November when fertilizers are applied to land used for growing trees (citrus, olive, etc.) and field crops (cereals). Fertilizer is also needed in smaller quantities in April and May for cultivation of vegetables.

Production of organic fertilizers in the Gaza Strip currently supplies less than 10% of demand. Currently most of the demand for organic fertilizers is met by imports, which are expensive. Sludge from wastewater treatment could provide an attractive alternative to imported organic fertilizers. Sludge would reduce the amount of fertilizers imported.

Staffs who manage sludge treatment would have to take into consideration the fertilizer application periods if it is intended to use sludge as fertilizer. The traditional sludge treatment systems such as sludge mechanical dewatering, sand drying beds, etc. produce sludge regularly, which means that sludge has to be stored for months. Reed bed systems could be an attractive option as reed beds provide storage inside the bed for years and there is no need for sludge storage places.

CHAPTER 7

Farmers' Attitudes to Sludge Use

7.1 Introduction

The farmers in the Gaza Strip use a significant amount of organic fertilizers yearly (794,765 m^3) in addition to chemical fertilizers to improve their agriculture products. Much of organic fertilizers are imported from outside, to supplement what is produced locally (8.5%) in the form of animal manure from farming. Farmers distribute organic fertilizer manually without using any mechanical equipment, which means that they have direct contact with fertilizers that could impact their health if fertilizers are contaminated. Site investigation shows that there is no clear information about the source and quality of imported organic fertilizers, but the basis for its use is its impact on the product as the farmers main priority is crop production.

Due to the shortage and high cost of imported fertilizer, some farmers in Gaza use partially treated sludge although it still illegal to use it in the area. Using treated sludge as an alternative competing with existing sources requires knowing the attitudes of farmers to acceptance and their willingness to use treated sludge.

As the previous experience is limited to just less than 1% of farmers who have used the sludge, the author sought to understand the attitudes of farmers and prepared a questionnaire for farmers to know their acceptance and willingness to use produced sludge.

This chapter presents the aim, the form of the questionnaire and the findings beside the recommendation of the author.

7.2 Questionnaire Aim

The questionnaires aimed to investigate the source and cost of existing organic fertilizers, the farmer's attitudes to use treated sludge, and the willingness of farmers to pay for such product.

7.3 Questionnaire Structure

The questionnaire consisted of eleven questions (see Appendix B) and was divided into six different categories.

1. The first category is related to land size owned by farmer, type of cultivation, and period of fertilizer application.
2. The second asked about the source, cost and satisfaction of available fertilizers.
3. The third is related to the experience with sludge use and attitudes to the acceptability of sludge use.
4. The fourth is about acceptance of treated sludge for use.
5. The fifth is related to willingness to pay for treated sludge compare with available sources of fertilizers.
6. The sixth discusses the awareness of farmers regarding the effect on the environment of using sludge.

7.4 Results and Discussion

The following section presents the results and discussion of the questionnaire. The discussion is based on the obtained results from the questionnaire and the data collected from other resources.

7.4.1 Agricultural Land Use.

There are considerable variations in the area of land that farmers own in the Gaza Strip. Some farmers own less than 5 dunums, while others own land with more than 50 dunums. In the study sample, the author divided the farmers according to their land ownership as shown in Table 7.1. 27% of those covered by the survey sample owned land having an area less than 10 dunums, 55% having an area between 10-30 dunums while only 18% having an area of more than 30 dunums. The author considers that within the Gaza

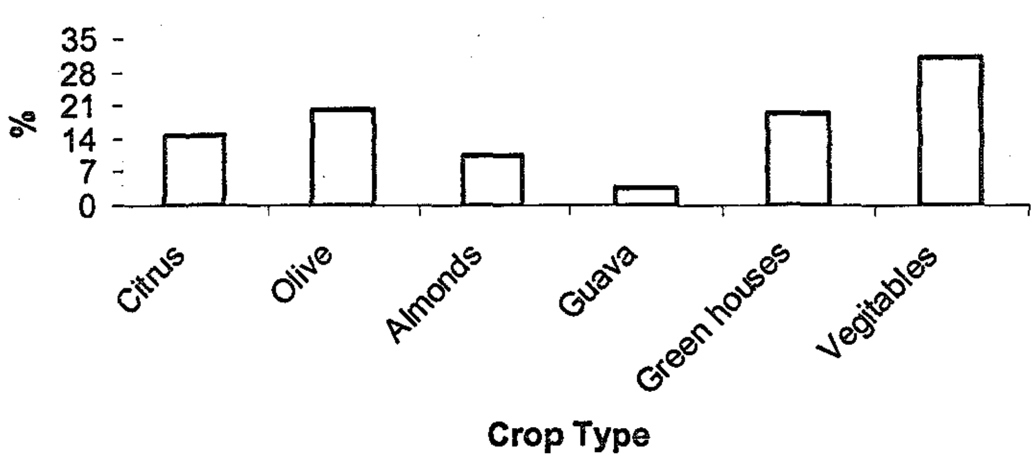
Strip farms of less than 10 dunums are small, farms between 10-30 dunums are medium and farms with more than 30 dunums are big farms.

Table 7.1: Farm sizes of the farmers included in the survey

Area Farm Size (dunums)	<5	5 -10	10-20	20 - 30	>30	Total
No. of farmers	18	20	50	26	25	139
Farm size	Small farms		Medium farms		Big farms	
Percent	27		55		18	100

Regarding the type of crops, the author divided the crops into six types based on his knowledge of cultivation in the area. The main crops are citrus, olives, almonds, guava, vegetables in green houses, and vegetables grown outdoors, see Figure 7.1. Vegetables are present in more than 30% of total land sampled while guava is present in less than 5%. Comparing areas of land for the same sample with the whole cultivated area in the Gaza Strip shows that the area of land given over to individual crops, expressed as a percentage of the land area for that crop within the Gaza Strip, varies from 1.16% for citrus to 5.95% for almonds, see Table 7.2. This unequal distribution is due to the sampling distribution. The author did not include farmers from Gaza city in the survey, where citrus is the largest cultivated

Figure 7.1: Percentage of land area for growing different crops



crop although questionnaires were distributed in Gaza city, no responses were returned due to the existing political situation. A lot of questionnaires were from Deir El Balah where green houses are used in large scale.

Table 7.2: Cultivated areas for different crops

Type of Crop	Citrus	Olive	Almonds	Guava	Green houses	Vegetables
Total area of the crop in dunums*	32070.25	26892	4502	4500	14973	30815.5
Area in dunums sampled	371	510.5	268	92	496	795
sampled area as percent of total area	1.16	1.90	5.95	2.04	3.31	2.58

: Source Ministry of Agriculture (2001)

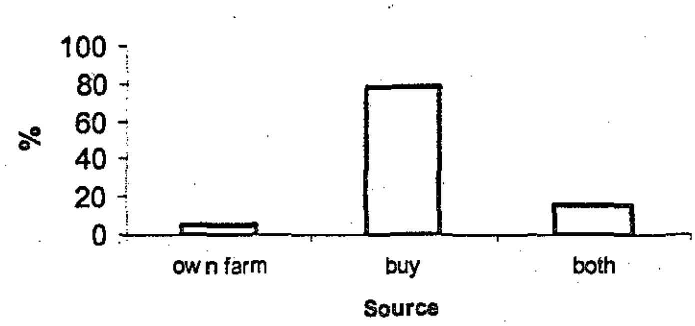
Note: there are other areas in Gaza used for other crops. These have not been included in the table

Table 7.2 shows that the sample covers at least 1% of the total agricultural land in Gaza used for cultivation crops.

7.4.2 Source and cost of existing fertilizes

The survey clearly shows that the vast majority of the farmers asked buy organic fertilizers, see Figure 7.2. Only 5% get fertilizers from their own farmland while 16% get some from their farm land and buy the rest. 79% depend completely on importing organic fertilizer from outside. On the basis that the 16% who get organic ferilizers partially from their farm land satisfy 50% of their needs and add this to the 5% who depend completely on their own sources, it means that 13% of fertilizers is produced locally, while 87% is still needed from outside. This may not be accurate but it provides an estimate of the percentage of locally produced

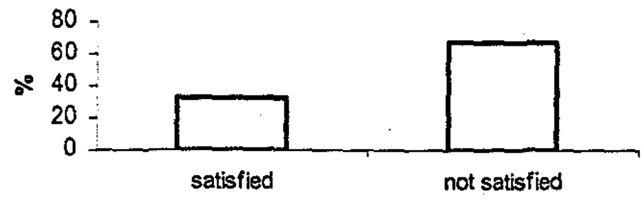
Figure 7.2: Sources of Organic Fertilizers



fertilizers. The figure of 87% agrees closely with a figure of 90% for the percentage of the imported fertilizers.

Getting fertilizers from outside is very difficult, especially in the severe political situation when borders are closed. This means that more than 67% of the farmers are not satisfied with existing sources and find real difficulties in getting fertilizers for the periods when they are needed, see Figure 7.3. Such problems provide opportunities for farmers to use treated sludge, which could be available at any time of the year regardless of any severe political situation or any other logistical problems.

Figure 7.3: Satisfaction with existing sources of organic fertilizers

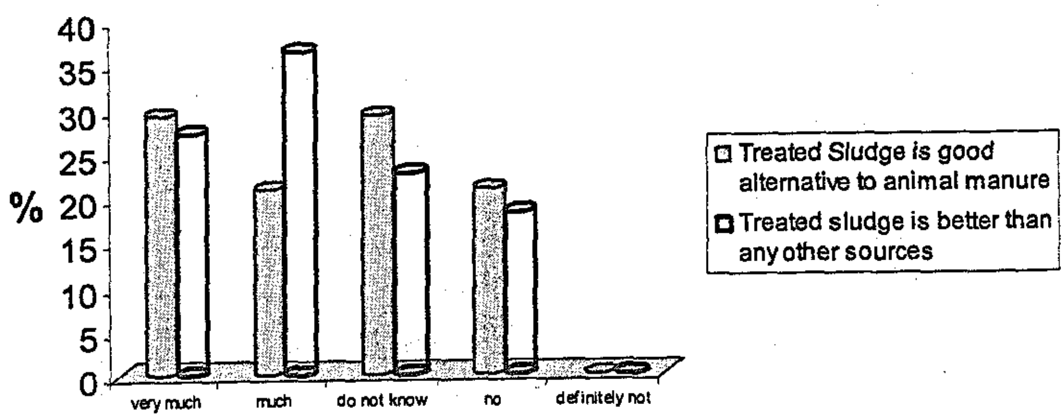


The prices of imported organic fertilizers are not stable for the whole year. Prices depend on the season and the importing conditions. At certain times and due to closures, prices become double their normal rates. On average the cost of one tonne of fertilizer is between US $ 10 and 20. This is very costly when each dunum require more than 6 tonnes per cultivation. Due to importing problems and the high cost, many farmers reduce the quantity of fertilizers applied especially for citrus crops. Some of them clarify that the cost of using the correct quantity of organic fertilizers will not enable the farmer to cover running costs especially if they do not manage to export their products because of closures on export restrictions.

7.4.3 Experiences of Sludge Application in Agriculture

Some farmers in the Gaza Strip tried illegally to use partially treated sludge in agriculture. From the farmers included in the survey, 18% have experience with sludge application while the majority does not have any personal experience, see Figure 7.4. Some farmers were not familiar with the characteristics of treated sludge, since although they have knowledge of wastewater reuse, they did not know that solid materials are also produced and can be used as fertilizers. From their limited experience, 50% of those having some experience of sludge use strongly support using sludge in land application, 29% cannot decide yet while 21% would not use it based on their experience. As an alternative to existing sources, 63% of those who have used sludge consider it a good alternative while 23% do not know and 18% consider it a poor alternative to existing sources.

Figure 7.4: Previous experience with sludge application



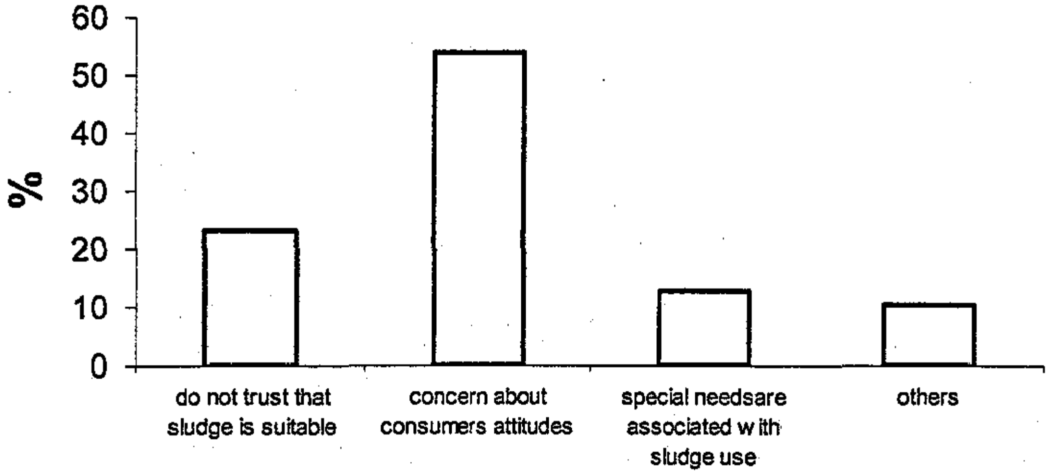
Of the farmers who have not used sludge before, a high percentage (64%) are willing to use it while 36% are not willing to use it according to their limited knowledge of treated sludge quality. Most of the farmers based their expressed willingness to use treated sludge on the quantity produced and its quality. Most of them in principal would not hesitate to use sludge if it is shown to be equal to or even better than existed fertilizers.

Farmers who are not willing to use sludge base their rejection on various reasons, see Figure 7.5. 23% of them are not sure that sludge can be a safe and good alternative, 54% believe that the consumers will not consume products fertilized using treated sludge while the rest feel that sludge needs special arrangements for handling and application especially as they have direct contact with fertilizers during application.

As a soil conditioner, 52% of the farmers surveyed expressed a strong willingness to use it, 20% were not able to decide while 28% think it cannot be used and prefer imported composted materials.

Constructing a pilot project for sludge land application and soil conditioner could improve the idea about sludge use, as many farmers prefer seeing a pilot project before introducing new materials or methods.

Figure 7.5: Concern about use of sludge

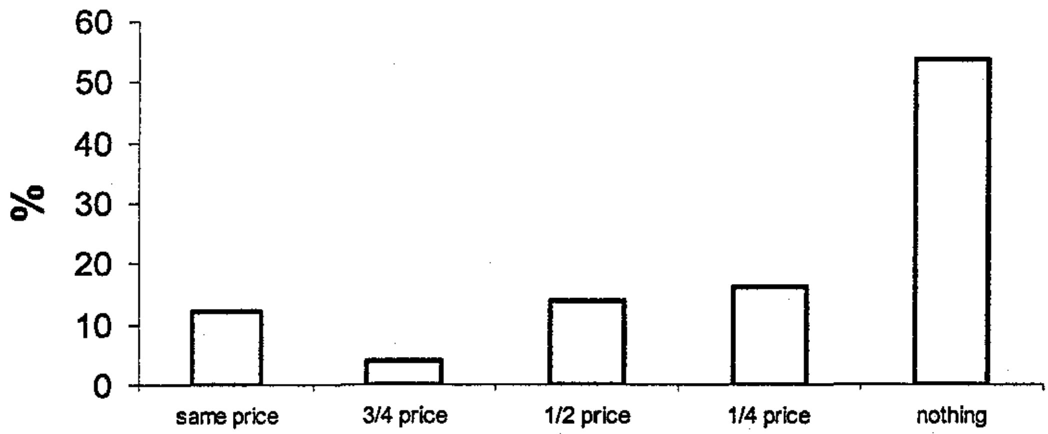


More than 63% of the farmers believe that sludge cannot be used for all crops without evidence of its effect on each crop. They prefer to start with trees and field crops and only try for other types of crops later. Only 37% believe that sludge can be used for any crop, and believe that there is no significant difference between treated sludge and animal manure which is used directly, without any treatment.

7.4.4 Willingness to Pay

The questionnaire asked farmers to indicate how much they would be willing to pay for treated sludge. In general, the farmers prefer to pay as little as possible and they would be pleased if it were free, see Figure 7.6. Many farmers find it difficult to decide how much they can pay as this will be based on the quality of treated sludge compared to organic fertilizers. Some farmers said that they will pay the same price or even more if sludge gives the same results as, or better results than, the existing fertilizers. Many farmers think that such a product will be cheap as the imported fertilizers are expensive because they come from outside and locally produced materials must therefore be cheaper.

Figure 7.6: Willingness to pay compared to existing fertilizer prices



It is noticed that farmers who used sludge are willing to pay more than who did not use sludge. 28% of farmers using sludge are willing to pay the same price of existing fertilizers while only 9.1% of farmers who did not use sludge have the same willingness. On average, farmers who used sludge are willing to pay 37.5% of the cost of existing organic fertilizers while farmers who did not use sludge are willing to pay 23.5% of that cost.

Based on the questionnaires and interviews with farmers it is concluded that cost is not the only issue affecting the willingness of farmers to pay, the following points can be addressed:

- Supply and demand: farmers consider sludge and fertilizers as a market product and their willingness to pay is based on the availability of the materials and its cost.
- Some farmers may give a false answer, as they are not capable to decide how much they will pay for a product they do not know.
- Due to the existing situation and as support to agricultural sector, the Palestinian Ministry of Agriculture supplies the farmers with free of charge chemical fertilizers. Such support decreases the willingness of farmers to pay and create a feeling of getting things free.

7.5 Conclusions

1. The farmers in the Gaza Strip own small areas of land, from less than 5 dunums up to 50 dunums. When applying fertilizers, the farmers come into direct contact as farmers do not have machines for applying fertilizers. This makes it important to take into consideration that treated sludge quality has to be safe when farmers come into contact with it during application.
2. The scarcity of organic fertilizers and their high prices could encourage farmers to use treated sludge instead of importing organic fertilizers.
3. The limited experience of using sludge shows that farmers can accept it and deal with especially if it is of good quality and is safe to handle.
4. The farmers who have not used sludge before are willing to use it if it well treated and shows good results after application. Also sludge can be used as soil conditioner if it is composted as imported compost materials used in the Gaza Strip.
5. Most farmers prefer not to use sludge for all crops. They prefer to start with trees and field crops.
6. The farmers' willingness to pay for treated sludge is based on the quality of sludge and its degree of safety.

7.6 Recommendations

1. It is recommended to conduct a pilot project concerning sludge use for land application in parallel with an awareness programme to the farmers.

An awareness programme needs to include the best way of handling sludge and the advantages and disadvantages of sludge compared with existing fertilizers. A pilot project can be conducted by non-governmental organizations or the private sector in cooperation with Palestinian concern institutions.

2. The sludge at the beginning should be limited to use for trees and crops that are not eaten directly, such as field crops.
3. The cost of sludge at the start has to be at a level that encourages the farmers to buy. Later it could be increased to cover the treatment cost or possibly make a profit.

CHAPTER 8

Gaza Reed Bed Case Study

8.1 Introduction

A literature review regarding sludge dewatering using reed beds shows significant differences between different locations. The difference in experience is mainly due to environmental and meteorological differences between the areas of study. Since experiences are site-specific, a pilot study in the Gaza situation is necessary to obtain local data about sludge dewatering in Gaza.

The constructed pilot project consists of two sludge drying beds with a surface area of 200 m^2 each. One of these was planted with *Phragmites australis* whilst the other functioned as a simple sludge-drying bed without vegetation.

In this part of the study, results from a pilot project carried out over a period of three years at the Gaza wastewater treatment plant are illustrated, and final conclusions and recommendations are drawn.

8.2 Pilot Project Objectives

The aims of the pilot project are to make a direct comparison between the two constructed beds, and specifically to:

- Examine the capacity of the two beds for hydraulic and solid loads.
- Assess suitable loading rates and frequencies for each bed.
- Monitor the evaporation and evapotranspiration capacity of both systems
- Characterize the quality of raw sludge and drained water.
- Assess the quality and the quantity of accumulated sludge.
- Calculate the relative drying efficiencies of the two methods allowing for seasonal variations in loadings and climate.
- Evaluate the suitability of constructed wetlands/reed beds for sludge treatment in Gaza.

- Establish suitable bed construction design for replication of this system.
- Establish suitable operation and maintenance schedules for:
    - Sludge application rates.
    - Drying times
    - Removal timings
    - Resting/recovery periods for beds after removal of dried sludge.
- Determine comparative capital, operating and maintenance costs.
- Correlate sludge loading rates with
    - Evapotranspiration rate.
    - Planting density.
    - Application rates and methods (dosing or continuous flow).
    - Overall bed design requirements.
- Establish seasonal variations in efficiency.

8.3 Pilot Project Description

The Pilot Project is located on the same site as Gaza City wastewater treatment plant, see Figure 1.2. The location is selected there because of the availability of land and the possibility of using sludge generated in the treatment plant. At the same time, the municipality laboratory is located at the same site and the municipality appointed a technician to help in monitoring and analyzing the samples. The beds are open (uncovered) with a base area of 200 m^2 each, and with concrete banks sloping at 1:3. Figure 8.1 presents a plan of the two beds. The left hand bed was planted and the right hand bed was unplanted. Each bed is provided with a drainage system in the base; consisting of perforated UPVC pipes of 200-mm diameter surrounded by gravel of 5-7 cm size. The bed media consists of three layers of aggregate. The bottom layer is 20-cm depth of aggregate 3-5 cm diameter. The second layer is 20-cm depth of aggregate 1-3 cm diameter. The third (top) layer is 10-cm depth aggregate layer of size less than 1-cm diameter. On the top of the three layers, there is a 20-cm sand layer. The bed layers are laid to a slope of 1:50. The bottom of each bed is sealed with hypalon lining which is an impermeable geotextile used to prevent water percolating through the base of the bed. Figure 8.2 shows a section through the bed base and edge of a bed showing drainage and layers configuration. The influent system is a 200-mm pressure pipe provided with a current meter. The pressure pipe distributes

Figure 8.1: Pilot Project Layout

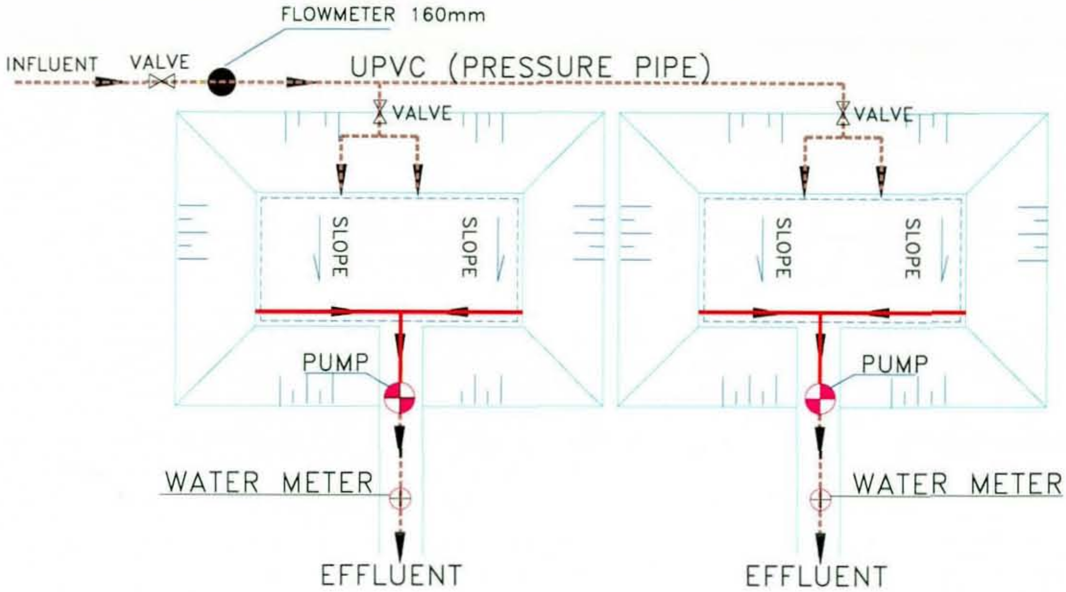
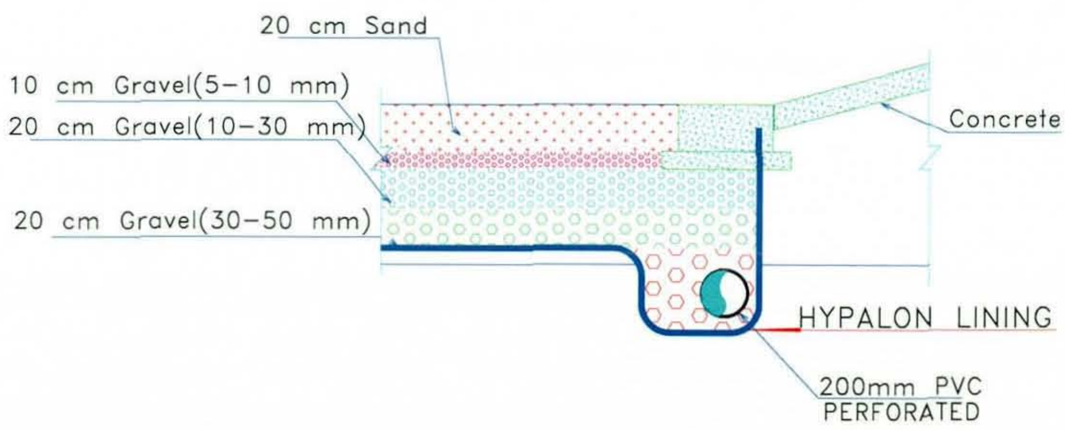


Figure 8.2: Pilot Project Cross Section



sludge to the beds through an inlet pipe, which is provided with a valve. Beds are loaded with the sludge frequently through controlling the valves installed at the inlet pipe of each bed. First, sludge is loaded to the planted bed through opening the valve of planted bed and keeping the unplanted bed valve close and the quantity of loaded sludge is counted through the current meter. Then the planted bed valve is closed and the unplanted bed valve is opened to load the unplanted bed with the same way. For the next loading, the process is repeated but the unplanted bed is loaded first. The valves are operated manually. The outflow from the drainage system leads to a collection chamber where the leachate is collected by gravity and then pumped back to the treatment plant for further treatment. The outlet is provided with a water meter to measure the quantity of infiltrated water. In each of the four corners of each bed, there are four vertical scales to indicate the depth of accumulated sludge. The system is designed as vertical flow. The sludge distributed into the surface and infiltrate vertically by gravity into bed layers where infiltrated water is collected through drainage pipe.

8.4 Planting and Plant Growth

One of the beds was planted with the reed "***Phragmites australis***". Planting was carried out on 6th May 2000, and the plants were provided from two different locations in the Gaza Strip. The first location is a natural wetland area in Gaza "Wadi Gaza" which is a saline area where the water electrical conductivity reaches more than 30 mS/cm. The second location is a wastewater dumpsite in the south of the Gaza Strip close to the Egyptian borders. The reeds were planted at a spacing of 30-50 cm between centers and the other bed was left unplanted.

Photo 8.1: Bed ready for planting

Photo 8.2: Reeds imported for planting

Sludge was applied to the beds immediately after the reeds were planted. In the first six months the reeds were watered by sludge containing 0.4% solids twice a week on Sundays and Wednesdays. For each bed 20 m^3 of sludge was applied on Sundays and 30 m^3 was

Photo 8.3: Reed planting in the bed

applied in Wednesdays during this six month period. On one occasion, the sludge had a solids content of more than 4%, which had an impact on the plants. The day after loading, some of the reeds became brown but regained their green colour after one week.

Photo 8.4: Reeds after one week

Photo 8.5: Reeds after five months

Photo 8.6: Reeds after 6 months

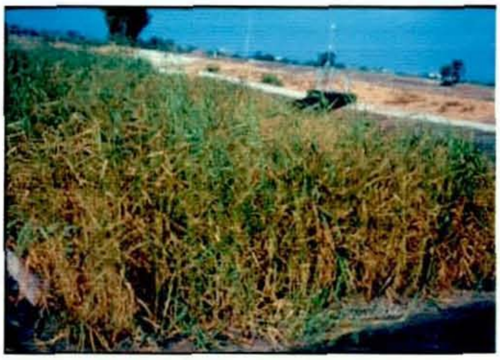


Photo 8.7: Reeds in winter

The growth of the reeds was monitored for the first six months. The average growth rate of the reeds was about 50 cm per month. After six months, the reeds attained an average height of 3 meters. After that, growth became slightly slower and, after one year of planting, the average height of the first generation was around 4 meters. In wintertime (from November till February), parts of the plants became brown but they did not dry out completely even in December and January. In March 2001, the new generation of reeds started to grow and by the end of May 2001 their height was around 2 meters while most of the first generation was still green. A few of the original reeds dried, however.

In January 2002 (start of third year), most of the reeds were green and few new reeds were noticed in March 2002. On average the plant density in the third year was around one stalk every 5-7 cm, which means around 300 plants/m^2 existed in the planted bed.

In March 2001, some seeds from the planted bed were carried by the wind to the unplanted bed, where they germinated. The author removed these in May 2001. This was repeated in 2002, in greater numbers than before. Most of the self-seeded reeds were successfully removed from the unplanted bed.

8.5 Hydraulic Loading Rate

During each sludge application, the quantity of loaded sludge was measured using the current meter installed at the inlet as described in section 8.3. The reading on the effluent meter measuring the flow of infiltrated water was recorded at the beginning and the end of each loading time. From the meters at the inlet and outlet, the quantity of loaded sludge and infiltrated water was calculated. The applied hydraulic load was calculated as cm/m^2.day according to the following formula:

$$HLR = \frac{Qm \times 100}{30 \times As} + P$$

Where;

HLR = Hydraulic loading rate cm/m^2.day

Qm = Hydraulic load m^3/month

As = Accumulated sludge surface area

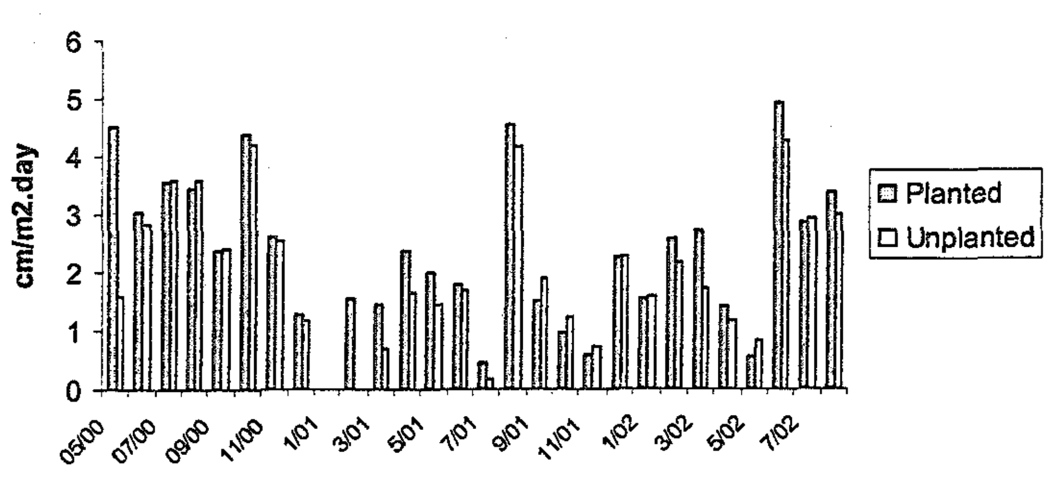
P = Rainwater precipitation cm/day

The author took into consideration the slopes of the bed's base and the slope of bed banks in calculating hydraulic loading rate. The hydraulic loading was calculated based on the surface area of sludge, which increased as the depth of accumulated sludge increased. For the first six months, sludge loading was carried out twice a week after which it was carried once a week. The author tried to make hydraulic loading every week or two weeks based on the observed impact of loading on reed health and the dryness of the accumulated sludge surface. It was noticed that in summer time (May-September), hydraulic load could be applied each week, based on the quantity of applied sludge. The author monitored the effect of applying sludge once a week or applying double the amount every two weeks. It was more favorable to apply sludge every two weeks with the double amount of that applied every week. The performance and health of the reeds was better and less sludge accumulated in the bed.

The author tried to apply sludge in both beds with the same amount in the same time to study the performance of planted and unplanted beds at the same loading rate. The area of the pilot project is close to the Israeli settlement "Nitzarim settlement" and due to the high security of reaching the location in some times of the year, loading rate was stopped for some intervals in dry bed or even in both beds. Due to the configuration of the pilot project, to load both beds the inlet valves has to be reconfigurated, which was the most dangerous activity. The author in critical times kept the planted bed's valve open and the unplanted bed's valve close and loaded only the planted bed. The quantity of sludge applied in such intervals was estimated based on the sludge loading duration (minutes) and the power of sludge pumps as the influent meter has the same problem as valves.

In some intervals (in summer times), the author loaded the planted bed with more sludge than the unplanted bed to investigate the potential capacity of planted bed for hydraulic loading. Due to the above reasons, hydraulic loads in the two beds were not the same for the whole period of the project or some times it was stopped. This is presented in figure 8.3 which illustrates hydraulic loading rate in both beds.

Figure 8.3: Applied Hydraulic Load



Whatever the applied quantity of sludge, four to five days later, infiltration stopped in the planted bed while it took more than seven days for infiltration to stop in the unplanted bed. After infiltration stopped on both beds, cracks began to develop on the sludge surfaces. This was more noticeable on the planted bed. The most suitable time to apply more sludge was found to be when the cracks were 10 cm deep, which takes ten days in average after infiltration, stopped. The cracking rate in summer was more than in winter. Five to seven days in summer after infiltration stopped were enough to develop 10 cm cracks on the accumulated sludge surface. It was also noticed that cracks do not occur at the same rate in all parts of the same bed. Cracks develop more quickly where drainage is good, close to the area where drainage pipes were installed. This could be due to the ventilation. The outlet of the perforated pipe is open to the atmosphere; this increases ventilation and appears to make the reed performance more effective. It is evident that the reeds in this area are more dense and green although the accumulated sludge depth is greatest here. Due to the bed slope the depth of accumulated sludge is more than that in the other side of the bed by approximately 20 cm.

It was noticed that keeping the beds saturated has a negative impact on the development of the reed plants. This was noticed in the Wadi Gaza which is the source of reeds. Reeds in Wadi Gaza are saturated most of the year but the health of plants in beds is better than that in Wadi. Reeds in the planted bed are longer, more thick and green than that in Wadi. Reeds in Wadi dry for part of the year (within summer time) when there is no rainwater and the existing water is saline and stagnant. A better health of reeds in the planted bed could be due to:

- Frequent loading of the bed gives the reeds better conditions as any plants, which survives better when it is irrigated in a certain intervals (not continuous irrigation).
- Sludge is filled with nutrients more than the saline water in the Wadi, which is more suitable for plant growth.

- Dryness of the bed surface and cracks development facilitate oxygen transfer to the plant roots, which is necessary for reeds to be in a good health conditions.

Table 8.1 presents the hydraulic loading rate of the two beds. Hydraulic loading was started in May 2000 until August 2002 where the accumulated sludge drying period was started for 4-6 months. The project hydraulic loading period is divided into four intervals to study hydraulic loading rate per interval.

- The first interval is from planting time (May 2000) up to December 2000 the time where the reeds were nearly full-grown.
- The second interval is from January 2001 up to end of May 2001
- The third interval is the second half of 2001
- The fourth interval is the rest of project period (January 2002 until the end of August 2002).

Table 8.1: Hydraulic loading rate cm/m^2.day

Period	Planted	Unplanted
May/Dec. 2000	3.2	2.7
Jan./May 2001	1.8	1.4
June/Dec. 2001	1.7	1.7
Jan./Aug. 2002	3.0	2.6

Based on table 8.1, the following points are addressed:

1. Loading rate in the first interval was high; this is due to loading two times per week.
2. For the second interval, loading rate was low. This is due to the times of lack of security and stopping loading mainly in unplanted bed.
3. Loading rate in the fourth interval was high mainly in the planted bed, which shows high performance in the third year (fourth interval).
4. For three years, the planted bed was loaded with a sludge loading rate of 2.9 cm/m^2.day in average and unplanted bed average loading rate was 2.6 cm/m^2.day excluding the times of irregular sludge loading. Such figures

represent the applied rates not the potential capacity of beds. It was noticed that beds could be loaded with higher rates, mainly the planted bed.

8.6 24-Hour Infiltration Rate

Studying infiltration rate of the system is difficult as infiltration rate varies from day to day after sludge loading and stopped after few days of loading. Drainage flows were measured for the first 24 hours after loading. The 24 hours period was chosen after consideration, and allows comparisons to be made between planted and unplanted under the same conditions. From the quantity infiltrated in the first 24 hours, the initial infiltration rate can be determined. This test was carried out one to two times per month. A 24-hour infiltration rate is calculated based on the following formula:

$$Ir = \frac{Qd \times 1000}{A}$$

Where;

Ir = Infiltration rate (mm /day)

Qd = Quantity of drained water in the first 24 hours (m^3)

A = Base area of bed (m^2)

It is clear that infiltration rates are influenced by hydraulic load, solids load and time. It is difficult to study the impact of each of these three factors independently, as all three variables are constantly changing. It was noticed however that the solids content of the sludge was almost constant, especially after the first six months of the project. It was therefore decided that as the solids content was almost constant, hydraulic load and solids load were proportional linearly and could be represented by hydraulic load as a single variable.

The author divided the study periods into three separate years to facilitate studying the relationship between infiltration rate and each of time and hydraulic load, where:

- Year one presents the period from starting the project in May 2000 until the end of year 2000.

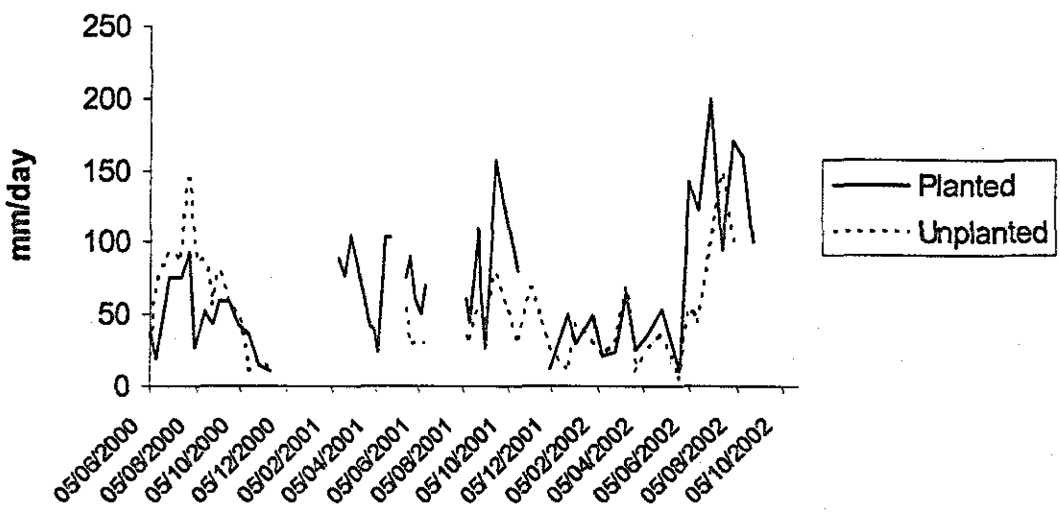
- Year two is 2001 from January until December
- Year three is 2002 from January until August.

8.6.1 Infiltration Rate & Time

24-hr infiltration rate vs. time is presented in figure 8.4 for the three years of the project, gaps in data presents the unloading intervals of beds. Based on results shown in the figure, the following points can be noted.

The infiltration rate in summer is higher than in winter. In the planted bed, the infiltration rate increases from 60 mm/day in winter to 200 mm/day in summer. This compares with an increase from 60 mm/day in winter to 150 mm/day in summer in the unplanted bed. This is due to that in summer as temperature is higher, reeds are more active and evaporation/evapotranspiration rates are higher which increase the dryness rate of accumulated sludge. The applied hydraulic load in summer was higher than in winter, which increased infiltration rate.

Figure 8.4: 24-hrs infiltration rate mm/day



The infiltration rate of the planted bed was greater in year three than in year two, especially in summer. Using infiltration rate as an indicator of bed performance shows that the bed performance is getting better with time.

It was noticed that the 24-hr infiltration rate in the planted bed was higher than in the unplanted bed in summer while in winter it is approximately the same.

8.6.2 Hydraulic Loading Rate & Infiltration Rate

To study the relation between hydraulic load and infiltration rate, the author analyzed the results for the three years. Figures 8.5 and 8.6 present the relation for the planted and the unplanted beds. Hydraulic load was calculated as mm depth of applied sludge every application time. Results obtained seem scattered and the relationship between hydraulic loading rate and infiltration rate are not so clear. Drawing a trend line for the results and taking the correlation (R^2 value) as an indicator for such a relation made the relation more clear. In general according to the trend line, the infiltration rate has a direct proportional relation with hydraulic loading rate. This proportion is more evident in the planted bed than in the unplanted bed. The correlation value is a good indicator of the relation. R^2 for planted bed is 0.45 while it is 0.0145 for unplanted bed. This means that hydraulic load affects significantly infiltration rate in the planted bed, while there is less evident in the unplanted bed.

Figure 8.5: 24-hr infiltration rate vs. hydraulic load
Planted Bed

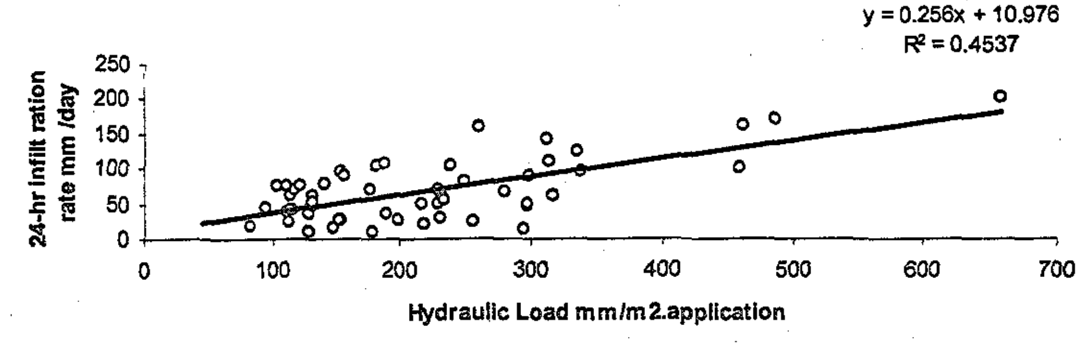
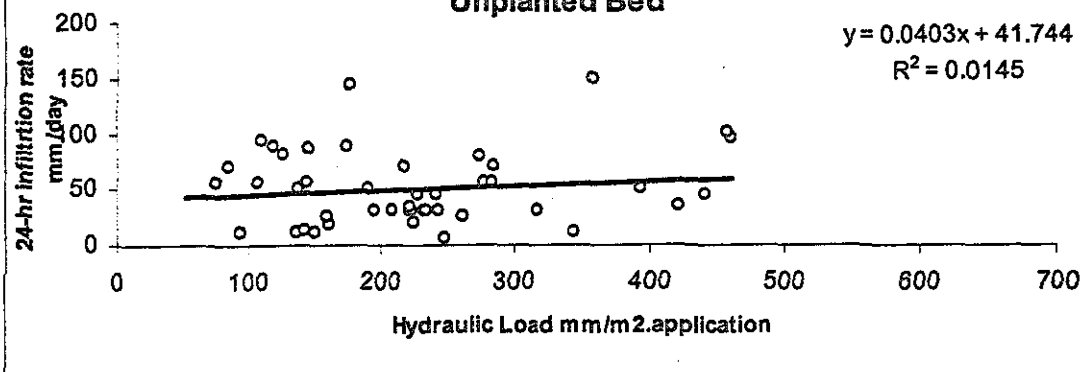


Figure 8.6: 24-hr infiltration rate vs. Hydraulic Load
Unplanted Bed



In general, a third of applied sludge could infiltrate within 24 hours if a hydraulic load of 1.1 m^3/m^2 is applied per month in summer time in planted bed. On average 25% of the applied hydraulic load infiltrates within 24-hrs in the planted bed while this decreases to 20% in the unplanted bed. The infiltration rate in the planted bed increases with time but in the unplanted it is less evident.

8.7 Solids loading Rate

Solids loading are calculated based on the hydraulic loading rate and the solid percent of the applied raw sludge. From the concentration of SS and the hydraulic loading, the solid load is determined according to the following formula:

$$SLR = \frac{Qm \times SS}{1000 \times As}$$

Where;

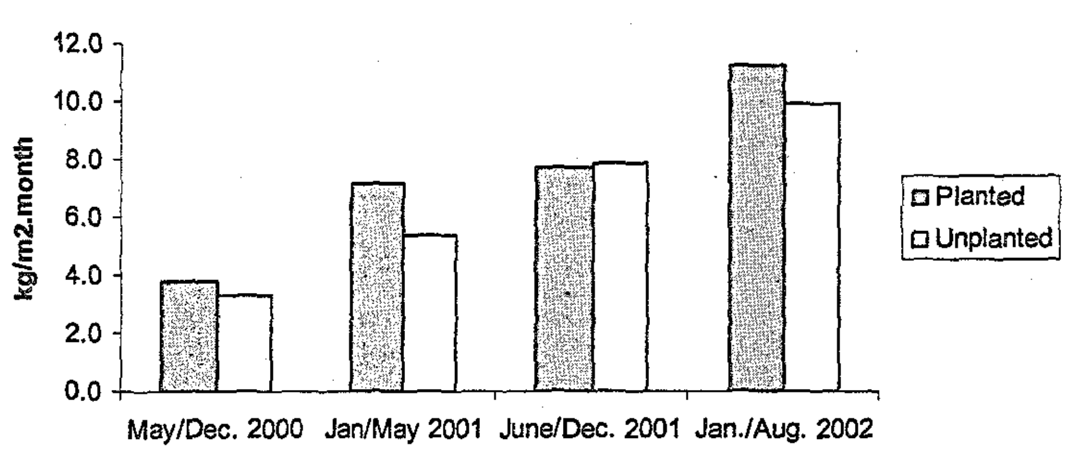
SLR = Surface loading rate kg/m^2.month

SS = Suspended solid concentration in raw sludge $gram/m^3$

Qm = Total applied sludge in the bed as m^3 /month

As = Accumulated sludge surface area (m^2)

Figure 8.7: Average Solid Loading Rate



Solids loading rate increased from 3.8 kg/m^2.month for the first six months up to 11.3 kg/m^2.month in the third year in the planted bed, see Figure 8.7. In the unplanted bed, solids load increased from 3.3 to 9.9 kg/m^2.month for the same intervals. In the second year (2001), lower solids loadings were applied. This was due to the inability to apply sludge to beds for long times in the periods from January to March and from June to August. It was very difficult to reach the site, which is close to an Israeli settlement, and it was dangerous to be there. On average for the whole period of the project (excluding irregular loading periods), 7.5 kg/m^2.month of solids were loaded on the planted bed while 6.7 kg/m^2.month were loaded on the unplanted bed.

8.8 Evaporation and Evapotranspiration

Evaporation and evapotranspiration were estimated by measuring flows of all sludge applied to the beds and filtrate water draining from the beds to be pumped back to the treatment plant.

The evaporation rate (Ep) or evapotranspiration (Et) rate per month is calculated based on the following formula:

$$E = \frac{(Qm - Qd) \times 1000}{As} + P$$

Where;

E = Evaporation or evapotranspiration rate (mm/month)

Qm = Hydraulic load (m^3/month)

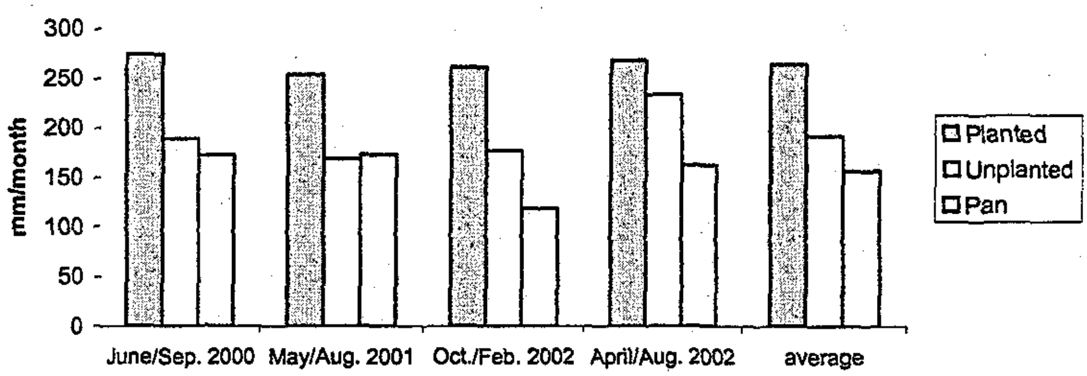
Qd = Drained water (m^3/month)

As = Accumulated sludge surface area (m^2)

P = Rainwater precipitation mm/month

The equation above excluded water stored in beds. The sludge height in beds increased with a rate of less than 15 mm/month. This means that an increase of water in bed is less than 10 mm/month (assuming the moisture content of accumulated sludge is 70%). As evaporation/evapotranspiration is more than 200 mm/month on average, this means that stored water is not a significant amount compare with evaporated amount ($\approx$5%). Due to that, the volume of water stored in the bed was assumed to remain constant.

Figure 8.8: Evaporation & Evapotranspiration



The evaporation rate from the unplanted bed was compared with the evapotranspiration rate from the planted bed, and both were compared with the Pan evaporation rate determined by Gaza Meteorological Station.

To study evaporation/evapotranspiration rates, the author divided the project period into four intervals and calculated the average evaporation/evapotranspiration for each interval and compared them with pan evaporation. The division to four intervals is based on summer/winter periods which are expected to be the most important factors affecting evaporation/evapotranspiration.

From Figure 8.8, the following points can be addressed:

- Evapotranspiration rates for the planted bed range from 254-274 mm/month, which is nearly constant for all periods. This means that the evapotranspiration rate for this bed is largely independent of climatic conditions. The calculated values for evapotranspiration represent the actual evapotranspiration not the potential of plant to evapotranspirate. In summer times, the bed is only 4-5 days saturated after each loading and the calculations are made for the whole period, which is 14 days. In wintertime, the beds are kept saturated for longer periods due to a decrease in infiltration rate and raining water. This could explain the approximate constant evapotranspiration rate, as in winter the actual and the potential evapotranspiration are approximately equal, while in summer the beds can evapotranspirate more if it been saturated.

- The evaporation rate in the unplanted bed varied from 168 to 233 mm/month. This variation is due to climatic changes such as wind and temperature.
- On average evapotranspiration from the planted bed is 170% of pan evaporation. Evapotranspiration is expected to be higher than pan evaporation due to following reasons:
  - Leaf surface area of reeds is high, which increases the surface of evapotranspiration.
  - Most plants can take up water with osmotic pressure superior to 16 atmospheres while this pressure in reed can reach 20 atmospheres, which enables reeds to absorb more water even in adverse conditions, and according to Lienards (1993) the evapotranspiration quantity of reed is double the evaporation of open water surface.
- It was noticed that the unplanted bed evaporation is approximately 120% of pan evaporation. This can be attributed to two reasons
  - The surface of the bed is black due to the sludge accumulation. This gives the surface a higher ability to absorb heat from sunshine and increase the capacity for evaporation.
  - The sludge surface is not regular. This increases the surface area for evaporation.

Compare evaporation and evapotranspiration of reeds, Burgoon (1997) stated that the evapotranspiration rate of reed was 6.4 mm/day while evaporation from open water surfaces at the same climatic conditions was 3.8 mm/day

It is evident that reeds have a high evapotranspiration rate, which increases the dryness rate of accumulated sludge. As hydraulic loading interval is affected with dryness rate of sludge, it means that the evapotranspiration capacity of reeds could increase the hydraulic load of reed bed.

8.9 Quality of Raw Sludge and Infiltrated Water

The raw sludge and infiltrated water quality were registered frequently for the following parameters:

- Chemical Oxygen Demand (COD) & Suspended Solids (SS)
- Dissolved Solids (DS), Electrical Conductivity (EC), pH, Temperature
- Total Kjeldahl Nitrogen (TKN), Ortho-Phosphate (PO_4)

The tested parameters were used as indicators of dewatering and treatment level achieved in the beds as follows:

- COD, SS as indicators of organic matter removal
- TDS, EC as indicators of the salt accumulation in or washing out from the system
- The nitrogen and phosphorus parameters as indicators for capacity of reed to uptake nutrients from raw sludge.

8.9.1 Sampling and Analyses

The sludge samples were taken directly from the sludge outlet. Sludge thickness varies with time during loading and to have representative samples, the author took several samples during loading and either mixed them together to form a composite or analyzed all of them in some cases. For infiltrated water, samples from both beds were collected from the outlet of the drainage pipe the day after hydraulic loading (24 hrs after hydraulic loading). The analyses were carried in the Gaza Municipality Laboratory and in the Islamic University –Environmental/Rural Research Centre laboratory. The American Standard methods of analysis were used. Methods used for the different parameters analyses are given in appendix A.

8.9.2 Results

More than 75 samples were collected and analyzed for most of physical and chemical quality of raw sludge and infiltrated water in both planted and unplanted beds. Table 8.2 summarizes the quality of loaded sludge and the quality of decanted water in both beds. The figures in Table 8.2 present the average values of chemical characteristics of sludge and decanted water.

Table 8.2: Quality of sludge and decanted water

Sample Source	DS mg/l	EC mS/cm	COD mg/l	SS mg/l	TKN mg/l	PO_4 mg/l
Raw Sludge	1554 ± 203	3.2 ± 0.37	11,746 ± 9,772	19,468 ± 19,964	570 ± 349	8.1 ± 0.86
Unplanted Bed	2324 ± 323	4.1 ± 0.54	166.5 ± 113.9	33 ± 36	52 ± 66	20.4 ± 14.2
Planted Bed	2441 ± 297	4.7 ± 0.53	161 ± 112	21.5 ± 25	50.5 ± 68	21.6 ± 18.3

It is concluded from the above table that:

- The suspended solids concentration in decanted water is very low and the efficiency of SS removal is more than 99%. This is in both beds and the percentage removal in the planted bed is more than in the unplanted. It is noticed that SS in infiltrated water in the planted bed ranges within 21.5 mg/l, and 33 mg/l in the unplanted bed. The primary mechanisms for solid removal are settling, filtration and flocculation of suspended and large colloidal particles. Seasonal variation in SS concentration was not detected, it means that suspended solid effluent quality is not affected with time or even with quality of applied sludge. This result is also the same for COD, which received a removal efficiency of more than 98.5% in both beds.
- The electrical conductivity in the effluent is 151% of the electrical conductivity of the raw sludge in the planted bed and 128% in the unplanted one; this is due to evaporation/evapotranspiration rates, which increases the salt accumulation in accumulated sludge. In the next hydraulic loading, accumulated salts are leachated with infiltrated water, which increases the electrical conductivity of infiltrated water. The same indication is obtained for dissolved solids. DS concentration is higher in the infiltrated water than in the raw sludge. One could conclude that no salts accumulated in accumulated sludge due to high

evaporation/evapotranspiration ratios, which is a good point if the final product is to be used as a soil fertilizer.

- Electrical conductivity and dissolved solids concentration in the effluent of planted bed is higher than that in the unplanted bed; this supports the result of evapotranspiration being higher than evaporation.
- Concerning the nitrogen component, a significant removal of nitrogen is achieved and the percentage removal is higher in the planted bed than in the unplanted. This is due to the effect of plants, which consume a significant amount of nitrogen components.
- The primary removal mechanisms of nitrogen (mainly reduced and organic fraction of N) are filtration, sedimentation, plant uptake and biodegradation. Organic nitrogen trapped within the beds will undergo many biological reactions. These biologically transformations species are ammonificaton, nitrification, de-nitrification and fixation. In addition, reed plants take up nitrogen as macronutrient through their roots. Nitrate concentration in raw sludge was not detected while in the influent of the planted bed was 56 mg/l in average and 46 mg/l in the unplanted bed. Wetland plants can facilitate gas transfer (mainly oxygen and CO_2) both into and out-of the wastewater of a vegetated submerged bed system (EPA, 1999). Brix and Schierup (1990) reported in their study about the transfer of oxygen by reed plants on an operating wetland. This could be an indicator of nitrification of NH_4-form to NO_3-form of nitrogen compounds.

8.10 Accumulated Sludge Volume

Vertical scales were installed in each of the four corners of each bed. The zero datum of each scale is at the top of the sand surface, so that sludge depth can be measured directly from each scale. The accumulated sludge volume as m^3 is calculated according to the formula based on the shape of accumulated sludge:

$$\textbf{\textit{Accumulated Sludge}} = 200d + 90\,d^2 + 12\,d^3$$

Where;

d= Depth of accumulated sludge

The aim of computing the accumulated sludge volume is to study the volume reduction of the sludge and the degree of mineralization of the accumulated sludge in relation to time.

Figure 8.9:Accummulated Sludge Volume& Total applied Sludge Vs. time - Unplanted Bed

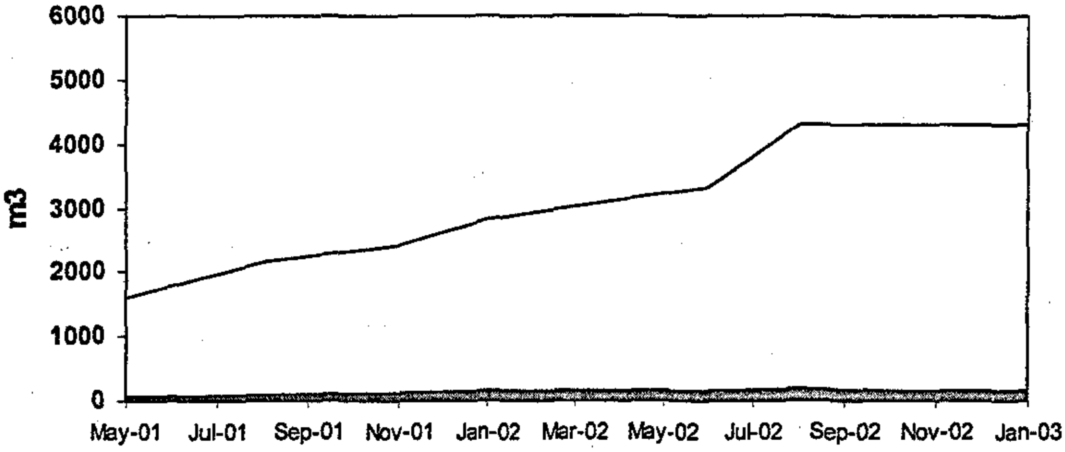
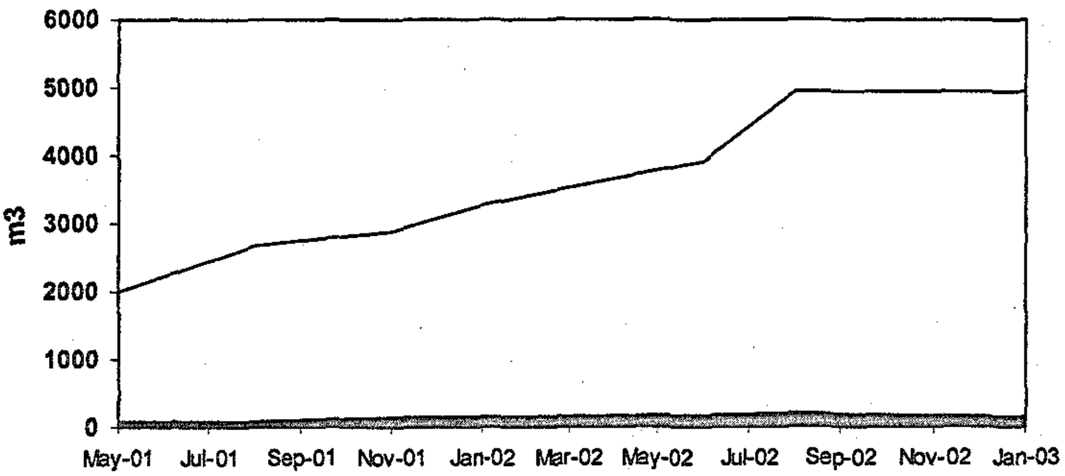
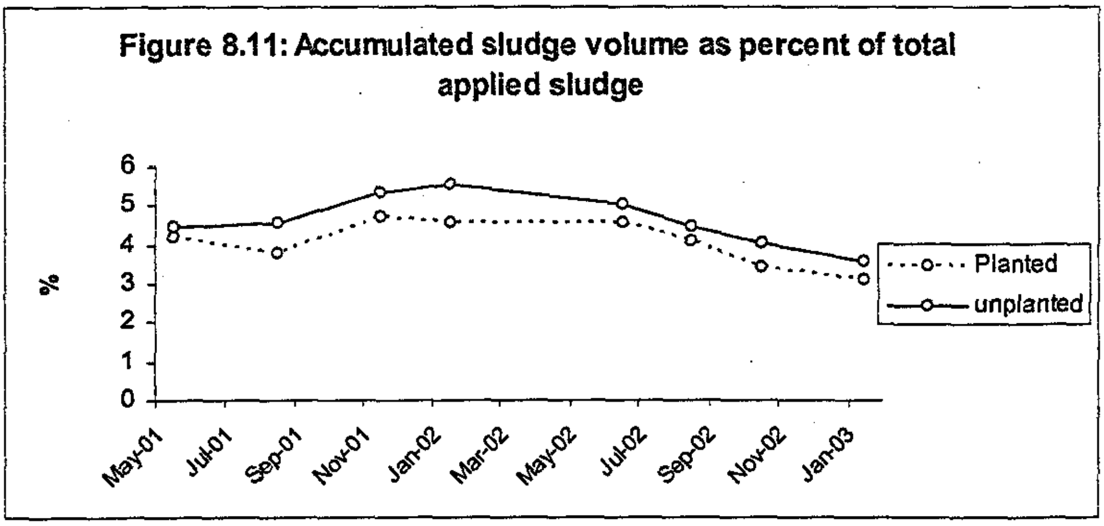


Figure 8.10: Accummulated Sludge Volume & Total Applied Sludge Vs. Time - Planted Bed



The volume of the applied sludge undergoes a significant reduction in both beds, as water is lost from the sludge. In the planted bed the accumulated sludge initially (after seven months of loading) occupied a volume of 4.2% of that of the sludge applied. This represents a 95.8% reduction in volume.

Following this volume of accumulated sludge (as a percentage of the volume of applied sludge) increased slightly, but then fell to 4.1% by the end of loading period (August, 2002), indicating a 95.9% reduction in volume.

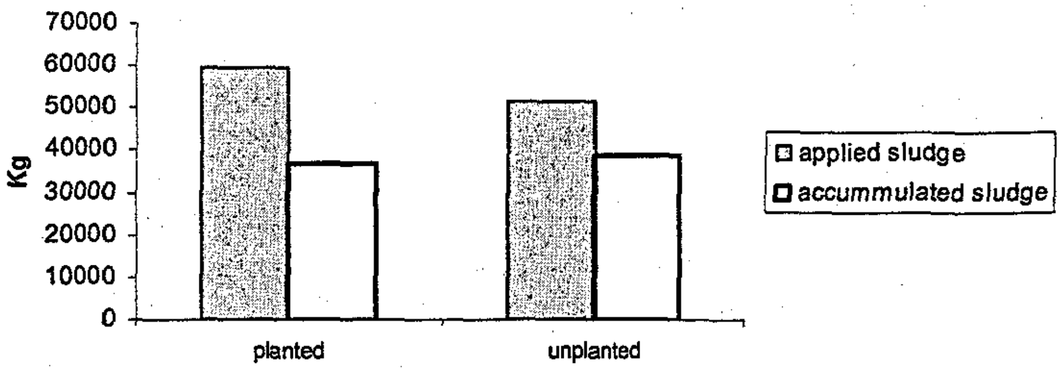


Results from the unplanted bed were similar, with the volume of accumulated sludge (as a percentage of the volume of applied sludge) increasing from an initial value of 4.4% to 5.5% before dropping to 4.4% by the end of the loading period. Increase of sludge volumes in winter could be due to decrease of biological activities because of low temperature.

Drying of sludge for five months after the last sludge application reduces the volume of accumulated sludge to 3.1% of applied sludge in the planted bed and to 3.6% in the unplanted one. The calculation assumes that the accumulated sludge is solid, and ignores the volume of plant roots and rhizomes and the air voids in accumulated sludge. The volume of accumulated sludge will therefore be less than that calculated.

Total applied sludge in the planted bed for the three years was 4952.7 m^3 and for unplanted bed was 4288.5 m^3. Although the applied sludge in the planted bed is 15% more than in the unplanted, the reduction in sludge volume of planted bed is higher. This means that significantly more mineralization of accumulated sludge is achieved in the planted bed than in the unplanted one. Mineralization is "*The process by which elements combined in organic form in living or dead organisms are eventually reconverted into inorganic forms to be made* *available for a new cycle of growth. The mineralization of organic compounds occurs through oxidation and metabolism by living microorganisms"* ***(EPA, 2002a).***

Figure 8.12: Mass of applied and accummulated sludge (January, 2003)



To determine the degree of mineralization of accumulated sludge, the author calculated the quantity of applied solids and the quantity of accumulated solids based on weight, not only the volume. In January 2003, nine samples from the planted bed and six samples from the unplanted bed were collected and tested for density, water content and solid content, see Appendix A. The samples were collected from three locations in the planted bed and two locations in the unplanted and at three different levels from each location. It was noticed that from 59.4 tonnes of solids applied to the planted bed only 36,98 tonnes (62.2%) accumulated. In the unplanted bed, 51.5 tonnes of solids was applied and 38,65 tonnes (75.1%) accumulated. This means that 37.8% of applied solids are mineralized in planted bed in three years and 24.9% of applied solids mineralized in unplanted bed. Many authors paid attention to the mineralization of accumulated sludge. Neurohr (1983) stated that disposal costs of sludge from reed bed are less than those for drying beds because composting and mineralization of accumulated sludge in reed bed system reduces its volume, which has a direct impact on disposal costs.

8.11 Accumulated Sludge Quality

The author aimed to examine the possibility of using final sludge produced in fertilizing agricultural land as an alternative to imported organic fertilizers in the Gaza Strip. Accumulated sludge has been tested for physical, chemical and biological quality to compare it with drafted Palestinian standards of sludge use in land application. In this part, the sampling method, analyses and the quality of the accumulated sludge with a comparison with Palestinian and others standards for sludge use in agriculture are presented.

8.11.1 Samples Collection

The last sludge loading was carried in 25th of Aug. 2002 in both beds. In October 25, 2002 the author collected the samples to be tested. To take a representative samples, the samples were collected from more than one location and from different levels at the same location. Two locations from the unplanted bed were determined and three locations from the planted bed. Samples locations were decided based on the bed surface slopes. Samples locations were 2-m from the edges of the 10 m width of beds. The distance between the two samples locations is 6 m. The author paid attention to the quality of accumulated sludge in the planted bed more than in the unplanted bed, so samples were taken from three locations; two locations are close from the bed edges and the third location at the middle of the bed.

Photo 8.8: Accumulated sludge samples

The depth of the accumulated sludge varied from 50 cm in one edge to 70 cm in the other edge of the beds. From each location, three samples were collected from different levels. The samples were collected at levels of 5-15cm, 25-35cm and 45-55cm from the top of accumulated sludge. A soil corer was used to collect the samples, see photo 8.8. The quantity of each sample was around 1.5 kg.

8.11.2 Samples Preparation

Each sample was kept in open plastic dish of 30 cm diameter in room temperature for one week before analyzed. Each day, the sample was mixed to dry. After one week, samples were crushed then sieved using 2mm-sieve size. Around 200 g of crushed sample was collected to be tested for physical and chemical parameters.

10 gram of each sample was taken and dried for 24 hrs at 105 °C to calculated moisture content and dry matter, then burned at 550 °C for one hour to determine the organic fraction. The residue was dissolved in 50 ml of distilled water to examine it for other chemical parameters.

For total nitrogen and total phosphorus, dried samples were digested directly. Micro-Kjeldahl apparatus was used to determine TKN.

Water content of fresh samples:

The water content of fresh samples was determined directly after collecting the samples. One kilogram of fresh samples was dried in drying oven at 105 °C for 24 hours. The water contents were calculated as percentage of the fresh sample.

Determination of Water Soluble K, Na, Mg, and Cl:

For determination of water soluble K, Na, Mg and Cl in sludge samples, 50 ml of distilled water was added to the remainder of 10 grams of crushed sample which was burned at 550 °C for an hour. The sample was shaken for 2 hours and then filtered. The content of extract of different element was determined using the analytical method presented in table A7, appendix A, the result calculated based on dry weight.

Determination of Total Heavy Metal:

The concentration of the total heavy metals (Iron – Fe, Lead – Pb, Copper – Cu , Nickel – Ni, Zinc – Zn, Mercury – Hg , Chromium - Cr) were analysed in accumulated sludge. The concentration of metal ions in the aqueous solutions was measured using Atomic Absorption Spectroscopy –AAS instrument (Perkin Elmer Analyst-100, spectrometer).

Determination of parasites

Fresh collected samples were used to study the parasites content of sludge. The samples were brought fresh to the laboratory to test the parasite contents of them. The helminths (Nematodes) were used as indicator for parasite contamination. A modified formal-ether sedimentation method was used to determine Nematodes numbers in sludge samples. The reagent and method used are as follows:

Reagent I: 10 % formalin solution in distilled water.

Reagent II: diethyl ether(or ethyl acetate)

- Emulsify 1 gm of sludge in 7 ml of 10 % formalin in a centrifuge tube.
- Strain the suspension through a brass wire sieve-40 mesh/inch, 425 μm pore , and collect in a beaker.
- Pour the filtrate into a 15 cm boiling tube and add 3 ml of ether, mix well -15 s. on a whirlimixer or 1 min in by hand.
- Transfer the ether /formalin suspension back into the washed centrifuge tube and centrifuge at 3000 rpm for 1 min.
- Loosen the fatty plug and debris at the top of the tube with an applicator stick and invert the tube quickly to discard the supernatant. On righting the tube, a few drops only should remain with the deposit.
- Mix the deposit well, transfer one drop onto a glass slide and cover with a 22 mm^2 cover-slip.
- Scan the whole cover-slip using the x10 objective, turning to the x40 objective for confirmation of identification of parasites.

8.11.3 Results and Discussion

The author divided the quality of sludge into three groups, the organic and nutrient quality, heavy metals concentration and biological quality. The following section discusses each of these parameters.

Organic Matter and Nutrients

Table 8.3 summarizes the results of organic matter concentration and nutrients (K, N, and P).

Table 8.3: Organic Matter and Nutrients Concentration

Sample location	Sample Code	Sample depth from surface (cm)	Organic matter %	K g/kg	TKN %	Total Phosphorus %
Unplanted	D1	5-15	43.8	0.71	2.8	0.35
	D2	25-35	40.8	0.43	2.4	0.37
	D3	45-55	35.1	0.35	2.3	0.39
Unplanted	E1	5-15	37.0	0.51	3.04	
	E2	25-35	27.3	0.23	2.5	0.48
	E3	45-55	40.4	0.34	2.9	0.52
Planted	F1	5-15	41.3	0.67	3.09	0.31
	F2	25-35	43.5	0.63	2.9	0.44
	F3	45-55	41.1	0.53	2.8	0.41
Planted	G1	5-15	39.9	0.46	2.7	0.54
	G2	25-35	34.9	0.27	2.8	0.36
	G3	45-55	37.1	0.29	2.6	0.34
Planted	H1	5-15	39.8	0.60	2.8	0.37
	H2	25-35	37.5	0.42	2.1	0.32
	H3	45-55	42.4	0.51	2.6	0.14
Planted Average			39.7 ± 2.7	0.49 ± 0.14	2.7 ± 0.27	0.36 ± 0.11
Unplanted Average			37.4 ± 5.8	0.43 ± 0.17	2.7 ± 0.3	0.42 ± 0.08

Regarding organic matter content, accumulated sludge from the unplanted bed contains organic matter range between 27.3-43.8 % with an average of 37.4, while in the planted bed, organic matter concentration range from 34.9% to 43.5% with an average of 39.7%. Nutrients content in accumulated sludge is relatively high regarding nitrogen and potassium compare with typical sludge quality (see table 5.2). The average nitrogen content in accumulated sludge in planted bed is 2.7% per dry matter and 2.65% in the unplanted bed. Potassium concentration in accumulated sludge in the planted bed is 0.49% and 0.42% in the unplanted bed. Phosphorus concentration is low; its average concentration in the planted bed is 0.36 g/kg and 0.42 g/kg in the unplanted one.

Comparing the quality of accumulated sludge with regional standards (Egypt) shows that accumulated sludge quality regarding physical properties, organic matter and nutrients is suitable for land application according to Egyptian standards, see Table 8.4.

Table 8.4: Sludge quality compare with standards

Parameter	Planted	Unplanted	Egypt Standards
Density Kg/m^3	782	844	>400
Dry Solids %	68	70	>30
pH	7.0	7.1	
Na g/kg	1.23	1.30	
Cl g/kg	1.06	1.12	
Organic matter %	39.73	37.41	>40
K g/kg	0.49	0.43	
N %	2.71	2.66	>2
P %	0.36	0.42	

The concentration of organic matter and nutrient of accumulated sludge varies from location to another and from level to another at the same location at both beds. Table 8.5 presents the ration of OM and both of nitrogen and phosphorus compare with an accumulated sludge left for 7-21 years in the reed bed system.

Phosphorus concentration in the unplanted bed is slightly more than that in the planted bed; this could be due to plant consumption. The OM/N ratio in the planted is higher than that in the unplanted; this could be also due to plant nitrogen uptake. Compare OM/N ratio of raw sludge with accumulated sludge show that the OM/N ration reduced from 21 in raw sludge to 14.5 in accumulated sludge. This means that a significant composting and mineralization of accumulated sludge are achieved. The author noticed that most of samples collected from the planted beds were odourless or soil smell while samples from the unplanted bed had *an offensive odour.*

Table 8.5: Organic Matter vs. Nitrogen and Phosphorus

Location code	OM/N	OM/P	N/P
Planted close from drainage pipe	14.3	109.1	7.6
Planted at the middle of bed	13.8	90.8	6.6
Planted at the other side of bed	16.0	144.8	9.0
Unplanted close from drainage pipe	16.0	107.9	6.8
Unplanted at the other side of bed	12.4	69.5	5.6
Planted Average	14.5 ± 1.5	102 ± 19	7.1 ± 1.5
Unplanted Average	14.2 ± 2.3	92 ± 27	6.2 ± 1.1
Pempkowiak and Obaraska, 2002	15 ± 0.9	149 ± 2	20 ± 4

Heavy metals

The tests carried out for all collected sludge samples (planted, unplanted) concerning heavy metals show that accumulated sludge has very limited concentration of heavy metals. The concentration mostly was below detecting limit - BDL *(see table 8.6).* Heavy metals such as Hg, Cr, Cu, Ni and Pb are almost below the detection limit. Fe and Mg exist with small amounts.

The results are compatible with the previous results carried for accumulated sludge in the Gaza Strip, see Table 4.7 and the raw wastewater quality (Table 4.3), which show that heavy metals do not exist, or in a very low concentration. Based on tables 8.3-8.6, the physical and chemical quality of sludge show that accumulated sludge could be suitable for agricultural purposes.

Table 8.6: Heavy Metal Concentration (mg/kg dry matter)

Sample location	Sample depth from surface (cm)	Sample Code	Hg	Cr	Cu	Ni	Fe	Mg	Pb
Unplanted	5-15	D1	BDL	BDL	BDL	BDL	1.81	0.70	BDL
	25-35	D2	BDL	BDL	BDL	BDL	1.59	0.24	BDL
	45-55	D3	BDL	BDL	BDL	BDL	0.70	1.65	0.59
Unplanted	5-15	E1	BDL	BDL	BDL	0.11	1.57	3.01	0.19
	25-35	E2	BDL	BDL	BDL	0.02	1.69	3.98	0.28
	45-55	E3	BDL	BDL	BDL	BDL	1.41	1.39	0.50
Planted	5-15	F1	BDL	BDL	BDL	BDL	1.42	2.43	BDL
	25-35	F2	BDL	BDL	BDL	0.02	1.61	3.38	BDL
	45-55	F3	BDL	BDL	BDL	BDL	2.16	1.44	0.80
Planted	5-15	G1	BDL	BDL	BDL	0.05	1.41	3.60	0.86
	25-35	G2	BDL	BDL	BDL	BDL	2.25	0.47	BDL
	45-55	G3	BDL	BDL	BDL	BDL	1.77	1.55	BDL
Planted	5-15	H1	BDL	BDL	BDL	BDL	1.45	0.20	BDL
	25-35	H2	BDL	BDL	BDL	BDL	2.10	1.62	BDL
	45-55	H3	BDL	BDL	BDL	BDL	1.35	1.83	BDL

BDL > 0.001 mg/kg

Biological Quality

Regarding biological quality indicators, Nematode was the only available test. The test for nematodes carried out two times. More than 30 samples were collected in both times and analyzed. The results show that only 3 samples were positive (contaminated) while 27 were negative. However, it is recommended that further analyses are required before permitting use of sludge as soil fertilizer to ensure its safety regarding biological contamination.

8.12 Cost Analysis

Existing sludge drying beds in the Gaza treatment plant are operated by loading sludge once every 20-30 days. The total volume of sludge loaded is 350 m^3 each time in a bed of 430 m^2 surface area. After drying, sludge is removed using a "Bobcat", see photo 1.2 and transported in vehicles to a solid waste dumpsite. Table 8.8 provides a cost comparison between reed bed and conventional sludge drying bed. Cost analysis is based on the reed bed cycle of three years. Of this, 30 months is for loading the reed bed and 6 months for accumulated sludge drying, harvesting and removal. For the sludge drying bed, an average 25-day cycle is assumed for loading, drying and sludge removal.

Calculations are based on sludge production of 400 m^3/day to estimate unit capital and running costs for both systems. Cost assumptions are presented in Table 8.7.

Table 8.7: Cost assumptions

Hydraulic loading (m3/day)	400
Construction cost of beds (US $/$m^2$)	100
Cost of land rent (US $/$m^2$.year)	0.2
Project life time (years)	25
Labour cost (US $/month)	400
Bobcate (US $/$m^3$)	1.5
Transportation cost to land fill (US $/$m^3$)	2
Landfill charge (US $/$m^3$)	3
Reed harvest cost (US $/$m^3$)	1.5
Pricing of sludge to farmers (US $/$m^3$) dry sludge	10

Cost analyses are presented in table 8.8 for reed bed and drying bed systems. The author takes into consideration the possibility of using sludge from reed bed as soil fertilizer. It is assumed that the one m^3 of treated sludge can be sold to the farmers with 10 US $ compare with 14 US $ the current cost of one m^3 of organic fertilizer. If sludge in the reed bed is distributed free to the farmers, the total cost of one m^3 of raw sludge treated by reed bed will increase from 0.34 US $ to 0.5 US $ which still 50% of the total cost of using conventional drying beds.

Table 8.8: Cost Comparison

1. Capital Cost	Reed bed System	Drying bed System
Hydraulic loading rate (cm/day)	2.9	3.2
Area required for construction (dunums)	13793	12500
Area for paths and roads 15% of construction area	2069	1875
Total area (dunums)	15862	14375
Construction cost (US $)	1379310	1250000
Rent cost per year (US $)	3172	2875
Construction cost per year (US $)	55172	50000
Total cost of construction and area (US $per year)	58345	52875
Unit cost (US $ per m^3)	***0.40***	***0.36***
2. Operational cost		
It is assumed that sludge is removed from reed bed system once every three years with over all reduction of 98% of total volume while drying beds are evacuated every 25 days with overall reduction of 90%. Cost is calculated for 400 m^3/day	12	60
Transportation to landfill (US $)		80
Landfill charge (US $)		120
Reed harvest cost (US $)	23.82	
Profit (US $)	-60.00	
Total unit operation (US $ m^3)	***-0.06***	***0.65***
Total cost (US $/$m^3$)	**0.34**	**1.01**

8.13 Conclusions

Three years of studying a reed bed system for sludge treatment in the Gaza Strip show that such system is more efficient than traditional sand drying beds. Based on the pilot project, the following conclusions can be addressed:

***Hydraulic load*:** Both planted and unplanted bed show that the best hydraulic loading interval is every two weeks. 14 days between loading and another is enough for infiltrating water and drying the surface of accumulated sludge until cracks are developed. Planted bed can be loaded with 40 cm every application time (two weeks) on average, and 36 cm for unplanted. The two beds show different in loading due to climatic changes. In summer conditions, hydraulic load reach 130% of the average load and in winter it is reduced to 70%.

Infiltration rate: Infiltration rate of both beds impacted significantly with climatic conditions. In general, infiltration rate in summer is higher than in winter. In planted bed 25% of hydraulic load is infiltrated in the first 24-hr of hydraulic load and 20% of hydraulic load is infiltrated in the same time in the unplanted bed.

Evaporation/Evapotranspiration: Evapotranspiration of planted bed varies from 254 mm/month in winter up to 274 mm/month in summer while in unplanted bed evaporation varies from 168 up to 233 mm/month. In planted bed there is no significant change in evapotranspiration between summer and winter, where in unplanted bed there is a significant change. Evapotranspiration rate of planted bed reaches 170% of Pan Evaporation and evaporation rate of unplanted reaches 120% of Pan Evaporation.

***Quality of drained water*:** In both planted and unplanted, there is a high removal ratio concerning suspended solids and COD. The planted bed is more efficient than the unplanted mainly for nitrification of nitrogen components. The concentration of NO_3 in drained water from planted bed is higher than from unplanted bed. This is due to availability of oxygen in the planted bed more than in the unplanted.

Quality of accumulated sludge: analyses carried for accumulated sludge show that sludge in both beds is free from heavy metals. This is due to non-existence of heavy meals in wastewater or raw sludge. Physical and chemical quality indicate that, sludge is rich in organic matter, nitrogen and phosphorous. Comparing such parameters with standards for sludge reuse in agriculture is impressive. The potassium concentration is low which is common in sludge. Biological analyses of accumulated sludge indicate that sludge is free from helminthes but other tests are required to insure its bacteriological safety for agriculture purposes.

Cost analysis: Reed bed systems require approximately the same area required for traditional drying beds if reed bed is designed for three years cycle. The estimated capital costs is 0.40 US $ for treatment of one m^3 of raw sludge using reed bed systems compare with 0.36 US $ for traditional drying beds. The operation and maintenance cost of reed bed is very low compare with drying beds. The operational cost of reed bed is 0.1 US $/$m^3$ compared with 0.65 US/m^3 for drying beds. If accumulated sludge in reed beds is used for agriculture purposes and the farmers pay for sludge 70% of the cost of organic fertilizers imported, the total cost of treatment and disposal of sludge using reed bed is 0.34 US $/$m^3$ compare with 1.01 US $/$m^3$ for drying beds.

8.14 Recommendations

It is recommended to use reed bed system for sludge treatment in the Gaza Strip and reuse of accumulated sludge for agricultural purposes. The Palestinian institutions have to conduct training courses to wastewater treatment plant operators regarding reed bed systems design, operation and management. In the same time, a pilot project regarding use of sludge in agriculture has to be conducted and the Gaza farmers have to know how to apply treated sludge in a safe way for their agricultural lands.

CHAPTER 9

Research Implications and Proposals for Implementation

9.1 Introduction

Large quantities of sludge (400 m^3/day aerobic sludge and 5000 m^3/year anaerobic sludge) are produced in the Gaza Strip, which at present are removed and spread on land adjacent to the wastewater treatment plants. This is causing a number of environmental and health problems. Accumulated sludge contaminates the ground water aquifer, wind-blown distributions of sludge particles create a local public health hazard to residents, and these particles also contaminate locally produced crops in the adjacent agricultural areas.

The main purpose of the study is to find a suitable sludge management policy, which circumvents the current problems and provides a long-term, affordable method for the processing of sludge.

This part of the study introduces the proposed management system for sludge treatment and disposal in the Gaza Strip based on the theoretical and practical work that has been carried out, and identifies proposals for further steps towards achieving the main goals of the research.

9.2 Sludge Treatment Technology

Reed bed systems for wastewater sludge treatment can match the needs of the Gaza Strip. The performance of the system is promising compared with traditional drying beds currently used in the Gaza wastewater treatment plant. Despite its good performance and the significant level of treatment achieved, many technical problems were encountered during the pilot project, and such problems must be avoided or minimised in any real project that can be constructed in the Gaza Strip or West Bank. This section sets out the steps for reed bed design, operation and sludge disposal.

9.2.1 Reed Bed System Cycle

The proposed cycle for the reed bed system is three years. This period is divided into three intervals. The first interval is the first six months, which is the period for establishing reed growth. During this period, sludge with a solids content of 0.4% can be applied to the bed. The second period is the following two years, which is the main period for sludge dewatering. Sludge is applied regularly during this period with solids content of 1-2%. The third period is the last six months, where accumulated sludge will be left to dry. At the end of the third interval, three years after the start of the cycle, accumulated sludge can be removed and used for agriculture.

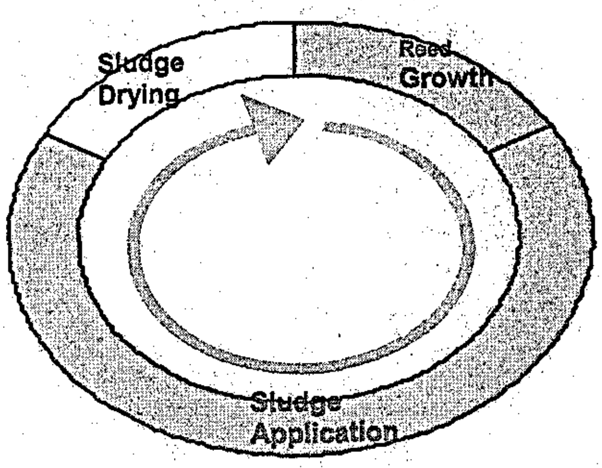
The study concerning agricultural land use in the Gaza Strip shows that, in October and November each year, the farmers use organic fertilizer for their crops. To minimize the storage period of treated sludge, it is recommended that the cycle should start in September and finish three years later, also in September. The cycle can be as follows, and as illustrated in Figure 9.1:

First interval: the first six months from September till February of the following year.

Second interval: the following two years.

Third interval: from February (two and a half years after the start of the First Interval) till August of the same year. This is the drying period. After this period reeds can be harvested and sludge removed to be used for agriculture purposes, and a new cycle can start.

Figure 9.1: Reed Bed Cycle



9.2.2 Hydraulic Loading Rates and Intervals

The two years (the Second Interval) after the six initial months are the main effective time for loading the beds. The current research has shown that the best loading is once every two weeks with an average of 40 cm/m^2 for each application (every two weeks) depending of sludge solids content. There will be significant seasonal variations in hydraulic loads because of higher evaporation and infiltration rates during summer months. The summer load is approximately 1.3 times the average load while the winter load is 0.7 times the average. After two years of loading, the bed can be left to dry for six months before harvesting the reeds and removing the accumulated sludge.

The author made an estimation of the area required for reed bed system based on solids loading. The average solids load is 7.5 kg solids/month. The area required for reed bed design system can be estimated according to the following formula:

$$A = \frac{Q \times SS}{168}$$

Where;

A = Area of reed bed system (m^2)
Q = Average sludge flow m^3/day
SS = Sludge solids concentration mg/l

The equation is based on winter conditions where loading is 0.7 times the average and has been checked for summer conditions when one third of the area is out of service due to sludge drying and sludge loading is 1.3 times the average.

9.2.3 Design Aspects of Reed Bed Systems

The system used in the pilot project achieved good performance regarding hydraulic load and accumulated sludge quality. To improve the efficiency of the system however, two issues need to be improved in the design of a new system.

The area of the reed bed close to the perforated effluent pipe performed better, achieving better treatment in regard to sludge quality, and reed density and health. This is believed to be due to subsurface ventilation provided by the perforated drainage pipe, which is directly open to the atmosphere. Lienard et al. (1990, 1995) stated that reed beds treating sludge require a passive ventilation system to avoid anaerobic conditions in the root zone. Providing the reed bed system with ventilation pipes may increase the oxygen transfer to the system bed, improve the biodegradability of the accumulated sludge, and improve the growth and health of the reeds. Unfortunately it was not possible to study the effect of increased subsurface ventilation during the pilot project, except in the vicinity of the perforated drainage pipe. Based on these observations, it is recommended to provide a full-scale system with vertical open pipes of 4" (200 mm) diameter at 2 m centres. The ventilation pipes will extend 10 cm below the bottom of the sand layer, and the top of the pipes will be 1.5 metres above the sand layer. The sand layer has a depth of 20 cm and the total length of the pipe would therefore be 180 cm.

Second, it is recommended to design a bed which has only one inclined side. A single inclined side is enough to allow for sludge loading and evacuation of accumulated sludge using mechanical equipment. Other sides can be vertical, making construction easier and making more efficient use of the land area available. The bed base area can be between 200 and 400 m^2 and the arrangements of beds can be as shown in Figure 9.2.

Figure 9.2 shows a plan view and section for a possible arrangement of reed beds, each measuring 10 m by 20 m. The beds are 1.5 deep and are separated by vertical concrete walls. One side of each bed has a slope of 1:3, and the other three sides are vertical. The section also shows the bed layers below the sludge.

9.2.4 Reed Planting and Growth

Reeds can be planted at a density of one plant every 30 cm in both directions and can be irrigated in the first six month with raw sludge having a suspended solids content of 0.3-0.5%. Sludge can be loaded one to two times per week in the first six months to ensure saturation of the bed. The operator has to pay attention to reed growth rate and reed health. Hydraulic load and raw sludge quality (Suspended Solids) are the main operational factors that an operator can use to keep reeds in good conditions. The operator has to avoid any shock loads, which could affect the growth of reeds during the initial six-month period.

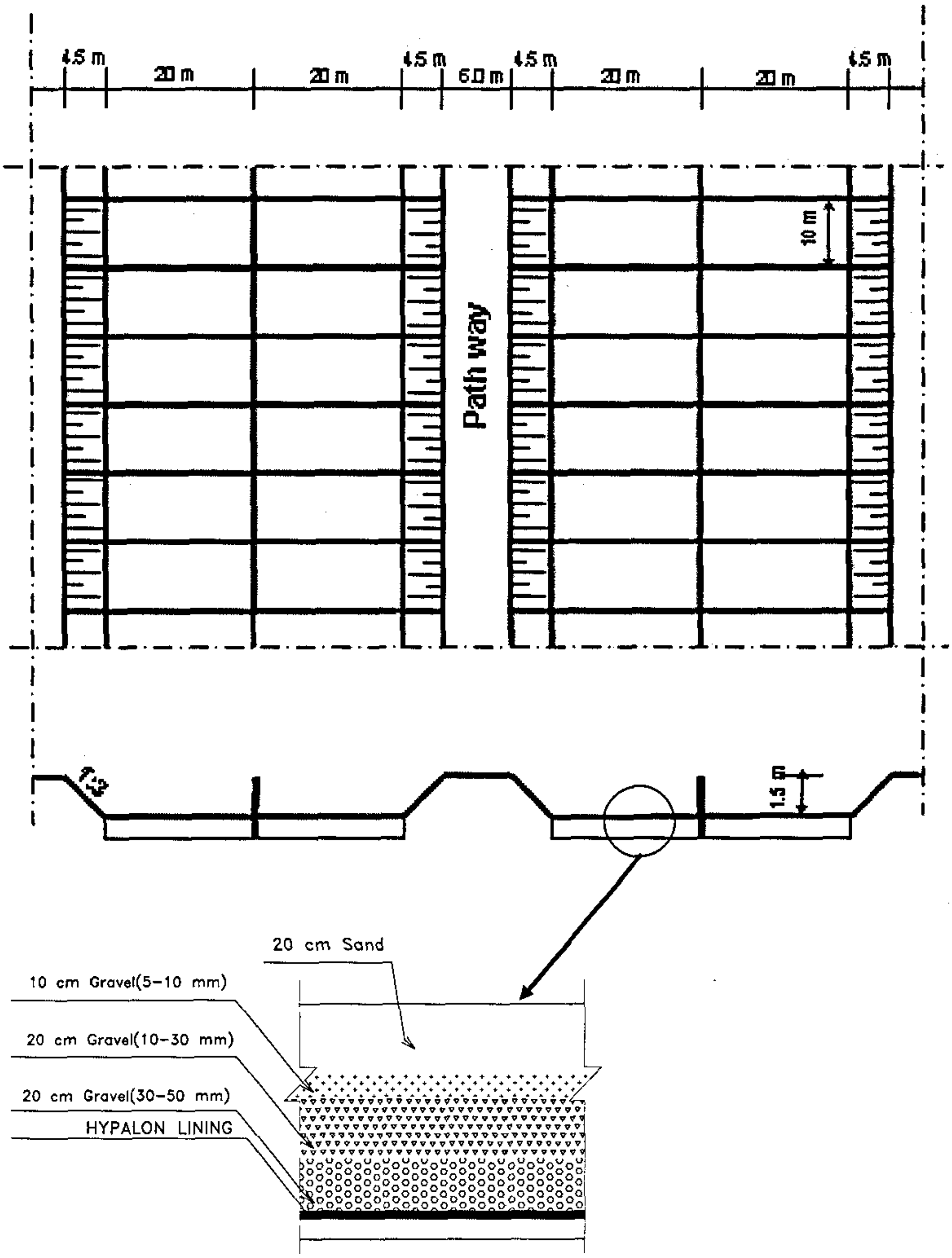


Figure 9.2: Reed Bed System, Layout and cross

9.2.5 Reed Harvesting

Due to weather conditions in Palestine, reeds grow well throughout the year and do not die back in any season. This means that annual harvesting of reeds is not required. Some reeds may die back and dry in winter time, but there is no need to harvest these. Harvesting is only required at the end of the cycle (every 3 years), and can be carried out manually as residents of the Gaza Strip are familiar with reed harvesting. Harvested reed can be used by residents for making shelters to provide shade from the sun, can be burned, or transported to a dump site. The author recommends making use of the reeds, which can be more than 4 m long. Precautions would be necessary to minimise the possible health risks associated with handling reeds grown in wastewater sludge.

9.2.6 Accumulated Sludge

The accumulated sludge can be removed using mechanical equipment, then mixed and graded before being sold to farmers. The institution selling the sludge would need to carry out physical, chemical and biological analyses of the sludge to ensure that it complies with relevant Palestinian standards.

9.3 Sludge Disposal

Palestinians are intended to reuse treated sludge for agricultural purposes. This section sets out a proposal for the responsibilities and roles of relevant Palestinian institutions, and recommends administrative procedures for sludge use in agriculture. The author reviewed the existing roles and responsibilities of concern Palestinian institutions and conducted various meeting with many stakeholders to investigate the possible responsibilities of the relevant authorities.

9.3.1 Proposed Roles and Responsibilities of Relevant Authorities

This section sets out the proposed roles and responsibilities of relevant authorities. These proposals are considered to be realistic as similar roles and responsibilities have already been recommended within the framework of a project "Policy guidelines for sustainable wastewater management in the Gaza Strip" *(IUG, 2002)*.

Palestinian Water Authority (PWA)

The Palestinian Water Authority has various important roles for future sludge management in the Gaza Strip. The proposed roles of PWA are summarized in the following points:

1. PWA is responsible for the strategic planning for the reuse of treated sludge
2. PWA issues licenses related to the operation of facilities for sludge treatment and disposal
3. PWA gives permission for the use of treated sludge and application of treated sludge to land as fertilizer.
4. PWA monitors the quality and quantity of treated sludge.
5. For the reuse of treated sludge PWA is working in close cooperation with other stakeholders; mainly the Palestinian Environmental Quality Authority, the Ministry of Health and the Ministry of Agriculture.
6. PWA can delegate special defined tasks to the Coastal Municipal Water Utility.

Palestinian Environmental Quality Authority (EQA)

The proposed responsibilities of the EQA regarding sludge management are summarized in the following activities:

1. EQA sets the standards, which are related to the conservation and protection of the environment. These include standards for reuse of treated sludge.
2. EQA has responsibility for checking and approving Environmental Assessments.
3. EQA has to monitor various environmental aspects, such as groundwater, soil, etc.

Ministry of Health (MoH)

MoH will set standards, which are related to public health. These include the standards for the use of treated sludge in the environment, which affects the quality of agricultural crops grown using, treated sludge as a fertilizer. Such standards do not exist at present, but the MoH have the responsibility for drafting such standards.

Ministry of Agriculture (MoA)

MoA will be one of the main stakeholders for sludge use in agriculture and the Ministry has many roles to play in the future, such as:

1. The MoA supervises all activities which are related to the use of treated sludge as a fertilizer.
2. The MoA responsible for selecting appropriate locations for land application of sludge.
3. The MoA responsible for determining the appropriate technology for sludge application to land.
4. The MoA carries out public awareness campaigns about agricultural practices and safety aspects for farmers and consumers.

Coastal Municipal Water Utility (CMWU)

The CMWU was intended to start in 1999 but the start has been delayed because of the uncertain political conditions. The main proposed roles of CMWU are summarized in the following points:

1. The CMWU will have responsibility for design, construction, operation and maintenance of water services, including facilities for wastewater collection and treatment, and sludge treatment.
2. The CMWU is local government owned, with community representation on the board. CMWU will be administratively and fiscally autonomous, although sludge use in agriculture will be licensed and monitored by PWA.

Committee for the Reuse of Treated Sludge

The EQA formulated a committee to set the standards and guidelines for sludge use in agriculture. The committee consists of representatives from PWA, EQA, MoH, MoA, Palestine Institute for Standardisation and Measurement (PSI), Municipalities, and Local Universities. This organisation can contribute to developing guidelines because they employ qualified staff and represent most of the governmental institutions closely involved in environmental aspects of sludge management. Academic institutions are also represented on the committee.

Guidelines for the reuse of treated sludge shall be prepared and reviewed by the committee every four years, taking into consideration the local conditions (e.g., climate, topography, hydro-geological situation) to assure the social and economical development in the Gaza-Strip. The review process will provide opportunity for the committee to revise the guidelines based on experience gained.

9.3.2 Administrative Procedures

Reuse of treated sludge in agricultural purposes requires approval from the relevant institutions in the Gaza Strip. The following points describe the suggested procedure for obtaining approval, and the monitoring programme required. The Palestinian relevant institutions have to agree among each other about these principles, and the existing formulated committee can facilitate such agreement.

Application for Approval

As for any environmental project, the proponent has to submit an application for environmental approval to the Environmental Quality Authority (EQA). The proposed approval process follows the Environmental Assessment administrative procedures as described in the "Palestinian Environmental Assessment Policy" ***(EQA, 1999)***.

Permission and License

After environmental approval the proponent will receive permission or a license from PWA to implement the sludge reuse project according to the requirements. The permission for using treated sludge for land application is issued by PWA in coordination with MoA. The required application forms and administrative procedures are prepared by PWA.

Supervision

It is proposed that PWA would have responsibility for the supervision of the technical, financial and operational issues of the sludge reuse facilities, especially the compliance with the conditions and requirements that have been issued. These may be in connection with the permission or the license of the facility, general guidelines applicable to the license, or other relevant laws and regulations.

- PWA shall check the compliance with the chemical and micro-biological standards of the sludge, for use as a soil fertilizer, either at the place of the use or the place of regular storage. Samples shall have to be taken, stored and analyzed.

- EQA would be responsible for the supervision of the environmental issues of the sludge reuse facilities.

- MoH would be responsible for the supervision of public health with regard to the consumption of food products that have been fertilized with treated sludge. It is also responsible for the safety of employees who work in facilities for the treatment or reuse of sludge.

Authorities having relevant responsibility for aspects of sludge management require legal authority to enter companies and properties at any time or enforce entrance with police assistance. The operator of the facility must cooperate and provide any support required, and has to allow the authority to look at specified documents.

Monitoring of Wastewater, Groundwater, Soil, Products and Human Health

A comprehensive monitoring programme is required to ensure that a proper treatment of sludge is achieved, and environmental degradation does not occur. Minimizing adverse health impacts on concerned parties and, at the same time, increasing agricultural production in a sustainable manner with complete health and environmental safety are the main objective of monitoring. Helminth eggs are of particular importance, as these can survive for long periods (see Table 5.6). The following need to be monitored:

1. Raw sludge quality (concerning heavy metals, pathogenic contamination, etc.)
2. Groundwater (concerning chemical, physical and microbiological quality mainly salinity and analysis for pathogenic organisms)
3. Soil (concerning physical and chemical properties of soil)
4. Quality of products (concerning possible biological contamination and heavy metal accumulation)
5. Human health (concerning possible biological contamination)

Sampling, Analysis and Conservation

Sampling, analyses and conservation should be carried out according to Draft Palestinian Standards for sludge reuse as fertilizer, as described in chapter 5.

9.4 Future Plans

A reed bed system could be a good option for sludge dewatering and treatment for the specific conditions of the Gaza Strip. Application of such a system, together with reuse of treated sludge for agriculture purposes requires further steps to extend the research work which has been carried within the context of this pilot study. Any future plans for full-scale facilities would require training of the treatment plant operators in how to operate reed bed systems and how to manage a reed bed system most effectively. At the same time, a pilot project for sludge reuse in agriculture is required to train the farmers in how to deal with treated sludge, and how to handle sludge to avoid any environmental health problems. The following section specifies the training required to establish a full and clear system for sludge treatment and disposal in the Gaza Strip.

9.4.1 Operator training

The operators of treatment plant have to improve their skills and be capable in operating reed bed systems. Training objectives, targeted groups and training topics are summarised in the following points:

Training Objectives:

To enhance skills of treatment plant operators in reed bed system operation and monitoring. This will improve the capacity of operators to operate and maintain a reed bed system safely and to achieve good performance.

Target group:

- Operators of treatment plants in the Gaza Strip Municipalities
- Engineers from PWA, MoA, MoH and the Palestinian Environment Quality Authority (EQA)

Main topics:

- Reed bed systems (operating principles, design and performance)
- Routine operation and maintenance
- Operational problems
- Monitoring
- Evaluation and report writing

Organization

The Palestinian Water Authority, in cooperation with Gaza Municipality and other institutions, can organize the training. Experienced staff from local universities would provide training, with support from external trainers as necessary. .

9.4.2 Farmers' Awareness

It is the evident that the level of awareness of farmers regarding environmental issues is quite low. One of the important issues is to raise awareness and motivate farmers to participate in sludge management plan. Through this scheme, farmers will be educated about the quality of sludge, the health and environment effects of sludge reuse in agriculture, and the proper methods of sludge handling. The mechanism for conducting such activities will be through a demonstration programme using treated sludge and training farmers in how to deal with sludge.

Organisation

The activities could be carried out through a local NGO that has experience of conducting awareness campaigns. One such NGO is the Palestinian Agriculture Relief Committee (PARC). The NGO would work in cooperation with other relevant Palestinian institutions such as the PWA, Ministry of Agriculture, Ministry of Health and the Palestinian Environment Quality Authority.

CHAPTER 11

Conclusions and Recommendations

The study aimed to establish a proper sludge management in the Gaza Strip that can protect the degraded environment and provide material suitable for use as a soil fertilizer. The sludge treatment system has to take into consideration the scarcity of land, limited ability of residents to pay for treatment and the available human resources.

The research methodology adopted at the beginning of the work has been followed. All activities proposed for conducting the research have been carried out in both Palestine and UK. In some periods of the project, the author was not able to monitor the project as intended because of the security situation and the proximity of the pilot project location to Israeli settlements. Despite such interruptions, the aims of the project have been achieved to an acceptable level.

In chapter 2 the research hypothesis was stated as: "Reed bed technology for wastewater sludge treatment can be demonstrated to be a feasible solution based on the constraints of land area, climatic conditions, and the social, political, and economical situation in the Gaza Strip". This research has demonstrated that sludge treatment using reed beds is possible based on the following factors:

Land area: the required land for sludge treatment using reed bed system is nearly the same as for conventional drying beds. The final product can be used for agricultural purposes, which means no land need be required for land filling as in the conventional drying beds. In total, land area required for treatment and disposal of sludge using reed beds is less than the area required for sludge treatment using conventional drying beds.

Climatic conditions: A reed bed system can be operated through the year as reeds cope with summer and winter conditions in the Gaza Strip. The system has to be designed to the worst conditions (winter times).

Social: farmers in the Gaza Strip are willing to use treated sludge for their agricultural land, and they consider sludge a good alternative to imported organic fertilizers.

Political: reed bed systems do not require any mechanical equipment or chemical substances for operation and maintenance. Imports of such materials are difficult in the current political situation. The produced sludge can partially compensate the scarcity of organic fertilizers which are difficult to import at the required periods.

Economical: A reed bed system is inexpensive compared with conventional drying beds. The cost of treatment and disposal of sludge using reed bed system is 50% less than for conventional drying beds. This is attractive in the Gaza Strip where the capacity of residents to pay for treatment is limited mainly due to the current political situation. Treated sludge can be sold to the farmers which will help to offset the costs of sludge treatment.

Several *conclusions and recommendations* have been made based on the three years project studying the reed bed for sludge treatment and review the available documents and investigating the social, institutional and financial aspects of sludge management in the Gaza Strip.

11.1 Conclusions

Based on the three years research, pilot project monitoring and data collection and analyses, the following conclusions are addressed:

1. The existing treatment plants in the Gaza Strip provide limited treatment; this is due to overloading, poor management and limited resources. The new development in the area sharply increases the quantity of wastewater and increases the problems at the treatment plants.

2. Existing sludge management and handling is unsatisfactory and improved management is required to protect the degraded environment in the Gaza Strip. More than 50,000 m^3 of anaerobic sludge is generated yearly in the Gaza Strip and 400 m^3/day of aerobic sludge. Sludge removed from stabilization ponds or sedimentation tanks is disposed into open areas inside the treatment plants. Such huge amounts of sludge pollute the surrounding agricultural land, the groundwater aquifer, and impacts on the health of residents who live close to the treatment plants.
3. The future plans in the area are to construct three main wastewater treatment plants to serve the entire Gaza Strip. It is intended to use oxidation ditches as the treatment technology instead of the existing stabilization ponds and aerated lagoons. Based on that, more than 55,740 kg/day of dry mass are estimated to be generated as sludge by year 2025 with a total volume of 3,716 m^3.
4. Previous and current analyses of wastewater and sludge in the Gaza Strip show that it is relatively free of contamination by heavy metals. This is due to the limited number of industries, and the fact that most wastewater is from domestic sources. This suggests that the treated wastewater and sludge could be applied to crops with minimal risk of heavy metal accumulation.
5. The previous worldwide experience of reed beds and the pilot project carried out in the Gaza Strip conditions for three years monitoring demonstrate that a reed bed system for sludge treatment in the Gaza Strip is the optimum system in regards to technical, environmental and financial analyses. A reed bed system can be operated for three year cycles with an average hydraulic loading rate of 2.9 cm/day, with sludge being applied once every two weeks. The estimated capital costs show that 0.40 US \$ is required as a capital cost for treatment of one m^3 of raw sludge using a reed bed system, compared with 0.36 US \$ for traditional drying beds. The operation and maintenance costs of reed beds are very low compared with drying beds. The operational cost of a reed bed is 0.1 US \$/m^3 compared with 0.65 US/m^3 for drying beds. If accumulated sludge in reed beds is used for agricultural

purposes, and the farmers pay for sludge, at 70% of the cost of imported organic fertilizers, the total cost (including capital cost) of treatment and disposal of sludge using reed beds is 0.33 US $\$/m^3$ compared with 1.01 US $\$/m^3$ for drying beds.

6. The volume of dry sludge accumulated in a reed bed system after three years is only 3.1% of that for raw sludge. Treated sludge that require removal from beds by the year 2025 (if reed beds are used in the Gaza Strip) is approximately 42,047 m^3/year (12,817 tonne/year as dry matter), which is 5.8% of the quantity of imported organic fertilizers required. Treated sludge from the Gaza Strip is rich in organic matter and nutrients and free from heavy metals, which is favoured when using sludge for agricultural purposes. Biological quality analyses indicated that sludge is safe even though more biological analyses are required to guarantee the safety of sludge use in agriculture. Accumulated sludge in reed bed systems is odourless due to mineralization and composting which make it attractive for use by farmers.
7. The total cultivated land in the Gaza Strip is 177,000 dunums, which requires 795,000 m^3 of organic fertilizer per year. The local production of organic fertilizer in the Gaza Strip is 66,800 m^3/year, which is only 8.5% of the required quantities. This means that farmers have to import 728,000 m^3 of organic fertilizer per year, which costs around 10,200,000 US $ per year.
8. The drafted Palestinian standards regarding sludge use in agriculture promotes use of sludge for trees (citrus fruits, olives) and field crops (cereals) with no more than one tonne per dunum per year. The size of land for such crops in the Gaza Strip is 111,927 dunum. Treated sludge generated (12,817 tonne/year by the year 2025) covers only 11.5% of the total agricultural area where sludge use is permitted. This means that sludge has a potential to be used in agriculture if it is treated well and accepted by farmers.
9. The farmers in the Gaza Strip are willing to use treated sludge in their farms. The main concern of farmers is the quality of sludge and its impact on crop production. The scarcity of organic fertilizers and their

high prices could encourage farmers to use treated sludge instead of importing organic fertilizers. At the same time, farmers are willing to pay for treated sludge, and their willingness is based on sludge quality compared with available organic fertilizers. The previous limited experience of using partially treated sludge in the Gaza Strip promotes the farmers' willingness to use treated sludge. The farmers share the same concern as Palestinian institutions in preferring sludge to be used for trees and field crops and not to be used for that may be eaten uncooked crops or vegetables.

10. The Palestinian environmental institutions pay attention to the environmental impact of sludge and they are willing to protect the degraded environment in Palestine through establishing a proper sludge management system. The Palestinians as all regional and international countries intend to use final treated sludge in agriculture. Draft Palestinian standards and guidelines are under preparation by many Palestinian institutions. The draft standards take into consideration the regional and international standards and the special situation of Palestinian conditions. The guidelines aim to determine and specify the proper management of sludge treatment and reuse in agricultural purposes.

11.2 Recommendations

The research is a first step towards establishing a sustainable sludge management system in Palestine. Many further technical, social, institutional and academic steps are required in the short and medium terms to ensure the sustainability of the system. The author recommends the following points as required steps towards achievement of proper sludge management:

1. The existing sludge drying beds have to be converted to reed bed systems with modifications proposed in article 10.2. Retrofit of drying beds into reed beds is easy and not costly.
2. A training programme regarding design, operation and management of reed bed systems has to be delivered to treatment plant operators. Such training can be carried out using local human resources, and

strengthened by international experience. The pilot project can be used as a demonstration project for such training.

3. A public awareness programme for farmers has to be initiated. The aim of such a programme is to increase the awareness of farmers about the impact of using sludge in agricultural areas and the safest method of sludge handling. The programmes can be run through agricultural organizations in cooperation with the Palestinian Ministry of Agriculture and the Environmental Quality Authority. The existing accumulated sludge in the reed bed of the pilot project can be used for demonstration purposes. Brochures and leaflets have to be produced and disseminated among the Palestinian farmers.
4. The Palestinian Environmental Quality Authority has to establish a comprehensive monitoring program. The monitoring program will consider the impact of using sludge on health, soil and water resources. Such a programme has to be a long-term programme and should be conducted in co-operation with local academic institutions such as universities.
5. The current research did not cover all design and operational aspects of reed bed systems. The Palestinian academic institutions have to follow up the research through monitoring any new reed bed system in Palestine and study the system for more than three years.
6. Privatization of sludge treatment and reuse has to be one of the Palestinian aims. The quality of raw sludge in the Gaza Strip and the climatic conditions could make the reed bed system for sludge treatment attractive for investors to make a profit.
7. The Palestinian institutions have to monitor the wastewater in the Gaza Strip and protect the municipal wastewater from any industrial wastewater which could be a source of heavy metal pollution that will impact negatively the potential of using sludge in agricultural purposes.

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Appendix A
Pilot Project Data

Table A1: flow & 24-hr infiltration vs. time

Time	Planted		Non Planted	
	Flow m^3	24- hr inf. m^3	Flow m^3	24- hr inf. m^3
05/06/2000	24	7.6	19	2.3
12/06/2000	17	3.7	17	14.2
29/06/2000	29	15	23	18.8
16/07/2000	22	15.1	25	17.6
26/07/2000	41	18.7	41	29
02/08/2000	40	5.3	41	17.6
16/08/2000	33	10.3	33	17.4
27/08/2000	20	8.5	22	11.1
03/09/2000	25	11.8	27	16.2
18/09/2000	32	11.9	32	11.2
01/10/2000	32	8.6	30	10.2
14/10/2000	32	7.1	30	2.2
29/10/2000	38	3	37	3.5
12/11/2000	31	2	32	2.4
08/02/2001	34			
14/02/2001	42	17.7		
20/02/2001	36	15.3		
28/02/2001	53	21	50	
18/03/2001	26	13.6		
27/03/2001	26	8.2		
02/04/2001	26	8		
09/04/2001	26	4.8	26	
16/04/2001	74	20.6	83	
23/04/2001	50	20.7	14	
12/05/2001	27		22	
16/05/2001	26	15	19	11
21/05/2001	99	18	69	6
28/05/2001	70	12	73	6
05/06/2001	68	10	62	6
12/06/2001	70	14	68	6
09/07/2001	12			
16/07/2001	13			
24/07/2001	9		13	
07/08/2001	106	12	140	7
13/08/2001	97	9	53	6
22/08/2001	106	22	86	11
26/08/2001	48	14	51	10
02/09/2001	40	5.2	66	9
16/09/2001	83	31.4	86	16
16/10/2001	78	16	102	6
04/11/2001	50		60	14
02/12/2001	95	2.4	80	5
25/12/2001	98	10	112	2

Table A1 continue

Time	Planted		Non Planted	
	Flow m^3	24- hr inf. m^3	Flow m^3	24- hr inf. m^3
06/01/2002	69	6	72	9
27/01/2002	63	9.9	63	6
10/02/2002	64	4	64	4
26/02/2002	80.6	4.8	57	6
11/03/2002	90	13	90	14
24/03/2002	57	5.1	39	2
08/04/2002	54	7	42	5
27/04/2002	71.7	10.7	64	7
21/05/2002	50	2	75	1
02/06/2002	106	28.4	90	11
15/06/2002	115	24.5	148	9
30/06/2002	235	40	157	19
14/07/2002	117	19	117	30
28/07/2002	172	34	157	20
11/08/2002	162	32	154	
25/08/2002	160	20	130	10

Table A2: Hydraulic load & infiltrated water quantity vs. time

Month	Flow m^3		Infiltrate m^3	
	Planted	Unplanted	Planted	Unplanted
05/00	271	95	230	55.2
06/00	187	174	150	122.2
07/00	223	225	165	155.7
08/00	220	229	143.3	184.9
09/00	154	158	110.2	130.9
10/00	290	280	223.1	242.5
11/00	178	173	134.4	106.1
12/00	88	82		
3/01	105	50		
4/01	176	123		
5/01	152	110	60	44
6/01	138	130	61	60
7/01	34	13		
8/01	360	330	168.6	135
9/01	123	152	119.3	132
10/01	78	102	40.1	47
11/01	50	60		34
12/01	193	192	77.2	89
1/02	132	135	148.8	143
2/02	225	190	72.6	48
3/02	241	151.5	69.4	73
4/02	125.7	106	50	47
5/02	50	75	13.8	5
6/02	456	395	80.5	56
7/02	269	274	124	81
8/02	322	284	287	96

Table A3: Accumulated sludge height vs. time

Time	Height of accumulated sludge cm		Volume of accumulated sludge m^3	
	Planted	Unplanted	Planted	Unplanted
12/5/01	0.3	0.24	83.672	70.48717
22/8/01	0.38	0.37	101.6106	99.34569
16/9/01	0.55	0.45	141.1183	117.6478
4/11/01	0.53	0.5	136.3709	129.3
27/1/02	0.58	0.61	148.2895	155.5214
2/6/02	0.7	0.66	177.584	167.7101
30/8/02	0.8	0.75	202.752	190.0813
25/10/02	0.67	0.68	170.1683	172.6333
15/1/03	0.6	0.6	153.104	153.104

Table A4: Meteorological Data of the Gaza City 2000

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Temp. °C	13.0	13.8	14.8	19.5	21.1	24.9	27.3	27.5	26.0	22.9	19.8	15.8
Mean Max temp °C	16.6	17.2	17.7	22.9	23.8	27.5	31.2	30.0	28.6	25.5	23.0	18.9
Mean Min. Temp °C	9.8	10.0	11.5	15.9	17.8	21.7	16.0	24.5	22.8	19.1	15.9	12.6
RH %	68	68	71	69	72	75	75	71	70	65	59	72
Evaporation (mm)	81	78	112	129	161	174	180	183	153	136	141	108
Rainfall (mm)	213	41	27	0	0	0	0	0	1	132	18	133

Table A5: Meteorological Data of the Gaza City 2001

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Temp. °C	18.4	18.2	21.4	23.4	24.7	26.7	28.9	29.9	28.7	26.5	22.8	18.9
Mean Max temp °C	10.8	10.8	14.8	16.4	18.7	21.7	23.2	24.5	23.3	20.3	15.6	14.8
Mean Min. Temp °C	14.7	14.5	18.1	19.9	21.8	24.8	26.4	27.7	26.2	24.0	19.5	15.9
RH %	57	68	74	67	72	73	76	72	69	69	65	66
Evaporation (mm)	113.7	106	146	152.6	178.6	250.9	201	211	184.2	155.5	114	95.3
Rainfall (mm)	130.4	53.2	10.5	35	27	0.0	0.0	0.0	0.0	14.4	23.7	198.3

Table A6: Meteorological Data of the Gaza City 2002

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Temp. °C	15.9	18.3	20.9	21.8	23.1	27.0	29.7	30.0	28.6	26.1	24.1	19.4
Mean Max temp °C	9.5	12.2	14.0	15.6	18.1	21.7	24.5	24.9	23.2	21.3	17.3	13.1
Mean Min. Temp °C	12.8	15.7	17.6	18.9	20.9	24.7	27.4	27.8	26.5	24.3	21.1	16.3
RH %	69	69	70	68	74	73	75	71	76	71	54	66
Evaporation (mm)	96.2	95.8	118.8	135.6	171.5	185.8	190.2	173.3	122.9	101.7	79	138.1
Rainfall (mm)	202.4	17.8	11.8	12.1	6.6	0.0	0.0	0.0	0.0	38.8	6.4	163.2

Table A7: Quality of accumulated sludge

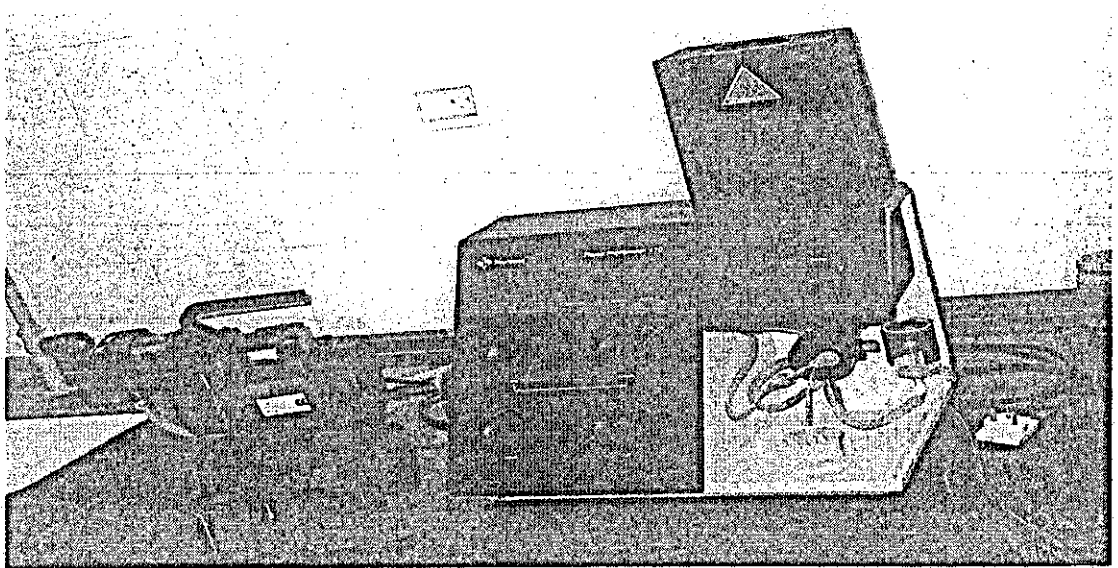
	sample no	mass g/25 ml	helminthes	W1	W2	W3	EC/s	pH	Cl	Na	K	Color	Hg	Cr	Cu	Ni	Fe	Mg	Pb
non planted	D1	14.96	Negative	32.396	41.641	37.588	3000	6.9	165	13.84	3.37	grey	nil	nil	nil	nil	0.334	0.13	nil
	D2	16.99	Negative	32.316	41.636	37.834	3130	7.2	235	9.82	2.05	black	nil	nil	nil	nil	0.297	0.044	nil
	D3	17.72	Negative	20.388	29.783	26.481	2920	7.2	165	7.33	1.69	grey	nil	nil	nil	nil	0.132	0.31	0.11
non planted	E1	15.15	Negative	31.729	41.035	37.592	3160	7.1	255	13.5	2.45	grey	nil	nil	nil	0.02	0.293	0.56	0.036
	E2	15.98	Negative	19.454	28.992	26.387	2780	7.1	130	8.14	1.12	grey	nil	nil	nil	0.004	0.323	0.76	0.054
	E3	14.86	Negative	35.247	44.591	40.82	3110	7.1	305	9.98	1.63	grey	nil	nil	nil	nil	0.263	0.26	0.094
planted	F1	16.33	Negative	20.939	30.201	26.38	3060	7.2	255	15	3.18	grey	nil	nil	nil	nil	0.263	0.45	nil
	F2	14.9	Negative	20.224	29.551	25.494	2740	7.1	200	10.87	3.02	grey	nil	nil	nil	0.004	0.3	0.63	nil
	F3	15.14	positive	32.041	41.402	37.55	2870	7.2	270	10.3	2.53	black	nil	nil	nil	nil	0.404	0.27	0.15
planted	G1	15.25	Negative	21.149	30.458	26.745	3150	6.9	190	10.47	2.2	black	nil	nil	nil	0.009	0.263	0.67	0.16
	G2	17.3	Negative	32.5	41.933	38.64	2670	6.8	145	7.97	1.31	grey	nil	nil	nil	nil	0.425	0.088	nil
	G3	16.76	Negative	12.723	22.086	18.608	3040	7.2	170	8.46	1.4	grey	nil	nil	nil	nil	0.331	0.29	nil
planted	H1	16.26	Negative	18.505	27.818	24.108	2820	6.9	150	10.14	2.87	grey	nil	nil	nil	nil	0.27	0.037	nil
	H2	15.41	Negative	31.612	40.568	37.208	2850	7	210	7.1	1.93	black	nil	nil	nil	nil	0.377	0.29	nil
	H3	15.39	Negative	33.331	42.636	38.691	2820	7.1	180	9.02	2.41	black	nil	nil	nil	nil	0.252	0.34	nil
ponds	I1	6.24	Negative	32.84	42.079	36.012	2880	6.7	145	15.05	4.5	grey	nil	nil	nil	nil	0.224	0.22	nil
	I2	14.03	positive	52.345	61.66	58.067	3290	7.1	255	13.44	1.55	black	nil	nil	nil	nil	0.458	0.42	nil
dry from holding bed	J1	16.57	Negative	32.112	41.459	37.683	2850	7.1	340	14.49	3.5	black	nil	nil	nil	nil	0.293	0.21	0.039
	J2	16.66	Negative	20.576	29.979	27.277	2790	7.1	225	7.3	1.48	grey	nil	nil	nil	0.005	0.209	0.42	nil

Table A8: Quality of raw sludge & infiltrated water

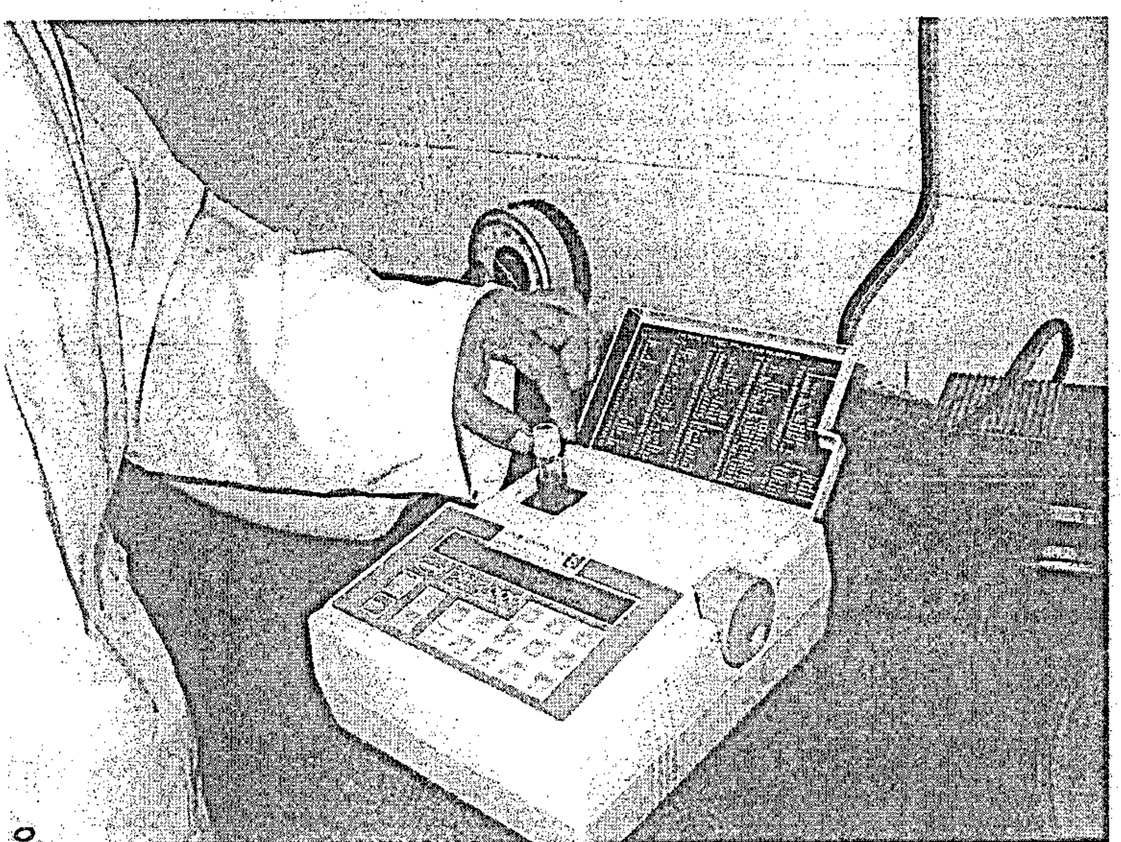
Time	TSS			TDS			EC			COD			TKN			pH			PO4		
	Sludge	unplanted	planted	Sludge	unplanted	planted	Sludge	unplanted	planted	Sludge	unplanted	planted	Sludge	unplanted	planted	Sludge	unplanted	planted	Sludge	unplanted	planted
08/06/2000	15060		7	1916		1915															
18/06/2000	2940	13	14	1612	2707	2782				3400	150	155									
26/06/2000	5940	23	18	1528	2337	2534				6000	109	109									
02/07/2000	2480	10	14	1264	1958	2306				2425	105	100									
23/07/2000	3080	111	7	1510	2589	2765	3.06	3.39	4.49		226	113									
26/07/2000	5880	15	23				3.17	3.68	3.72				308	18.6	9.3						
16/08/2000	5040	9	5	1500	2487	2735	3.11	3.94	4.4	4800	135	91									
27/08/2000							3.09	4.14	4.61	5680	109	135									
30/08/2000							3.39	4.16	5.18												
07/09/2000	1290	8	7	1490	2181	2704	3.32	3.9	4.84	1424	82	81	700	10.64	5.6	7.73	6.83	6.86	7.74	11.47	9.21
21/09/2000	13020	6	10				3.2	3.73	4.69	11690	79	66	952.47	10.64	0	7.56	6.57	6.65	7.12	13.41	9.22
08/10/2000	3100	3	11		1905	1989	4.24	4.62	5.08	5130	67	75	196	15.41	23	7.83	6.91	6.9	8.68	15	20
22/10/2000	29780	12	13	1336	2112	2379	3.94	4.68	5.36	25000	76	76	1078	31.37	31.37	7	6.9	6.89			
05/11/2000	25060	37	13		2478	2502	2.56	4.25	5	25860	102	92	672	43.4	61	7.25	6.63	6.92	9	41.6	48
28/02/2001	13760			2120			3.4														
28/05/2001	51840	17	6				3.42	4.37	5.55	3820	90	88				7.09	7.03	6.99			
13/08/2001		17	15		2850	2170		5.43	5.2		218	145									
04/11/2001		18	11								96	115		120	119		7.1	7.1			
06/01/2002		13	13		1970	2520		3.87	4.88												
17/02/2002	23800	94	67	1440			2.6			26500	268	289									
24/03/2002	8500			1260			2.79	3.24	3.84	28500	222	334	106			8.1	7.5	7.3			
27/04/2002	65760			1680			3									7.5					
27/04/2002	44220			1540			3.27									7.8					
27/04/2002	10800			1380			2.98									8.1					
27/04/2002	9140			1440			2.88			12600			102.2			8.1					
02/06/2002	42530	64	36	1595						24000	544	489				7.9	7.6	7.4			
29/07/2002	10550	120	110	1550			3.22	4.3	4.22	5275	230	250	546	202	200	8.4	8	8			
29/07/2002	10300			1620			3.22			6500			621			8.4					
29/07/2002	24200			1700			3.25			6000			1176			8.4					
29/07/2002	6500			1600			3.19			5750			453			8.4					

Table A9: Method used for determination of different parameters of sludge and leached water

Parameters	Methods Used
pH	Electrometric, pH- HI 1280 Hanna
Electrical Conductivity - EC	Ion Selective Electrode, Jenway, 4310
Total Solids -TS	Dried of 100 ml (for leached water and 10 g for accumulated sludge) at 105 °C
Biochemical Oxygen Demand – BOD	WTW, OxiTop, Incubation at °c 20 for 5 days.
Chemical Oxygen Demand COD	Oxidation with Dichromate, Hach Reagent and Hach Photometer DR 2000
Total Organic Carbon – TOC	Determination of volatile Solids by burning at 550 °C in muffle furnace.
Total Kjeldal Nitrogen TKN	Micro-Kjeldahl tacator 1002
Chloride –Cl	Titration: Calorimetric, Silver Nitrate
Sodium –Na	Flam Photometric, Sherwood, Scientific Ltd., 410
Potassium – K	Flam Photometric, Sherwood, Scientific Ltd., 410
Calcium - Ca	Titration calorimetric, EDTA Reagent
Total Phosphorus T-P	Digestion in concentrated acids and Spectro –photometric, Hach Photometer DR 2000 and SnC_2l-Reagent.
Iron – Fe	Digestion in concentrated acids and AAS (Atomic Absorption spectroscopy) Perkin Elmer, 100
Lead – Pb	Digestion in concentrated acids and AAS (Atomic Absorption spectroscopy) Perkin Elmer, 100
Copper – Cu	Digestion in concentrated acids and AAS (Atomic Absorption spectroscopy) Perkin Elmer, 100
Nickel – Ni	Digestion in concentrated acids and AAS (Atomic Absorption spectroscopy) Perkin Elmer, 100
Zinc – Zn	Digestion in concentrated acids and AAS (Atomic Absorption spectroscopy) Perkin Elmer, 100
Mercury – Hg	Digestion in concentrated acids and AAS (Atomic Absorption spectroscopy) Perkin Elmer,100
Chromium Cr	Digestion in concentrated acids and AAS (Atomic Absorption spectroscopy) Perkin Elmer, 100

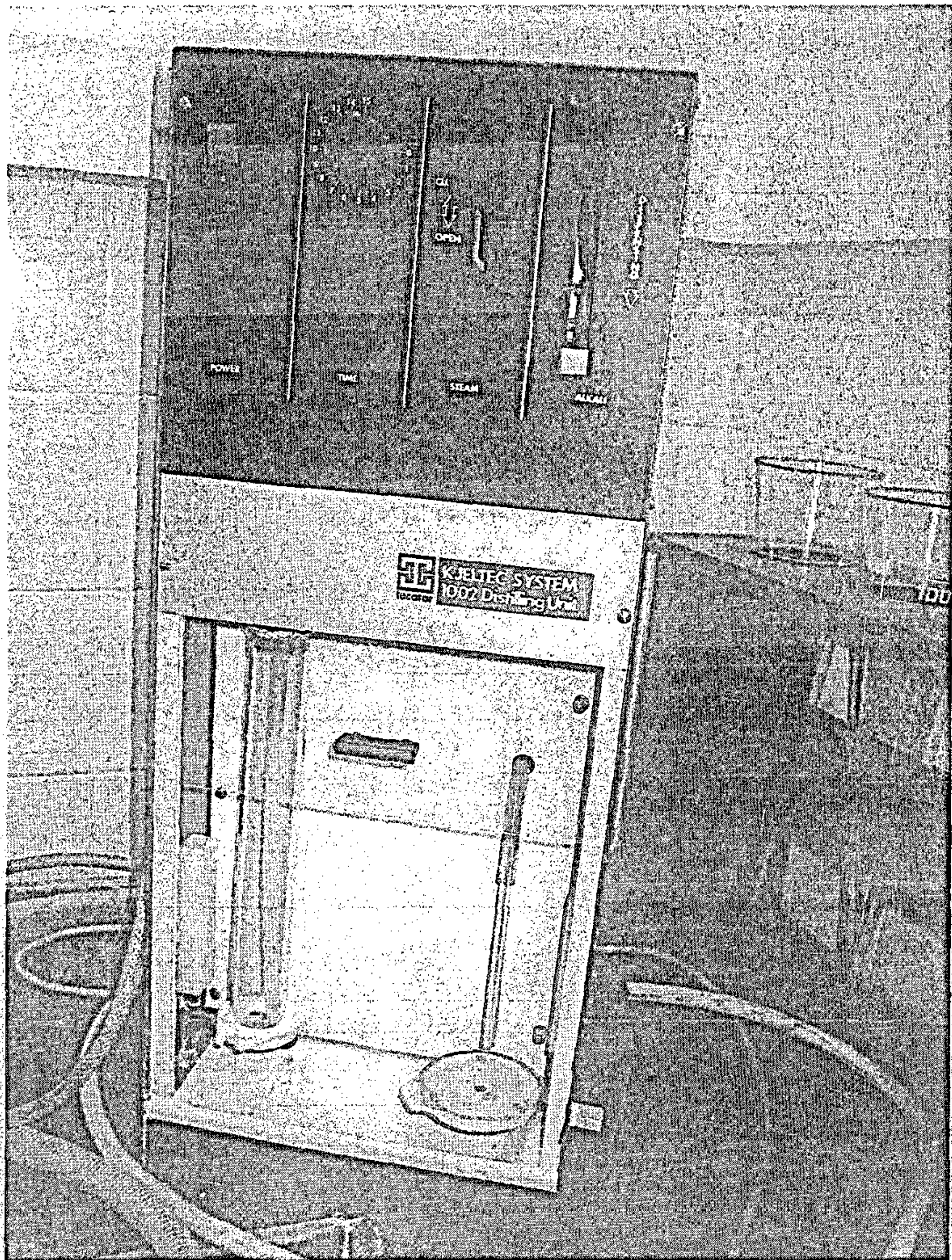


Flam Photometric, Sherwood, Scientific Ltd., 410

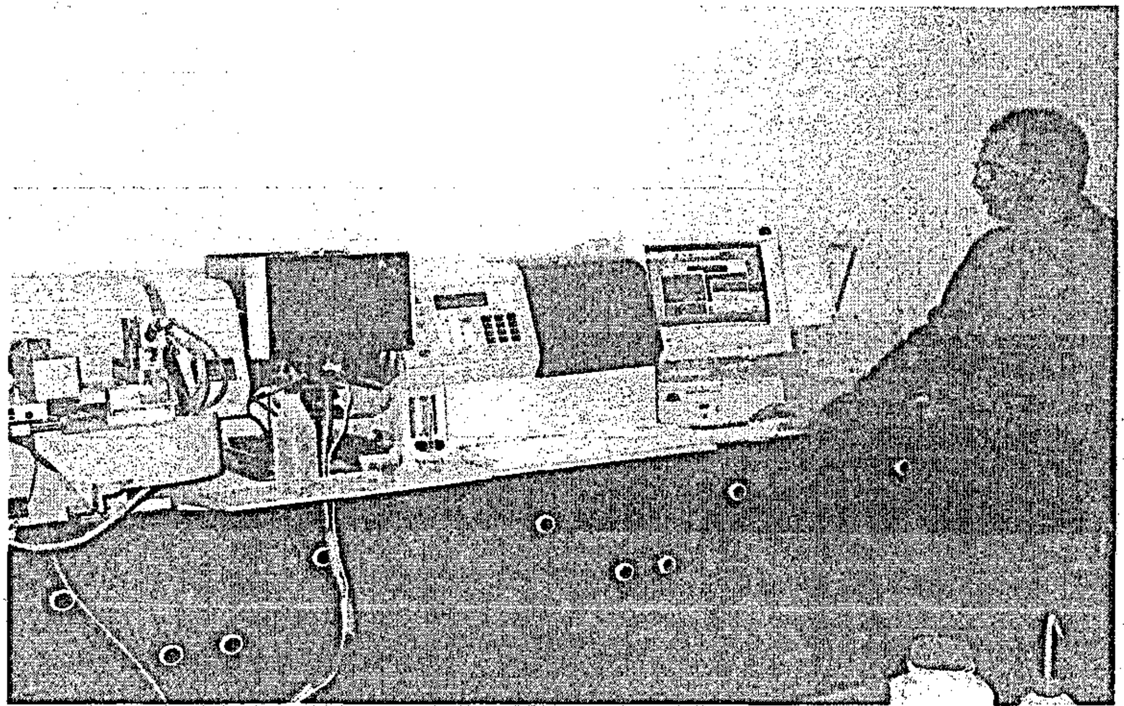


Hach Photometer DR 2000 for Chemical Oxygen Demand – COD Determination

Manometers for BOD_5 Determination



Distillation Unit of Micro-Kjeldahl - tecator 1002 - for Total Kjeldahl Nitrogen TKN



Atomic Absorption Spectroscopy – AAS - Perkin Elmer, 100 ,for Heavy Metal Determination

Appendix B
Farmer's Survey

1. What are the size of your agricultural land & the type of crops?

Type of Cultivation	Size (dunum = 1000 m^2)	Times of using fertilizers- specify the month	Amount of fertilizers	For which crop could you use treated sludge? (yes or no)
Citrus				
Olive				
Almonds				
Java				
Vegetables grown outdoors				
Vegetables grown in green houses				

2. From where do you get the organic fertilisers?

a. Own farm b. Bought c. Both a and b

3. How much do you pay per tonne?

a. Animal .... NIS b. Birds ....NIS

4. Are you satisfied with the existing sources of fertilisers?

a. Yes b. No

5. Did you use treated sludge before?

a. Yes b. No (If No go to question 7)

6. If yes,

6.1 you think that treated sludge is good alternative to existing resources?

a. Very much

b. Much

c. Don't know

d. No

e. Definitely not

6.2. Do you think that treated sludge better than available resources?

a. Very much

b. Much

c. Don't know

d. No

e. Definitely not

7. If you did not use treated sludge before,

7.1 are you willing to use it?

a. Yes b. No

7.2 if No, this is because

a. Do not trust that sludge is suitable

b. Concern about consumers attitude

c. Special needs are associated with sludge use

d. Others, Specify...

8. Would you be willing to use treated sludge as a soil improver for your agricultural land?

a. Very much

b. Much

c. Don't know

d. No

e. Definitely not

9. Do you think treated sludge can be used for all crops? a. yes b. no

10. How much are you willing to pay for treated sludge?

a. the same price as animal manure

b. ¾ the price of animal manure

c. ½ the price of animal manure

d. ¼ the price of animal manure

e. Nothing

11. How do you think using treated sludge will affect the environmental situation in Gaza? a. Yes b. No

Appendix C
Sludge Quantity Estimation

Estimation of existing quantities of sludge

Three existing wastewater treatment plants are in operation in the Gaza Strip. Sludge produced from the treatment plants doesn't measure and estimation is made based on theoretical calculations. The quantity of solids as dry matter is calculated based on the following formula ***(Hammer, 1986)***:

$M_s = Y \times BOD$

Where;

M_s = biological sludge solids, grams of dry mass per day

Y = fraction of applied BOD that appears as excess solids

BOD = BOD in applied wastewater, gram per day

Determination of aerobic sludge quantities generated daily in the Gaza Wastewater Treatment Plant

Flow	45,000	m^3/day
BOD in	500	mg/l
BOD at the inlet of bio-towers	250	mg/l
BOD out	30	mg/l
Y coefficient	0.6	kg biomass/kg BOD consumed
Sludge solids content	1.5	%
Calculation		
Sludge mass	5940	kg/day
Sludge volume	396	m^3/day

Determination of anaerobic sludge accumulated in ponds

Gaza City		
Flow	45,000	m^3/day
BOD in	500	mg/l
BOD after anaerobic ponds	250	mg/l
Y coefficient	0.3	kg biomass/kg BOD consumed
Sludge solids content	4	%
Calculation		
Sludge mass	3375	kg/day
Sludge volume	84.375	m^3/day

Jabalia & Rafah

Flow	15,000	m3/day
BOD in	500	mg/l
BOD after anaerobic ponds	50	mg/l
Y coefficient	0.3	kg biomass/kg BOD consumed
Sludge solids content	4	%
Calculation		
Sludge mass	2025	kg/day
Sludge volume	50.625	m^3/day
Total Anaerobic Sludge	**135**	**m^3/day**

Total anaerobic sludge = 135 X 365 = 49,275 m^3/year
Total Aerobic sludge = 396 m^3/day

Appendix D
Environmental Law

Palestinian Environmental Law

NO (7) 1999

The Chairman of PLO Executive Committee, President of the Palestinian Authority, After approval of the Palestinian Legislative Council in its session on 6 / 7 /1999,The following law was enacted

Title I

Definitions and General Provisions

Chapter 1

(Definitions)

Article (1)

In applying the provisions of this law, the following words and terms shall have their specified definitions below, unless otherwise is provided: Environment: the vital surroundings with all forms of life, including air, water, land, the facilities and the interactions among them.

Air: the mixture of gases, which form air with its natural characteristics and defined ratios.

Soil: the surface crust of the earth on which there can be activities of agriculture, construction, and digging. That includes all types of land.

Drifting: removal away any part of the soil.

Water: Includes surface and underground water in all forms, fresh, saline or semi-saline.

Environmental Pollution: Any direct or indirect changes in the characteristics of the environment, that may cause harm to any of its components or disrupts its natural balance.

Air Pollution: Any change in the characteristics or components of the natural air, which may cause harm to the environment.

Water Pollution: Any change in the characteristics or components of water, which may cause harm to the environment.

Pollutant Substance and Agents: Any substance in the forms of gas, liquid, solid, aerosol, vapor, odor, noise, radiation, heat, flashlight, or vibrations which may result in the pollution or deterioration of the environment.

Hazardous Substance: Any substance or compound, which because of its hazardous characteristics poses a danger on the environment as toxic, radioactive, biologically infectious, explosive or flammable substances.

Hazardous Waste: waste generated by the various activities and operations or the ash thereof, which preserve the characteristics of hazardous substance which have no usage, such as atomic waste, medical waste, or refuse emanating from the manufacturing of pharmaceutical products, medicines, organic solvents, dyes, painting, pesticides or any other similar hazardous substance.

Solid Waste: Any non-hazardous waste, or garbage generated by the different activities: household, commercial, agricultural, constructional, industrial waste and the sludge generated by wastewater treatment plants.

Waste Water: Water polluted by solid, liquid, gas, energy, or microorganisms' matters generated or resulted from homes, buildings or the variant facilities.

Underground Water: Any flowing, running or stagnant water in the underground.

Facility: Any land, building, structure, or equipment that constitute the facility.

Facility Owner: Any natural or legal person, who may own or lease a facility, or be responsible for operating and managing it.

Environmental Harm: Any harm generated by the exercise of any activity which may cause harms to public health, public welfare and environment.

License: An official document issued by the competent body authorizing the establishment and operation of the facility, and determining specific governing rules and restrictions thereof.

Environmental Impact: Any negative or positive outcome generated by the different activities from the facility or project which affect the different elements of the environment.

Pollution Prevention: measures and procedures taken to prevent any pollution.

Pollution Control: measures and procedures taken to reduce or eliminate the emission of pollutants.

Environmental Protection: includes preserving the elements of the environment, preventing or reducing the pollution and degrading thereof as well as upgrading these elements.

Dumping: discharge of various pollutants generated by all types of facilities or transportation facilities in inland, and territorial or free economic zone water.

Ship: Any marine unit, floating on or plunged in water, whether it is a civil or military one.

Marine Installations: Any stationary or mobile facility built on or under water for commercial, industrial, tourism, military or scientific purposes.

Public Areas: Areas designated to receive the public at large or any definite group for whatever purpose.

Standards: Percentages, quantities or norms as established by competent agencies to define the environmental pollutants and their harmful impacts.

Waste Management: Collection of the different wastes and the transportation thereof to specified zones for recycling, treatment or disposal.

Environmental Disaster: Any event generated by natural or human action, which results in severe harm to the environment, the combat of which requires possibilities beyond local capabilities.

Compensation: What is paid for harms caused by the variant pollutants as a result of an act or more performed by natural or juridical persons affecting the environmental components, pursuant to administrative or judicial orders, or in the implementation of provisions stipulated in international conventions.

Environmental Nuisance: The harm or material damage caused by the generation of noise, vibration, radiation, or irritations; the release of smells which result from any activity of humans, facilities, transportation facilities or any other agent in a manner that affects properties or the human (exercise of natural) life.

Environmental Monitoring: procedures undertaken by competent agencies, to ensure that all persons and agencies abide by the environmental standards and instructions prescribed to ensure that they are not violated or surpassed.

Environmental Control: Activities meant to monitor the quality of the environment.

Environmental Deterioration: Any impact on the environment or its components that may cause harms which degrades the environment or depletes its resources and harms living organisms.

Ministry: Ministry of Environmental Affairs.

Minister: Minister of Environmental Affairs.

Environmental Awareness: Spreading the knowledge which consolidate the principles and values to upgrade public awareness needed to preserve the environment and its components.

Closed Public Areas: Any public areas in the form of complete building where air comes in only through windows built in for that purposes and include (theaters, cinemas, museums, restaurants, meeting halls, etc.), public transportation facilities shall also be subject to this definition.

Natural Reserves: Areas designated to preserve certain types of living organisms or other ecosystems that have natural or aesthetic values which are forbidden to eliminate, affect or destroy them.

Discharge: Throwing, leaking, emitting, pumping, pouring, or discharging in a direct or indirect manner - of any environmental pollutants in the air, land, inland or territorial waters.

Free economic zone: The marine area which lies beyond and adjacent to the territorial sea, which does not exceed two hundred marine miles measured with the same lines used to measure the latitude of the territorial sea.

Environmental Approval: An official document issued by the Ministry expressing the environmental opinion regarding establishing or practicing any activities that require an environmental approval.

Environmental impact assessment "EIA": A detailed study for assessing the environmental impacts as a result of practicing any activities.

Article (2)

The objectives of this law are:

1. Protection of the environment against all forms and types of pollution;

2. Protection of Public health and welfare;

3. Insertion of the bases of environmental protection in social and economic *development plans; and encouragement of sustainable development of vital* resources in a manner that preserves the rights of future generations;

4. Protection of bio-diversity and environmentally sensitive areas, as well as improvement of environmentally harmed areas;

5. Encouragement of collection and publication of environment-related information to raise public awareness of environmental problems.

Chapter 2

(General Provisions)

Article (3)

Every person may:

A. regardless of personal interest and in order to secure a sound environment, file or *follow up on any complaint or appropriate legal proceedings against any natural or* juridical person causing harm to the environment.

B. obtain any necessary official information to discover the environmental impact of any industrial, agricultural, constructional or other activity within the development programs, in compliance with the law.

Article (4)

The Ministry, in coordination with the competent agencies, shall work on the generalization of the concepts and objectives of the environmental education through schools, universities, institutions, and clubs. It shall also encourage collective and individual initiatives for voluntary work aiming to protect the environment.

Article (5)

This law shall guarantee:

A. The right to every individual to live in a sound and clean environment and enjoy the best possible degree of health care and welfare.

B. Protection of the country's natural fortunes and economic resources, besides the preservation of its historical and cultural heritage without any harms or side effects that are likely to occur sooner or later as a result of the variant industrial, agricultural or constructional activities, with an impact on the quality of life and basic ecosystems such as air, water, soil; marine resources, animals and plants.

Title II

Environmental Protection

Chapter 1

Land Environment

Article (6)

The competent agencies, in coordination with The Ministry, shall prepare the general policy for land uses taking into account the optimal use thereof and the protection of natural resources and areas with special natural characteristics as well as the conservation of the environment.

Solid Waste

Article (7)

The Ministry, in coordination with other competent agencies, shall set a comprehensive plan for solid waste management on the national level, including the ways and the designation of sites for solid waste disposal as well as the supervision over the implementation of this plan by the local councils.

Article (8)

The competent agencies, along with their respective specialization, shall encourage undertaking appropriate precautions to reduce the generation of solid waste to the lowest level possible; re-use it as much as possible, recover its components or recycle it.

Article (9)

The Ministry, in cooperation with the competent agencies, shall determine the standards of solid waste disposal sites.

Article (10)

All agencies and individuals, in conducting any digging, construction; demolition, mining or transportation of debris and sands generated by such activities, shall commit themselves to take all necessary precautions for safe storage and transportation of such materials to prevent any environmental pollution.

Hazardous Substance and Waste

Article (11)

The Ministry, in coordination with the competent agencies, shall issue one or more lists of hazardous substances and wastes.

Article (12)

No person shall be authorized to manufacture, store, distribute, use; treat, or dispose any hazardous substance or waste whether it is solid, liquid, or gas, unless in accordance with the orders and directives specified by the Ministry in coordination with the competent agencies.

Article (13)

A. It is forbidden to import any hazardous wastes to Palestine.

B. It is forbidden to pass hazardous waste through the Palestinian territories or through the territorial water or free economic zone of Palestine, unless a special permit is obtained from the Ministry.

Pesticides and Fertilizer

Article (14)

The Ministry, in coordination with the competent agencies shall designate the environmental conditions for the import, distribution, manufacturing, use, and storage of pesticides, substances, and agri-chemical fertilizers, which may pose hazards to the environment.

Article (15)

The Ministry, in cooperation with competent agencies, shall set instructions and standards specified for the agri-chemicals that are allowed to be imported, manufactured and distributed in Palestine, and shall verify observance of it.

Quarrying and Mining

Article (16)

The Ministry, in coordination with the competent agencies, shall set up the environmental conditions compatible for mining, quarrying activities, rubbles, mines and stone quarrying places in a manner that ensures both the protection of the environment against the hazards of environmental pollution; and the preservation of natural resources.

Desertification and Land Drifting

Article (17)

For the purpose of combating desertification and preventing drifting, the Ministry in cooperation and coordination with the Ministry of Agriculture and other competent agencies, shall encourage undertaking appropriate procedures for farming the wasteland.

Article (18)

It is forbidden to drift arable lands or transport its soil in order to use it for purposes other than farming. It shall not be considered as drifting if the land is leveled, or its soil is transported to be improved agriculturally or preserve its fertility or build on it in compliance with the terms and restrictions enacted by the competent agencies.

Chapter 2

Air Environment

Article (19)

A. The Ministry, in cooperation with the competent agencies, shall specify standards to regulate the percentage of pollutants in the air which may cause harm or damage to public health, social welfare and the environment;

B. Each facility, which will be established in Palestine, shall abide by these standards; every existing facility shall make necessary changes in a manner that makes it conform to these standards within a period that does not exceed three years.

Article (20)

Every facility owner shall provide all means to ensure the necessary protection for workers and the neighbors of the facility in compliance with the conditions of occupational safety and health, against any leak or emission of pollutants in or out the working place.

Article (21)

It is forbidden to smoke in transportation means and closed public areas.

Article (22)

It shall be prohibited to utilize machines, engines or vehicles that generate exhaust that does not comply with the standards specified in accordance with the provisions of this law.

Article (23)

It is forbidden to dispose, treat or incinerate garbage and solid waste except in the sites designated for this purpose and in compliance with the conditions specified by the Ministry to ensure the protection of the environment.

Article (24)

The Ministry shall work on the reduction of ozone depletion in accordance with the provisions of international conventions to which Palestine is committed through undertaking appropriate procedures regarding importing, producing or utilizing any chemical substances that may cause harm thereto.

<u>Environmental Nuisance and Noise</u>

Article (25)

The Ministry, in cooperation with the competent agencies, shall work on establishing standards, directives and conditions to reduce environmental nuisance generated by different activities. In addition, every facility owner, entity or individual shall be forbidden to cause any nuisance to the others.

Article (26)

Every entity and individual, upon operation of any machine or equipment, or upon utilization of alarm devices, loud speakers, or during any other activities, shall not be allowed to exceed the permissible sound intensity and vibration levels.

Article (27)

Radioactive activities or radioactive substance concentrations emitted by any facility or other activity shall not be allowed to exceed the permissible limits specified by the competent agencies.

Chapter 3

Water Environment

Article (28)

The Ministry in cooperation with the competent agencies shall specify the standards for the quality and characteristics of drinking water.

Article (29)

The Ministry, in coordination with the competent agencies, shall set standards and norms for collecting, treating, reusing, or disposing waste water and storm water in a sound manner, which comply with the preservation of the environment and public health.

Article (30)

No person shall be allowed to discharge any solid or liquid or other substance unless such a process conforms to the conditions and standards that the competent agencies determine.

Chapter 4

Marine Environment

Article (31)

The Ministry, in coordination with competent agencies, shall set standards for the quality of seawater specifying the norms, directives and conditions necessary to control sea pollutants.

Article (32)

It shall be forbidden for any one to perform any action which may cause pollution of sea water in a manner that contradicts with the standards, directives or conditions prescribed for the purposes of marine environment protection against pollution.

Article (33)

The Ministry, in coordination with the competent agencies, shall specify the necessary environmental conditions required for the establishment of any coastal or offshore buildings or facilities.

Article (34)

It shall be forbidden to perform any action, which may affect the natural track of the beach, or adjust it inside or far from the sea unless an environmental approval is obtained from the Ministry.

Article (35)

The Ministry shall prescribe rules and regulations for the prevention of pollution, preservation and control of the marine environment, against what is generated by the different activities that occur in the free economic zone, continental drifting or the sea bottom which are all subject to the jurisdiction of Palestine.

Article (36)

The Ministry, in cooperation with competent agencies, shall set the rules and regulations for prevention of marine environment pollution that comes as a result of dumping.

Article (37)

The Ministry, in cooperation with competent agencies, shall set the rules and regulations to prevent or reduce marine environment pollution generated by ships in the Palestinian ports and territorial water.

Article (38)

All entities including ships, regardless of their nationalities, shall be forbidden to throw or discharge oil or oil compounds or any other pollutants in the territorial water or the free economic zone of Palestine.

Article (39)

All national and international companies and agencies authorized to undertake digging or exploration activities, or produce or manufacture crude oil, or to extract or exploit oil fields and other marine natural sources, shall abide by the environmental conditions.

Chapter 5

Protection of Natural, Historical and Archaeological Areas

Article (40)

The Ministry, in coordination with competent agencies, shall prescribe bases and standards for the protection of natural reserves and national parks, monitor and declare them, and establish and designate the national parks and supervise them.

Article (41)

It is prohibited to hunt, kill, or catch the birds, marine and wild animals, and the fish specified in the bylaw of this law. Moreover, it is prohibited to possess, transport, walk with, sell or offer them for sale neither dead nor alive, or to damage their nests or the eggs.

Article (42)

The Ministry, in coordination with the competent agencies, shall specify the conditions necessary to guarantee the preservation of bio-diversity in Palestine.

Article (43)

The Ministry, in coordination with the competent agencies, shall set the bases and standers that determine the plants, wild and woodland are forbidden by these standards to be, temporally or permanently, picked up, harvested, damaged or cut off to ensure their endurance and continuation.

Article (44)

It shall be forbidden for any person to conduct activities or perform any action that may cause damage to the natural reserves, forests, public parks or archaeological sites, or affect the esthetical aspects of such areas.

Part IV

Environmental Impact Assessment, Licensing, Inspection and Administrative Procedures

Chapter 1

Environmental Impact Assessment

Article (45)

The Ministry, in coordination with the competent agencies, shall set standards to determine which projects and fields shall be subject to the environmental impact assessment studies. It shall also prepare lists of these projects and set the rules and procedures of the environmental impact assessment.

Chapter 2

Licensing

Article (46)

When authorizing any facility, the competent agencies shall avoid environmental hazards by encouraging transfer to projects that use substances and operations less harmful to the environment, and by giving priority to such projects on the basis of economic development.

Article (47)

The Ministry, in coordination with the competent agencies, shall determine the activities and projects that have to obtain an environmental approval before being licensed. This includes the projects that are allowed to be established in the restricted areas.

Article (48)

The Competent Agencies are not allowed to issue licenses for establishing projects or facilities, or for any other activities specified in article (47) of this Law, or to renew them unless an environmental approval is obtained from the Ministry.

Chapter 3

Inspection and Administrative Procedures

Article (49)

The Ministry shall follow up the implementation of the decisions issued regarding environmental impacts by cooperating with the competent agencies.

Article (50)

The Ministry, in coordination with the competent agencies, shall monitor the variant institutions, projects and activities to verify their compliance with the requirements, standards and directives prescribed for protecting the environment and the vital resources, in compliance with the provisions of this law.

Article (51)

Inspectors of the Ministry and other inspectors appointed by other ministries and agencies, and who have the power of commissioners in accordance with this law. The inspectors may curb environmental contravention or crimes committed in violation of this law.

Article (52)

The Ministry inspectors, in cooperation with competent agencies and administrations, have the right to have access to any facilities for inspection, take samples and measurements to ensure their conformity with the standards and conditions of environmental protection and pollution prevention.

Article (53)

The owners of the different projects and activities have to enable the inspectors of the Environmental Planning and any other competent agencies to conduct their duties, and provide them with the information and data that they see necessary in compliance with the provisions of this law.

Article (54)

Every owner of a facility shall perform self-monitoring operations in conformity with the standards and conditions stipulated by the Ministry in coordination with competent agencies and shall submit reports according to the Ministry's directives or to any other agency prescribed by the executive regulation of this law.

Article (55)

Any facility or project that violates the environmental conditions required for granting the license, the competent agency has the right to revoke or suspend the license. The owner of the facility or project may impeach the decision of revoking or suspending the license before a specialized court.

Article (56)

The violating facility or project shall not be allowed to resume activities without the removal of the contravention causes; if these causes are not removed, the competent agency shall remove them at the expense of the owner.

Article (57)

The minister can decide to suspend the work of any project, prevent wholly or partially the using of any machine or material, if the continuation of such use has extreme hazard on the environment. The suspension or prevention shall not exceed two weeks, and it is not possible to extend the period without a judicial order from the specialized court; moreover, those affected as a result of suspension and prevention can appeal before the specialized court.

Title V

Penalties

Article (58)

The penalties mentioned in this law shall be applied without jeopardizing any more severe penalty stipulated in any other laws,

Article (59)

Any facility owner or operator provides incorrect or misleading information regarding the environmental aspects of the facility he owns or operates, shall be penalized by imprisonment of a period not exceeding six months and a fine of not more than two thousand Jordanian Dinars or the equivalent thereof in the legally circulated currency, or one of the two penalties.

Article (60)

If, as a result of violation to the provisions of this law or any regulations or resolutions issued thereupon, an epidemic illness spreads out, and that the violator could have - in the extent possible – expected such a nuisance, he/ she shall be subject to imprisonment of a period not less than 5 years and a fine of not less than ten thousand Jordanian Dinars, or one of the two penalties.

Article (61)

Any person violates the previsions of Article (10) of this law shall be punished by paying a fine of twenty Jordanian Dinars or the equivalent thereof in the legally circulated currency, or imprisonment for a period of not less than three days.

Article (62)

Any person violates the provisions of Article (12) of this law shall be punished by a fine of not less than 1,000 and not more than 3,000 Jordanian Dinars or the equivalent thereof in the legally circulated currency and not more than three years of imprisonment, or one of the two penalties.

Article (63)

A. Any person violates the provisions in section (A) of Article (13) of this law shall be sentenced to eternal imprisonment with hard work, in addition to confiscating or eliminating the wastes at the violator's expense.

B. Any person violates the provisions in section (B) of Article (13) of this law shall be penalized by a fine of not less than 3,000 and not more than 20,000 Jordanian Dinars or the equivalent thereof in the legally circulated currency, and the imprisonment of a period not less than three years and not more than fifteen years, or one of the two penalties.

Article (64)

Any person violates the provisions of Article (18)of this law shall be penalized by a fine of not less than 500 and not more than 3,000 Jordanian Dinars or the equivalent thereof in the legally circulated currency and the imprisonment of a period not less than one month and not more than six months, or one of the two penalties.

Article (65)

Any person violates the provisions of Articles (21), (22) and (23) of this law shall be penalized by paying a fine of not less than 10 and not more than 100 Jordanian Dinars, or the equivalent thereof in the legally circulated currency and the imprisonment of a period not less than two days and not more than one week, or one of the two penalties.

Article (66)

Any person violates the provisions of Articles (25) and (26) of this law shall be penalized by paying a fine of not less than 50 and not more than 100 Jordanian Dinars, or the equivalent thereof in the legally circulated currency and the imprisonment of a period not less than one week and not more than one month, or one of the two penalties.

Article (67)

Any person violates the provisions of Article (27) of this law shall be penalized by paying a fine of not less than 1,000 and not more than 7,000 Jordanian Dinars, or the equivalent thereof in the legally circulated currency and the imprisonment of a period not less than one month and not more than one year, or one of the two penalties.

Article (68)

Any person violates the provisions in Article (30) of this law shall be penalized by paying a fine of not less than 200 and not more than 1,000 Jordanian Dinars, or the equivalent thereof in the legally circulated currency and the imprisonment of a period not less than one month and not more than six months, or one of the two penalties.

Article (69)

Any person violates the provisions of Articles (32), (38) and (39) of this law shall be penalized by paying a fine of not less than 5,000 and not more than 50,000 Jordanian Dinars or the equivalent thereof in the legally circulated currency, and imprisonment of a period not less than one year and not more than ten years, or one of the two penalties.

Article (70)

Any person violates the provisions of Article (34) of this law shall be penalized by paying a fine of not less than 1,000 and not more than 5,000 Jordanian Dinars, or the equivalent thereof in the legally circulated currency and the imprisonment of a period. not less than one month and not more than six months, or one of the two penalties.

Article (71)

Any person violates the provisions in Article (41) of this law shall be punished by a fine of not less than 20 and not more than 200 Jordanian Dinars or the equivalent thereof in the legally circulated currency, and the imprisonment for period not less than three days and not more than tow weeks, or one of the two penalties.

Article (72)

Any person violates the provisions of Article (44) of this law shall be penalized by paying a fine of not less than 20 and not more than 200 Jordanian Dinars, or the equivalent thereof in the legally circulated currency, and the imprisonment for a period not less than three days and not more than one month, or one of the two penalties.

Article (73)

Any person violates the provisions in Article (53) of this law shall be penalized by paying a fine of not less than 100 and not more than 500 Jordanian Dinars, or the equivalent thereof in the legally circulated currency, and the imprisonment for a period not less than one week and not more than a month, or one of the two penalties.

Article (74)

In addition to the provisions mentioned in the articles of this chapter, it is assumed that the removal of the harm and its effects must be at the violator's expense.

Title VI

Final Provisions

Article (75)

In order to implement the provisions of this law or any other international conventions regarding the environment, and of which Palestine is a part, the Ministry in coordination with the local competent agencies shall cooperate with the signatory countries to exchange scientific and technical information, coordinate programs in the field of joint environmental research, set and implement joint cooperation programs to prevent or reduce environmental pollution, and exchange various forms of assistance in this regard.

Article (76)

Every normal or juridical person who causes environmental harm as a result of an action or negligence in violation of the provisions of this law or any international convention of which Palestine is a part, shall be compelled to pay the convenient compensations in addition to the penal liability explicated in this law.

Article (77)

According to the previsions of this law, International and regional conventions, treaties, and the provisions of the international entities of which Palestine is a part, or any other laws related to the environment which are in effect in the Palestinian territories, shall be considered complementary to this law, unless otherwise is stated.

Article (78)

The Ministry, with the participation other competent agencies, shall prepare emergency plans to combat environmental disasters.

Article (79)

The Ministry, in cooperation with competent agencies shall perform environmental monitoring in order to gather information about the various environmental elements and shall prepare comprehensive reports to be submitted to the authorized agencies.

Article (80)

Upon suggestion from The Minister, the Ministerial Cabinet shall issue the Executive Regulation, which is necessary for the enforcement of the provisions of this law.

Article (81)

Any provision or regulation that contradicts the provisions of this law shall be repealed.

Article (82)

Each competent entity must, in accordance with its responsibility, implement and apply the provisions of this law after thirty days from publication date in the official gazette.

Issued on: 28/ 12/ 1999

Yasser Arafat

Chairman of the PLO Executive Committee

President of the Palestinian National Authority.

Appendix E
Water Law

Water Law

Number (3/2002)

Chairman of the Executive Committee of the Palestine Liberation Organization
Chairman of the Palestinian National Authority

After reviewing the Safeguarding of Public Water Supplies Ordinance No.17/1937 effective in Palestine,
And Water Resources Testing Law No. 2/1938 effective in Palestine,
And Water Control Law No. 31/1953 effective in West Bank Governorates,
And Law No. 2/1996 regarding the establishment of the Palestinian Water Authority,
And Law No. 1/1997 regarding the Palestinian Local Authorities,
And Resolution No. 66/1997 regarding the Internal Regulations of the Palestinian Water Authority,
And on the proposed law submitted by the Cabinet of Ministers,
And after the approval of the Legislative Council in its session held on 18/2/2002
We issued the following law:

Chapter One
Definitions and General Provisions

Article (1)

The following words and expressions shall have the stated meaning unless the context indicates otherwise:

The Authority: The Water Authority

The Council: The National Water Council

The Head: The Head of the Palestinian Water Authority

Water Supply: The supply of water from all available resources.

Water Resources: All water resources which lie within the territorial land or sea of Palestine, whether conventional (surface or ground waters) such as the waters of springs, including hot springs, wells, ravines, rivers, lakes, seas, and water collection areas, or unconventional such as wastewater, desalinated water, and brackish water.

Water Resources Management: Development, improvement, and protection of water resources, and planning for its use.

Water Policy: The policy set by the Council for the preservation of natural and political rights on the water resources, its uses, and its projects in Palestine.

Facility: Any facilities or constructions intended for Water utilization, whether by extraction, or collection, or storage.

Water Recharge: Directing waters to the lower layers (ground) from any water resource including floods water, or treated wastewater, whether this is done directly by recharging the wells or reservoirs or by drilling or by permitting water to infiltrate from the surface to the subterranean soil.

Sanitary Sewage: A system for collecting, disposing of and treating Wastewater.

Well: Any facility intended for to extract ground waters to the surface.

Spring: Place for the exit of ground waters from inside the earth in a natural fashion.

Ground Waters: Waters available in the groundwater reservoir.

Surface Waters: Any moving or still waters above the ground surface including ravines, rivers, wadis, water springs, or any fountains, collection of sewage water, lakes, and seas.

Groundwater Reservoir: Formation or geological layers of materials which permit the infiltration of water to its inside, and its storage under the surface of the ground, and which are exploitable.

Right of Possession: Is the right to manage, supervise, plan, and regulate all water resources without derogation of the existing rights of usage.

National Water Utility: Is the party responsible for providing water in bulk, at the national level.

Regional Water Utilities: Institutions and interests that provide services of water and wastewater.

Pollution: Any change that occurs to the quality and constituents of water which leads to harm to the health of humans and to the environment.

Pollutant: Any material that could lead to a change in the qualities and constituents of water which may lead to harm to humans and to the environment.

Water Quality Standards: Standards which the Authority shall participate in setting in co-operation with the relevant official bodies, to preserve the ideal standards for water quality.

Water Meter: An approved instrument for measuring the quantity of water that flows past a specific point.

Water Tariff System: System that is based on studied standards in order to set a water tariff.

Network: The set of pipes deriving from the main water Pipe line to the end user.

Environment: The surroundings, which include living creatures together with the air, water, soil, and structures built upon it, and the interaction between them.

The Water Environs: A specified area surrounding a water resource and a water facility.

Exploration: All operations relating to search for, and investigating water resources and it includes drilling, analysis, and other detailed studies.

Article (2)

This law aims to develop and manage the water resources, increasing their capacity, improving their quality, and preserving and protecting them from pollution and depletion.

Article (3)

1. All water resources available in Palestine are considered public property.

2. The environs of a water resource or a public water facility shall be determined in accordance with objective criteria according to regulations to be issued for this purpose.

3. Every person shall have the right to obtain his needs of water of a suitable quality for his use, and every official or private institution that provides water services must take the necessary steps to insure this right and to make the necessary plans for developing these services.

Article (4)

It is prohibited to drill or explore or extract or collect or desalinate or treat waters for commercial purposes or to set up or operate a facility for water or wastewater without obtaining a license therefore.

Article (5)

1. The use of water shall be made for meeting the following needs:

a. Residential needs.
b. Agriculture and irrigation.
c. Industrial demand.
d. Commercial demand.
e. Tourism demand.
f. Any other public or private uses.

2. An approval and a license are deemed necessary to be obtained before changing the right of usage from one to another.

Chapter Two
The Water Authority

Article (6)

1. A public institution called "the Water Authority" shall be created by virtue of this law, and it shall have a juridical personality, and its budget shall be included within the general budget of the Palestinian National Authority.

2. The Authority shall be subject directly to the Chairman of the Palestinian National Authority.

3. The main headquarter for the Authority shall be Jerusalem, and its temporary headquarter shall be in any other place that is determined by the Authority.

Article (7)

In pursuance of the goals intended by this law, the Authority shall exercise the following tasks and responsibilities:

1. It shall have full responsibility for managing the water resources and wastewater in Palestine.

2. Setting the general water policy and working to implement it in coordination and cooperation with the relevant parties, and presenting periodic reports concerning the water status to the Council.

3. Surveying the different water resources, and suggesting allocations of water and determining the priorities of usage.

4. Creating reservation areas for protection from the danger of pollution, and exercising oversight and supervision over such areas, and approvals for transfer of water between the different geographic areas.

5. Licensing the exploitation of water resources including the construction of public and private wells, regulating them, water exploration, drilling exploratory, testing and production wells, and any other matters or activities relating to water or wastewater, in cooperation and coordination with the relevant parties.

6. Studying water and wastewater projects, and projects that integrate them, and setting design standards, and quality assurance, and technical specifications, and to control its implementation.

7. Rehabilitating and developing water departments for the bulk water supply at the level of the different national governorates, considering them national water utilities, and setting their tasks and responsibilities in accordance with regulations that are issued by the Cabinet of Ministers for this purpose.

8. Coordination and cooperation with the relevant parties to set plans, and programs for regulating the use of water, and preventing wastage, and conserve consumption, and carrying out public awareness campaigns regarding this aspect.

9. Supervising the profession of well drilling and qualifying contractors in the field of constructing water facilities in accordance with procedures that are set by the law.

10. Setting plans and programs for training the technical staff working in the water sector to develop the management of water resources and supervise its implementation and development.

11. Working towards achieving a fair distribution and optimal utilization in order to ensure the sustainability of ground and surface water resources through cooperation and coordination with the relevant parties and finding solutions and suitable alternatives in case of emergencies.

12. Regulating and supervising research and studies relating to water and wastewater, and following up with the concerned and specialized parties.

13. Rehabilitating the centers, for researches, and studies, and training, working in the water sector in accordance to the procedures to be set by the regulations referred to in paragraph 7 supra.

14. Participating in setting approved standards for the water quality for the different usages in cooperation with the relevant parties and insuring promulgation.

15. Working to develop and coordinate programs for international, regional, and bi-lateral technical cooperation in the field of water resources; holding conferences, and seminars, and representing Palestine in regional and international meetings in this field.

16. Preparing draft laws and regulations and issuing directives concerning water resources and executing them, and giving opinions with regard to the technical aspect in all disputes relating to water resources.

17. Any other tasks that are to be assigned by virtue of applicable laws and regulations.

Chapter Three
The National Water Council

Article (8)

First: The National Water Council shall be composed as follows:

The Chairman of the Palestinian Authority	-	Chairman.
2. The Minister of Agriculture	-	Member
3. The Minister of Finance	-	Member
4. The Minister of Health	-	Member
5. The Minister of Local Government	-	Member
6. The Minister of Planning and International Cooperation	-	Member
7. The Head of Environment Authority	-	Member
8. The Head of the Water Authority	-	Member
9. The Lord Mayor of the Capital	-	Member
10. A Representative for Chairman of the Union of Local Authorities.	-	Member.
11. A Representative for the Palestinian Universities	-	Member
12. A Representative for the Water Union and Societies	-	Member
13. A Representative for the Regional Utilities	-	Member

Second: The Council shall select among its members a vice - Chairman.

Third: The Head of the Authority shall be the secretary of the Council.

Fourth:The representatives of the private sector shall be selected on the basis of experience, specialization, and competency in this field, and they shall be appointed by a decision from the Chairman of the Palestinian National Authority.

Fifth: the period of a membership of the representatives of the non-governmental sector shall be two years and this period may be extended once.

Article (9)

The Council shall carry out the following tasks and responsibilities:

1. Sanction the general water policy:

2. Sanction the policy for development and utilization of water resources and the different usage.

3. Sanction plans and programs aimed at organizing the usage of water, the preventing wastage, and directing consumption.

4. Sanction the tariff policy.

5. Approving the allocation of funds for investment in the water sector.

6. Sanction the periodic reports concerning the activities of the Authority and its work.

7. Sanction the Authority's guidelines and confirming the internal regulations that govern its administrations and operations.

8. Confirming the appointment of the board of directors of the regional utilities.

9. Sanction the annual budget of the Authority and presenting it to the Cabinet of Ministers to confirm it.

10. Implementing the financial regulations prevailing in the Palestinian National Authority.

11. Any other tasks which are delegated to it according to the provisions of this law.

Article (10)

1. The Council shall meet at the invitation of its Chairman at least once every six months. An emergency meeting may be held at the request of the Chairman of the Council or four of its members when ever necessary. The meeting shall be chaired by the Chairman or by the Vice- Chairman in his absence.

2. For the validity of the meetings of the council, at least 8 members must be present including the Chairman of the Council or the vice- chairman. The decisions of the Council shall be issued by a majority of the present members and, where the votes are equal the side including the Chairman or the vice- chairman shall have a deciding vote.

3. The Secretary of the Council shall have the task of preparing the agenda for the meetings of the Council, for issuing the written invitations, and for drafting its resolutions and implementing them.

Article (11)

The Council may utilize the services of experienced and specialized experts, and consultants, and technicals.

Article (12)

The Council may form, from among its members, one or more committees, and permanent or temporary, to which it shall delegate some of its tasks or responsibilities, or assign to such committee a specific task and report about it.

Article (13)

1. No member of the Council, nor any employee of the Authority may be a party in any contract, including contracts for purchases of necessities, or bids for carrying out works that the Authority is party to, nor may such a person work in these projects or works or obtain any profit or material benefit from it directly or indirectly, except for the salaries and bonuses that he receives from his employment with the Authority, or for his participating in any of the tasks that are delegated to him according the provisions of the Law and the regulations issued with regard to.

2. If any member of the Council, of any employee of the Authority violates the provisions of subsection (1) of this article, he shall be subject to the legal sanctions and procedures, and will be required to return all the sums that he obtained as a result of this violation, in addition to paying compensation for the losses or damages to the Authority or to any party who has suffered as a result of his violation.

Chapter Four
The Head of the Authority: His Tasks and Responsibilities

Article (14)

1. The Chairman of the National Authority shall appoint, by a presidential decree, based on the recommendation of the National Water Council, a Head for the Authority, and a Deputy-Head, from among those with experience, specialization and competence in the field, and it shall be determined in the decree the employment level for both of them.

2. The Deputy-Head shall carry out the tasks and responsibilities delegated to the Head during his absence or when his position becomes vacant.

Article (15)

First: The Head shall have the following tasks and responsibilities:

1. Organizing and managing the Authority and supervision of all its employees, and its different directorates.

2. Preparing the budget and the financial reports and presenting them to the official bodies to approve, and confirm them in accordance with proper procedures.

3. Implementing the decisions of the Council.

4. Signing water agreements on behalf of the government, in accordance with the provisions of the prevailing laws and regulations.

5. Participating in activities aimed at improving regional and international cooperation in the field of water and wastewater.

6. Preparing periodic reports about the activities of the Authority, and its level of performance, and suggesting solutions to confront the difficulties and obstacles facing the progress of the work.

7. Any tasks assigned to him by the Council or the Cabinet of Ministers.

Second: The Head of the Authority may delegate some of his tasks to his Deputy.

Article (16)

1. The Authority may appoint an advisor, or a group of advisors for carrying out its tasks.

2. The Authority may use advisors or experts representing the different sectors to carry out its tasks whenever it is necessary to do so.

3. It is not permitted for any of the advisors or their relatives to the second degree, to have any interest in any matter that is presented to him for his opinion.

Article (17)

The employees of the Authority, and its advisors, shall bound to the instructions that are issued with respect to maintaining the secrecy of information and the obligation not to publish them, in the field of water, or any other field that is delegated to them.

Chapter Five
Licensing and Tariffs

Article (18)

In accordance with the provisions of this law, licensing fees shall be imposed and the conditions, and period, and procedures, and transferability, and amendments, and renewal, and all matters pertaining thereto, including permits, shall be set pursuant to regulations to be issued for this purpose.

Article (19)

The Authority may amend, suspend, or cancel a license if the licensee fails to initiate the project during the period specified in the license, or if it discovers that incorrect information was given, or if the project is not being implemented in the manner specified in the conditions of the license, or contrary to the provisions of the Law.

Article (20)

Unified tariff system for water shall be set, which may be amended from time to time, with the aim of encouraging the water users to conserve the available water resources and its optimal usage in accordance with the regulations that shall be issued for that purpose.

Chapter Six
Financial Resources

Article (21)

The financial resources of the Authority shall consist of:

1. The amounts allotted for it in the general budget of the Palestinian National Authority.

2. Grants, dons, assistance, loans, and any other resources that are available to the Authority and which the Cabinet of Ministers agrees to accept, shall be placed in a

special account for the Authority and shall be supervised directly by the Ministry of Finance and the Authority.

Article (22)

The monies of the Authority shall be considered public monies and shall be collected in accordance with the Law, in force, for the Collection of Public Monies.

Article (23)

1. All monies collected by the Authority shall be deposited in the general account of the Treasury, which is administered by the Finance Ministry.

2. The accounts of the Authority and its records and all its financial affairs shall be conducted in accordance with the laws of the Palestinian National Authority and in accordance with the accounting procedures adopted by the Palestinian National Authority.

3. The accounts of the Authority shall be audited by the Finance Ministry and the General Control Institution.

4. The Authority shall enjoy the exemptions and facilities available to the government and the ministries and governmental departments.

Article (24)

Despite the provisions of any other law, no governmental department, or official institution, or private institution or any person real or juridical, shall be exempted from the fees and costs, levies, or usage fees which are realized or imposed for services given by the Authority in accordance with the provisions of this Law.

Chapter Seven
Regional Water Utilities

Article (25)

By virtue of this law, National Water Utilities will be established based on the desire of local committees and water users associations, to provide water and wastewater services and it will set the tasks and responsibilities and their composition, and management, and financial resources, and dismantling, and all matters pertaining to their work in accordance with regulations that will be issued for this purpose.

Article (26)

Regional utilities and water users associations shall set the prices of water for different usage, in accordance with the approved tariff system.

Article (27)

The Authority may contract with regional utilities to operate alternative water systems.

Article (28)

1. The Authority shall have the right to supervise an control regional utilities and water users associations, in cooperation and coordination with the relevant parties, and to take all the procedures necessary regarding them for violating the provisions of this Law or the regulations or directives issued thereunder.

2. The Council, based on the recommendation of the relevant parties, to decide by means of a reasoned decision to suspend or dismantle the services board of directors for of any regional utilities or water user associations and this decision shall be subject to appeal before the relevant court.

Chapter Eight
Protection of the Environment

Article (29)

Without contravention of the provisions of the Environmental Law and the regulations and directives issued under it, and in cooperation and coordination with the relevant authorities for the protection of water resources and the prevention of its pollution, the Authority shall carry out the following actions:

1. Participate in regulating the use of agricultural and industrial materials, which may cause pollution to the water resources or its supply systems.

2. Participate in preparing special guidelines for the environmental impact assessment for any activity relating to water resources or their supply systems.

3. Participate in preparing special mechanisms for crisis management when there is a draught or flooding or a plague that is spread through water, or general pollution.

4. Participate in preparing a list of the names of pollutants, which require licensing, *and compensation for damages resulting therefrom.*

Article (30)

The Authority may issue a decree to halt the production or supply of water if it appears that its source or supply system is polluted, and it may close the source or system if pollution continues, and it must notify the relevant Authority of this and to eliminate the pollutants in an expeditious fashion.

Article (31)

1. The Authority, in coordination with the other relevant parties, may consider any area that contains ground waters a protected area, if the quality or quantity of water is in danger of pollution, or if carrying out the water policy requires such action, on condition that it provides alternate water resources.

2. A notice shall be advertised in the local news papers thirty days prior declaring an area to be a protected area, including restrictions on use of water, and it may also by a subsequent notice cancel or amend the original notice whenever such action is necessary.

Article (32)

Anyone who causes pollution in any water resource or its supply system must remove the pollution to that source or system at his own expense, and in case he refuses or fails to do so, the Authority must remove the pollution and carry out the cleaning operations on the expense of party causing the pollution after notifying him of this regardless of the costs, which shall be levied form him in accordance with the Law for Collecting Public Monies.

Chapter Nine
Control and Inspection

Article (33)

The Authority shall carry out the tasks of control over the water resources including:

1. Keeping records that contain detailed information about water usage and licenses.

2. Licensed Operators of water or wastewater facilities must give periodic reports concerning the production, distribution, or use of water at the times set by the Authority.

3. The Authority shall have the right to set the necessary rules and standard for inspecting, calibrating and repairing damaged meters and to control the leak of water.

Article (34)

1. Without contradiction from the provisions of this Law, the Authority may ask for requisite of land and property or enter the property of others in order to carry out its activities.

2. The Authority shall have the right to inspect water resources and systems of supply, and any place where pollution is suspected and to enter any private or public property or building to accomplish this purpose in accordance with proper procedures.

3. The Head of the Authority will assign by a decree, the employees, whom will be given the status of Law Officers, to apprehend crimes and violations which have been prohibited by the Law.

Chapter Ten
Violations and Sanctions

Article (35)

Without derogation from any more onerous punishments provided for in other laws,

a) A prison sentence of not less than six months' nor more than one year or a fine of not less than one thousand dinars and not more than five thousand dinars or its equivalent in local currency, shall be imposed on any one who commits any of the following actions:

1. Polluting any water resource or supply system, or causing such action and failing to redress it within the period set for him by the Authority.

2. Drilling ground water wells without license or contradicting the terms of the license issued to him.

3. Violating on any water resource or sewage system, causing its damage or leading to the break out of one of them.

4. Supplying water to or permitting the supply of water to him or to others without a license to do so.

b) A prison sentence of not less than one month and not more than six months or a fine of not less than one hundred dinars and not more than one thousand dinars or its equivalent in local currency shall be imposed on any one whom:

1. *Carries out any activity or tasks, which is not permitted for any one other than the* Authority by virtue of this Law without the prior written permission of the Authority.

2. Acts with respect to water resources, waters, or related projects or public sewage in a manner that contradicts the provisions of this Law.

Chapter Eleven
Final Provision

Article (36)

Anyone who is convicted of carrying out any of the actions specified in Article (35), the court may sentence him, to pay the cost of the damages that have resulted from his violation and to be obliged to remove its causes and consequences and return the status to what it was before he committed the violation, all that to be done within the period that is specified for him by the court, and if he fails to do so, the relevant authorities shall order the implementation of these activities and shall charge all the costs to the defendant.

Article (37)

In case of repetition of the crimes listed in Article (35), the punishment stated in that *article shall be doubled.*

Article (38)

Licenses issued by virtue of the prevailing Laws and regulations, before endorsing this law, shall continue to be valid until its period is finished, and it is brought into compliance with the provisions of this Law.

Article (39)

The owner of land or real estates which is being damaged as a result of the entry of *the employees of the Authority shall have the right to reasonable compensation* either for the denial of his ability to use the land, or any damage occurring to water or crops or the deprivation of the water resource.

Article (40)

By virtue of the provisions of this Law, all rights to supervise, regulate and plan for the water resources shall be transferred to the Authority upon the coming into force of this law.

Article (41)

Without contradicting any of the provisions of this Law, the relevant governmental authorities, or private or official institutions, or municipalities shall continue to exercise the authorities and responsibilities granted to it under the laws and regulations that are in operations till the regional utilities referred to in the provisions of this Law are brought into existence.

Article (42)

The Cabinet of Ministers, based upon the recommendation of the Council, may issue any regulations that it finds suitable, to implement the provisions of this Law.

Article (43)

The Law of the Water Authority. Number 2 for the year 1996 and any other legislation that contradicts the provisions of this Law are hereby revealed.

Article (44)

All parties, each within is jurisdiction, shall implement the provisions of this Law which shall come into force 30 days after it is published in the official gazette.

Issued in Ramallah on 17 / 7 / 2002 AD
8 / Jamadi Awwal/ 1423 A.H.

Yaser 'Arafat
Chairman of the Executive Committee
of the Palestine Liberation Organization

Chairman of the Palestinian National Authority

Appendix F

Sludge Reuse Experience in Egypt, Jordan and Tunisia

Institutional Aspects - Egypt

Under the current framework, water quality management responsibilities are shared by a wide array of government institutions at the national, regional and local levels of the GOE. In addition, a number of supporting institutions, such as Scientific Institutes, Universities, and NGOs, play a role in policy formulation and implementation. A brief description of these institutions and their role are as follows:

Ministry of Water Resources and Irrigation (MOWRI): The central institution in water quality management is MOWRI. This ministry was given the responsibility to review applications for discharge licenses from municipal and industrial facilities, inspect facilities to ensure that adequate treatment facilities are in place, and issue licenses to discharge if all appropriate conditions are met. If the Ministry of Health reports violations of the license, MOWRI issues a violation notice that requires the facility to improve its discharge quality. After three months, if subsequent sampling by the Ministry of Health indicates no improvements, MOWRI fines the facility for failure to comply with Law 48.

Ministry of Health and Population (MHP): The MHP has been given a central role in water quality management, especially in setting standards for the quality of the following:

- Potable water sources (River Nile and canals)
- Drain waters that can be mixed with other waters for drinking water.
- Industrial and sewage treatment plant discharges.
- Wastes discharged from river vessels.

Besides developing standards, the ministry must sample and analyze all industrial and municipal effluents and all drinking water treatment plant influents and effluents as well, which is considered a significant load of work.

Ministry of Housing , Reconstruction and New Communities (MHRNC): The General Organization for Sanitary Drainage in Cairo (GOSD), The Alexandria General Organisation for Sanitary Drainage (AGOSD) and the National Organisation for Potable Water and Sanitary Drainage (NOPWASD) are major organisations within the MHUNC that have the responsibility for planning, design, and construction of collection systems and municipal wastewater treatment plants.

Ministry of Industry and Mineral Wealth (MIMW): The General Organization for Industrialization (GOFI) supervises pollution control, safety and health issues in industry through its General Department for Environmental Protection. It also ensures that new plants include industrial waste treatment units. MIMW decree No. 380 of 1982 requires compliance with all applicable environmental laws, regulations, and standards as a condition for granting industrial licenses. A clause to this effect is written into all industrial licenses granted by the MIMW, committing the industry to taking the necessary preventive measures, such as installing necessary control equipment, to prevent pollution to the environment. However, GOFI does not perform any inspections at industries and, therefore, does not monitor whether industries are actually in compliance with these license requirements

Ministry of the Interior (MOI): The MOI, Egypt's national police force, has for some time maintained the Inland Water Police, a special police force for enforcement of

Law 48/1982 and protection of the environment in general. The Inland Water Police provide guidance to citizens and take enforcement actions for violations of the environmental laws. Law 4/1994 provides additional authority for this environmental police force, specifying that the MOI shall form a police force specialized in environmental protection within the ministry and in its Security Departments in the governorates (Article 65 of the Executive Regulations).

Scientific Institutions and Universities: In terms of supporting institutions, Egypt benefits from having a number of scientific institutes (e.g. the Academy for Scientific Research and Technology, the National Research Center, the National Water Research center, the National Institute for Oceanorgraphy and Fisheries Research) with research capabilities and universities (e.g., Ain Shams University, the University of Cairo, the American University in Cairo, the University of Alexandria) with good environmental science and engineering programs at both the undergraduate and graduate levels. These institutions carry out basic and applied research on water quality management issues.

Sewage Sludge Reuse – Jordan

Current Practice: The main practice for sewage sludge produced from wastewater treatment plants in Jordan is the disposal to solid waste landfills. However, for uses of sludge in agriculture the Jordanian Standard JS 1145/1996 is adopted.

Sludge Disposal/Reuse Guidelines: According to the Jordanian Standard JS 1145/1996 sludge is the wet or dry solid material, resulting from treating wastewater in wastewater treatment plants. Untreated sludge is not allowed for agricultural purposes.

The definition of treated sludge involves the distinction between first and second level of treatment. First level treated sludge is the sludge that has been treated according to the following methods:

- Aerobic digestion of sludge for a minimum of 40 days at 20°C to achieve a minimum of 38% volatile solids reduction.
- Air drying on beds for at least 3 months.
- Anaerobic digestion for at least 15 days at 35°C or 60 days at 20 °C to achieve a minimum of 38% volatile solids reduction.
- Composting for a minimum of 5 days at 40°C. During composting sludge temperature should exceed 55°C for at least 4 hours.
- Lime stabilization by addition of sufficient lime to maintain a pH of 12 for at least 2 hrs
- Any method that can achieve pathogen, vector and VS reduction equivalent to the ones obtained by any of the above methods.

Second level of treated sludge is the sludge that has been treated according to the following methods:

- Composting at a temperature of 55°C for at least 3 to 15 days, depending on the method employed (closed vessel, aerated pile, windrow composting method)

- Heat drying in direct or direct dryers to achieve a minimum 90% solids content.

First level treated sludge can be used to improve the desert soil. It can also be used in the lands ready to be forestry. The application period is between April and end of June.

Second level treated sludge is appropriate for the uses described for the first level treated sludge while additionally the sludge can be used when preparing the soil for planting trees, seeds and field crops upon condition that it should be cut or eaten by animals after at least three months of fertilizing. Furthermore, it is not allowed to use sludge in vegetables fertilizing, turf lawn, gardens, protected agriculture and in the urban lands.

The contamination of water basins, should be taken into consideration during the land application of sludge. Also the fertilized lands should be far from dams, valleys surface water and water harvesting projects. The sludge for agricultural purposes should be added after the official approval.

When sludge is used for agricultural purposes chemical limits as well as pathogenic parameters must be followed. With respect to chemical pollutants the limits are shown in Table 1. The pathogenic criteria for sludge used in for agricultural purposes are illustrated in Table 2.

Table 1: Maximum Level for Chemical Elements Concentrations in Treated Sludge

Element	Elements Concentration in Sludge (mg/kg DS)	Average Addition to Elements level (kg/ha/year)	Maximum Accumulative Elements in Soil (kg/ha)
Arsenic As	75	2	41
Cadmium Cd	85	1.9	39
Chromium Cr	3000	150	3000
Copper Cu	4300	75	1500
Lead Pb	840	15	300
Mercury Hg	57	0.85	17
Molybdenium Mo	75	0.9	18
Nickel Ni	420	21	420
Selenium Se	100	5	100
Zinc Zn	7500	140	2800
Cobalt Co	150	1.8	36

Ha = 10000 m^2

Table 2: Pathogenic Pollutants Limits of Sludge Used for Agricultural Purposes

Pathogenic Pollutants	Pollutants Limits in Treated Sludge to the first level	Pollutants limits in Treated Sludge to the Second Level
Escheria Colli (MPN)	$2x10^6$ MPN/gm	10^3 MPN/gm
Salmonella	Not limited	<3 MPN./4gm DS*
Nematode Eggs	Not limited	<1 egg/4gm DS*
Intestinal viruses	Not limited	<1 (unit)/4gm DS*

*: Dry Solids

Institutional and Financial Aspects – Tunisia

In Tunisia responsibility of wastewater reuse in agriculture is shared among various Ministries: the Ministry of Environmental and Land Management, the Ministry of Agriculture, the Ministry of Public Health and the Ministry of Tourism.

In large cities, the National Sewerage and Sanitation Office (ONAS), a subsidiary agency of the Ministry of Environment and Land Management, is responsible for wastewater collection, treatment and disposal. This includes construction, operation, and maintenance of the entire sanitation infrastructure.

The Ministry of Agriculture is responsible for the implementation of wastewater reuse projects, i.e., supply and development of irrigation schemes (pumping stations, reservoirs, pipes, etc). This work is carried out by different Departments and includes collecting charges, monitoring the application of the legislation related to wastewater reuse, conducting research on wastewater reuse in agriculture and formulate wastewater reuse standards.

The Ministry of Public Health is responsible for the regulation of the hygienic quality of reclaimed water and of irrigated crops, for pollution monitoring and pollution control enforcement.

The Ministry of Tourism participates in financing wastewater reuse projects for irrigation of green areas (gold courses and hotel gardens). A better coordination among institutions in charge of wastewater reclamation and reuse is required to prevent responsibilities overlapping.