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Physio-Chemical Behavior of the Leachate Due to Landfilling of Municipal Solid Waste and Secondary Wastewater on Groundwater Quality: A Review

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Abstract

Groundwater is a major source of water in many parts of the world for different purposes viz. agronomical, domestic, industrial etc. However rapid development of living standards, high population growth and massive urban migration, have resulted in the demand of water dramatically. This leads to diminution of groundwater both qualitatively and quantitatively due to anthropogenic activities. With respect to groundwater degradation from human activities, we then have two significant aspects 1) Contamination based on non-engineered municipal solid waste (MSW) dumping and 2) Partially treated or secondary wastewater (SWW) application on land. In the recent years, increase in the quantity of SWW originating from wastewater treatment processes has resulted in significant disposal problems. Recharge of SWW is favoured as a viable management practice because it provides further filtering and biological treatment of the partially treated wastewater through the soils for recharging local water resources. When the capacity of soil to retain these materials declines due to continuous loading of SWW, the soil properties may change and in turn soil may release these materials into the groundwater. Consequently groundwater contamination has become a long-term problem where contamination persists in aquifers for decades without treatment because groundwater travel times are relatively slow. Since the contaminants persist for a long time in the groundwater which adversely affects the groundwater quality, it has become an imminent study area for social causes. The review paper gives a broader outline on MSW and SWW about their generation, composition, disposal, treatment, usage etc. But the study was focused on groundwater contamination due to MSW and SWW leachates. Most of the studies showed that the contamination was taking place separately at different locations, whereas in Puducherry, India a unique situation prevails where the co-disposal of MSW and SWW takes place concurrently at the same location. So a field investigation is underway to study the pollution aspects of these two factors and based on the investigation suitable remedial measures will be thought of.

Keywords

Solid Waste, Secondary Wastewater, Leachate, Groundwater Contamination

1. Introduction

Groundwater constitutes about 95 percent of freshwater making it fundamental to life and economic development. The contribution from groundwater is vital, perhaps as many as two billion people depend directly on groundwater and major portion of world's food is produced by irrigated agriculture that relies largely on groundwater. Aquifers are able to offer natural protection from contamination and thus much of groundwater is of good quality because of natural purification processes and with little treatment it can be made potable economically. The aim is to provide adequate good quality water which should be maintained, managed and stored, while preserving the hydrological, biological and chemical functioning of ecosystems.

One of the objectives of this paper is to give an overall picture on two factors viz., 1) Municipal Solid Waste (MSW) and 2) Secondary Wastewater (SWW), which are responsible for groundwater contamination. In this paper a general outline on the MSW generation, composition and disposal methods are discussed on a Global, Regional (Asia) and

Country (India) levels. Similarly, a general picture on wastewater generation, treatment and usage has also been given. But, the main objectives of this paper are 1) to review and analyse the groundwater contamination due to non-engineered, indiscriminate solid waste disposal with a view to control groundwater contamination to the maximum possible extent and 2) to evaluate and quantify the short-term effect, long-term effect and leaching behavioural impact of treated/partially treated SWW application on soil and groundwater spatially and temporally. It is perceived that generally the contamination due to these two factors are happening separately in different locations. But, a unique situation is prevailing at Puducherry in India, where the contamination due to these two factors takes place simultaneously within the same campus. So a field investigation is underway to study the combined effect of these two polluting factors on groundwater quality. Based on the study suitable remedial measures will be proposed, suiting local conditions. This review may motivate researchers and engineers to apply and develop new techniques, methodologies and policies enabling better understanding of solid waste management and groundwater contamination attenuation for a better and pollution-free world.

2. Groundwater Contamination

Eventhough groundwater contamination is geogenic in nature, generally it is the result of human activity. Where the land use pattern is intensive, groundwater is especially vulnerable, depending on soil properties. A contaminant that has been released into the environment may move in the same way as the groundwater moves. Soils that are porous and permeable tend to transmit water and contaminants with relative ease to an aquifer below. Generally the contaminants and groundwater move slowly. Consequent to this slow movement, contaminants tend to remain concentrated in the form of a plumethat flows along the same path as the groundwater.

The biggest challenge to groundwater quality is not from high-profile contaminants like arsenic or toxic industrial chemicals but local anthropogenic activities like municipal solid waste dumping, secondary wastewater land application, etc.Groundwater contamination is said to occur when the chemical constituent is altered as a result of man's activities, either directly or indirectly, as is the case of indiscriminate solid waste dumping and partially treated or SWW.

The sources of groundwater contamination are many, varied, and can be broadly classified as (1) point sources, and (2) non-point sources. Point sources which arise from waste treatment facilities are concentrated and areally bounded. Various types of point sources which have the potential to contaminate the groundwater are (1) sanitary landfills for solid non-hazardous municipal waste, (2) chemical landfills for hazardous liquid waste, (3) sewage lagoons, infiltration ponds and recharge ponds for liquid municipal waste and (4) surface buried tanks for liquid industrial waste. In all cases, waste fluids or leachates can infiltrate across the unsaturated zone and contaminate the water table. Non-point sources are due to application of herbicides, pesticides and fertilizers in agricultural areas.

3. Municipal Solid Waste (MSW)

3.1. Significance of Municipal Solid Waste Management (MSWM)

The quantum of waste produced is largely determined by two factors (1) population, and (2) consumption patterns – which are controlled by the Gross Domestic Product per Capita (GDP). In 2025, world solid waste production will have doubled in relation to 2005. By 2050 the world's production will be twice as that of 2025. According to the UN, in 2025, the world population will increase by 20% attain 8 billion inhabitants (from 6.5 today). Moreover, in 2050, the total population will be around 9.6 billions [40]. It is important to note that 97% of this growth will happen in Asia and Africa. This growth also will push urbanization which will be around 65% of the total after 2040. Besides overpopulation, a remarkable increase in GDP especially in developing countries is on its way. The global average GDP during 2025 will be 4.7% which is more or less one and a half times the current one (2.9%).

Waste quantities are inseparably linked to economic activity and resource consumption. Asia is witnessing a rapid increase in urban population with about 35 percent of its total population living in urban areas with an annual growth rate of nearly 4 percent. In China urbanization intends to increase urban population from 30 to 50 percent. It is anticipated that by 2025, about 52 percent of the Asians will be living in expanded urban boundaries. In fact, rural-to-urban migration is expected to be 40 to 60 percent of annual urban population growth in the developing world. This puts more pressure on the partially existing Municipal Solid Waste Management (MSWM) infrastructure.

Based on the population estimates of the United Nations, predicted by the World Bank, it is likely that total solid waste generation will be increased to 27 billion tons in 2050. In 2009, the annual total solid waste generation was approximately 17 billion tons. The current annual MSW generation is estimated to be 19 billion tonnes with almost the 30% remain uncollected, and 70% is taken to landfills and dump sites of which 19% is recycled or recovered, and 11% is used for energy recovery. The number of people that lacks access to MSWM services is estimated to be at least 3.5 billion. If this situation prevails 5.6 billion of the estimated population that will have no access to MSWM services in 2050 [41].

The waste generated in the developing countries is similar in composition,while regional variations are governed by topographical, climatic, cultural, industrial, infrastructural and legal factors. China has an annual economic growth of 7.4%, India 7.4%, Sri Lanka 6.3% and Thailand 2.9%. All the four countries undergo a rapid economic growth and urbanization. This rapid economic growth has improved the standards of living of the urban inhabitants. This has been creating a higher per capita waste generation thereby putting the MSWM system on the risk of massive failure. Quantification and characterization of MSW is one of the vital formulations in its executive strategy. In the developed economies, credible MSW generation and management data are updated and available. On the other hand, in developing countries the data on MSW generation is insufficient. However, anthology of MSW study throughout the world is scant.

Table 1. *Income-Wise Waste Generation Projections(2025).*

Region	Total Urban Population (millions) (2005)	Urban Waste Generation		Projected Population		Projected Urban Waste	
		Per Capita (kg/capita/day) (2005)	Total (tons/day) (2005)	Total Population (millions) (2025)	Urban Population (millions) (2025)	Per Capita (kg/capita/day) (2025)	Total (tons/day) (2025)
Lower Income	343	0.6	2,04,802	1,637	676	0.86	5,84,272
Lower Middle Income	1,293	0.78	10,12,321	4,010	2,080	1.3	26,18,804
Upper Middle Income	572	1.16	6,65,586	888	619	1.6	9,87,039
High Income	774	2.13	16,49,547	1,112	912	2.1	18,79,590
Total	2,982	1.19	35,32,256	7,647	4,287	1.47	60,69,705

Source:World Bank: What a Waste: A Global Review

3.2. Solid Waste Generation and Waste Trends

Solid waste generation is based on the economic development, degree of industrialization, civic habits, local climate, density of population, size of the urban habitation and consumption rate of commercial goods. In general, the economic development and rate of urbanization are directly proportional to the amount of solid waste produced. Income level and urbanization are highly correlated. The standards of living, consumption of goods and services have got a direct bearing on the amount of waste generated. In general urban inhabitants produce about twice as much waste as their rural counterparts [41].

3.2.1. Waste Generation by Region

Waste generation is a function of affluence, food habits, climatic conditions, economy, education etc. However, regional, country variations and generation rates are all significant. Waste generation in Sub-Saharan Africa is approximately 62 million tonnes annually [41]. Per capita waste generation extends from 0.09 to 3.0 kg per person per day, with an average of 0.65 kg/capita/day. In Eastern and Central Asia, the waste generated per year is at least 93 million tonnes [41]. The per capita waste generation ranges from 0.29 to 2.1 kg per person per day, with an average of 1.1 kg/capita/day. In Latin America and the Caribbean, the total amount of waste generated per year is 160 million tonnes, with per capita ranges from 0.1 to 14 kg, and an average of 1.1 kg/capita/day [41]. In the Middle East and North Africa, municipal solid waste generation is 63 million tonnes per year [41]. Per capita waste generation is 0.16 to 5.7 kg per person per day with an average of 1.1 kg/capita/day. The OECD countries generate 572 million tonnes of solid waste per year [41]. The per capita ranges from 1.1 to 3.7 kg with an average of 2.2 kg/capita/day.

3.2.2. Waste Generation by Regional Income Level

The low-income countries produce the least waste per capita, while high income countries produce the maximum solid waste per capita. Thetotal waste generation for upper middle income countries is lower than that of lower middle income countries. Table 1 shows projected waste generation for the year 2025 according to trends in population growth as determined by country income level [41].

3.2.3. MSW in Asia

The urban population in Asia is over 38 percent and the waste generation has been escalating over the years. The urban population of India is over 30%. The larger level of waste generation in Sri Lanka is due to increased consumption patterns as well as the movement of the people from the rural areas to urban centres. In Thailand over 25% of the population is urban and the economic growth is mainly responsible for higher waste generation. Generally, the greater the economic prosperity and the urban population, the greater the quantum of garbage produced.

As China, India, and Mongolia become more flourishing they drift away from coal as the traditional fuel, the ash composition will greatly decrease and the percentage of compostable organic matter will raise. Card board, packaging wastes, paper, glass and plastic, will become more significant in waste management as the population becomes more urbanized. On the contrary the middle income countries should expect a per capita increase of about 0.3 kg per day as their economies are expected to grow at the highest rates and will experience significant population growth in the urban sector.

As a whole, urban population from low and middle income countries will triple their current MSW generation rate in next 25 years. Nepal, Bangladesh, Myanmar, Vietnam, Lao PDR, and India will produce about four to six times the current amount. By 2025, the low income countries will produce more than twice as much municipal waste than all of the middle and high income countries combined i.e. approximately 480 million tons of waste per year [42]. Such a dramatic increase will place enormous strain on MSWM system financially. The per capita municipal solid waste generation will probably remain stable in high income countries.

Low and middle income countries have a larger proportion of organic matter and ash residues in their waste streams which weigh more, but do not take up as much space, as discarded packaging materials and household goods. In 2025, the high income countries are expected to generate about the same quantity of wastes, in terms of both mass and volume. Low income countries will be the largest producer of solid waste, and will also surpass the total volume of waste produced by the high income countries. The increasing percentage of paper and plastic will contribute to the growing waste volume. In the next 25 years, both low and middle income countries will experience about a three-fold increase in their overall waste quantities and volumes, while South Korea, Hong Kong, Singapore, and Japan will stay relatively constant [42].

3.2.4. MSW - An Indian Scenario

Over the past decades, there has been a migration of people from rural and semi-urban areas to towns and cities. The urban population has increased from 10.8% in 1901 to 27.8% in 2001. Now more than 30% of the Indian population lives in the urban areas. In India, there are 498 Class-I cities, having a population of more than 1 lakhs and 410 Class-II towns having a population between 50,000 and 1,00,000 [37]. The uncontrolled growth in urban areas has left many Indian cities deficient in infrastructural services like municipal solid waste management. Due to lack of serious efforts by town/city authorities, garbage and its management has become a tenacious problem. Nearly, half of solid waste generated remains unattended. No segregation system is available for organic, inorganic and recyclable wastes at household level. Door to door collection is not practiced in most of the cities. It is estimated that 300 million people living in urban India produced about 38 million tonnes per year. MSWM is one of the pressing issues of urban India the recent past. Generally the collection efficiency ranges between 70 and 90% in major metro cities whereas in several smaller cities the collection efficiency is below 50%. Landfill sites have not yet been identified by many corporations and in several states the landfill sites have been exhausted.

3.2.5. Solid Waste Management and Generation in India

In India solid waste management is a neglected sector and it is suggested that the following measures are to be taken up seriously in a time bound manner.

- To reduce the quantity of solid waste disposed of on land by segregation and energy recovery.
- To understand that municipal solid waste management is part of a broader urbanization problem.
- To create awareness for competent management of municipal solid waste in urban areas.
- To understand various systems available for collection, transportation, resource recovery through sorting, recycling, separation and disposal.
- To achieve resource recovery through waste processing i.e. recovery of materials (such as compost) or recovery of energy through biological, thermal or other processes.
- To prepare comprehensive, long-term municipal solid waste management programs in view of the potential problems and issues.
- To monitor waste transformation (without recovery of resources) and make it suitable for final disposal.
- To streamline disposal on land which should be environmentally safe and sustainable.
- To provide operational guidelines for MSWM.

It was estimated that about 1,00,000 MT of MSW had been generated daily during the year 2000 in India [43]. Per capita waste generation in major cities/towns ranges from 0.20 Kg to 0.6 Kg. The quantity of solid waste in Indian urban centres based on population and per capita generation are shown in Table 2 [34]. In India MSW rules have been framed during the year 2000. The Central Pollution Control Board (CPCB) shall co-ordinate with the State Boards, to implement and review the standards and guidelines. But the responsibility lies on the respective State Governments in implementing the policies regarding collection and disposal.

Table 2. *Quantity of Municipal Solid Waste and per Capita Generation in Indian Urban Centres.*

Population Range (in million)	Number of Urban Centres (sampled)	Total population (in million)	Average per capita value (kg/capita/day)	Quantity (tonnes/day)
< 0.1	328	68.3	0.21	14343
0.1 – 0.5	255	56.914	0.21	11952
0.5 – 1.0	31	21.729	0.25	5432
1.0 – 2.0	14	17.184	0.27	4640
2.0 – 5.0	6	20.597	0.35	7209
> 5.0	3	26.306	0.5	13153

Source: CPHEEO, Manual on Municipal Solid Waste

3.3. Waste Characterization and Composition

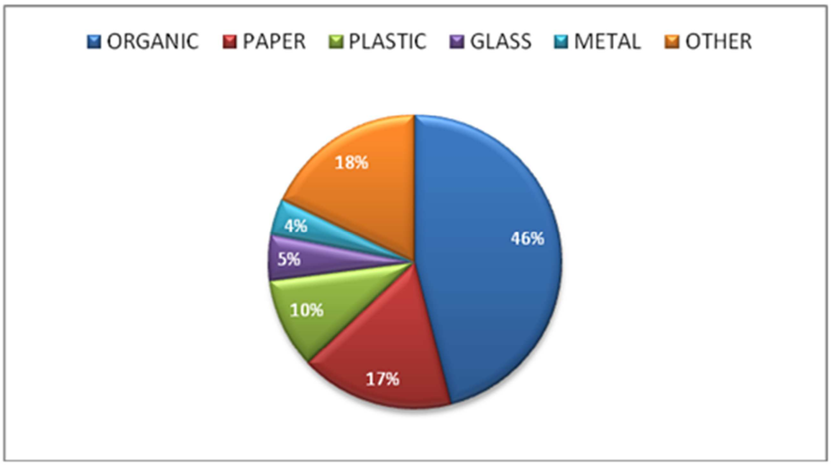
Solid waste streams can be characterized by their sources or by the types of wastes produced, as well as by generation rates and composition. The major classifications are domestic, commercial, industrial, municipal, agronomical, institutional, construction and demolition. Often only residential waste is referred to as MSW. Waste composition is largely governed by topography, location, standard of living, energy source, weather, etc. The inter-related factors contribute to different patterns of waste composition.

3.3.1. Waste Composition by Region

In the municipal solid waste stream, waste is chemically classified into organic and inorganic. Figure. 1 shows the general organic and inorganic waste composition globally [41]. MSW composition by region illustrates that the major portion comprises of organic waste, then comes paper followed by metal, plastic, glassand other wastes. Organic waste plays a significant role in East Asia and Pacific Regions (62%) compared to OECD countries, which have the least (27%) [41]. The proportion of paper, glass, and metals are the highest in OECD countries (32%, 7%, and 6%, respectively) and lowest in the South Asia Region (4% for paper and 1% for both glass and metals) [41].

3.3.2. Waste Composition by Regional Income Level

The organic fraction tends to be lowest in high-income countries and highest in low-income countries. Total of organic waste tends to increase steadily as affluence increases. High-income countries have an organic fraction of 28% compared to 62% in low-income countries. Table 3 represents the types of income-wise waste composition for the projected period (2025) [41].



Source: World Bank: What a Waste: A Global Review

Fig. 1. *Global Solid Waste Composition.*

3.3.3. Waste Composition in Asia

In Asian countries the biodegradable portion constitutes the bulk of MSW and it is mainly due to food and yard waste in developing countries whereas paper and card board play a crucial role in developed countries. Generally, all low and middle income countries have a high percentage of compostable organic matter in the urban waste stream ranging from 40 to 85 percent of the total. In high income countries the compostable fraction ranges between 25 and 45 percent. China and India drift from this trend because they traditionally use coal for domestic purposes.

Ash makes up 45 and 54 percent of India and China's waste composition. China has higher ash percentage because of temperate latitudes and common use of raw coal. The percentage of packaging wastes escalate as people's wealth and urbanisation increases relatively. The presence of plastic, glass, paper and metal becomes more dominant in the waste stream of middle and high income countries. The waste composition from India indicates a comparable lower organic but higher inorganic (ash and dust) content. The lower values for paper, glass and plastic are because of diligent garbage collection and scavenging by informal waste collectors. On the other hand paper and plastic show an increasing swing in Thailand - an impact of the progressing industrialization and urbanization with a growing GDP. The general composition of MSW in Asian countries based on income for the year 2025 is depicted in Table 4 [42].

3.3.4. Waste Composition and Characterization in India

The composition and characteristics of municipal solid wastes vary throughout India. Even in the same country it changes from state to state as it depends on number of factors such as social customs, topography, living and climatic conditions. MSW is heterogeneous in nature and consists of various materials as a result of different activities. Even then it is worthwhile to make some general observations to obtain some useful conclusions as follows:-

- The major components are decaying organic matter and paper.
- Metal, plastics, glass, textiles, dirt, ceramics and wood are mostly present although not always so, the relative proportions based on local conditions.
- The constituents reaching a disposal site(s) for a particular urban area change in long term although there may be significant seasonal variations within a year.

In a country like India with fast economic growth, migration to urban areas as a result of planned economic growth and industrialization, problems are becoming acute day by day and immediate and concentrated action is imminent and absolutely necessary. The proper disposal of urban waste should be mandatory for the preservation and improvement of health. Also groundwater contamination, aquifer recharge, resource recovery, etc. should be given a serious thought. Else India will lose the race with other developing countries especially in the infrastructural development sector. The physical and chemical characteristics of MSW in Indian cities based on population range [34] are given in Tables 5 and 6 respectively.

Table 3. *Waste Composition by Income Level (2025).*

Income Level	Organic (%)	Paper (%)	Plastic (%)	Glass (%)	Metal (%)	Other (%)
Low Income	62	6	9	3	3	17
Lower Middle Income	55	10	13	4	3	15
Upper Middle Income	50	15	12	4	4	15
High Income	28	30	11	7	6	18

Source: World Bank: What a Waste: A Global Review

3.4. Processing and Disposal

The so-called landfill is mostly covering refuse in the dumpsite by soil neither scientifically nor with treatment to air, water and soil contamination. The disposal of MSW in landfill occurs in three categories, which are:

- Open dump or open landfill in low lying areas haphazardly, which is the most common for all developing countries.
- Semi-controlled or operated landfills where the garbage is compacted and daily topsoil cover is provided to prevent nuisance. All kinds of municipal, industrial clinical/hospital waste are dumped without segregation and are not engineered to cope with the leachate production and gas emissions.
- Sanitary landfills are those practiced in the developed countries with facilities for leachate generation and treatment using a series of ponds and arrangements for the control of gases from waste decomposition.

Among the three, sanitary land filling is an engineered system which is the best option taking into consideration all impacts environmentally with respect to the pollution of air, water and soil. However, this kind of secured system is scarcely found around the world.

So proper disposal of MSW is a necessity to minimize system environmental health impacts and degradation of land resources. Figure 2 shows the current annual global MSW disposal with various systems for the entire world [41]. Table 7 illustrates different MSW disposal methods according to country income level around the world [41]. In developing countries, MSW is commonly disposed of by transporting and dumping in open fields, which are perilous environmentally. Figure 3 shows the different methodologies which are currently followed in Asian Countries in disposing of MSW [44]. Looking at the most common disposal methods in Asian countries indicate the share of open dumping to be 60% in India, 85% in Sri Lanka, 65% in Thailand and 50% in China [44].

In India, implementation of waste disposal facilities is not satisfactory. Most of cities/towns are facing problems in identifying sanitary landfill sites. This is due to public defiance, rapid expansion of urban population and areas, increasing land cost and not having proper master plan. However, of late, many states in India have taken initiatives to establish regional or common landfills for disposal of MSW. As of now there are 59 existing landfills in the country, 376 landfills under planning and 1305 landfill sites are identified for future use [43].

Table 4. *Income-wise waste composition (ASIA).*

Materials	High Income	Middle Income	Low Income
Organic %	33	50	60
Paper %	34	20	15
Plastics %	10	9	6
Glass %	7	3	3
Metal %	5	5	4
Others %	11	13	12
Total %	100	100	100

Source: World Bank: What a Waste: A Global Review

Table 5. *Physical Composition of MSW in Indian Cities / Towns in percentage.*

Population range (in million)	Number of cities surveyed	Paper	Rubber, Leather and Synthetics	Glass	Metals	Total compostable matter	Inert
0.1 to 0.5	12	2.91	0.78	0.56	0.33	44.57	43.59
0.5 to 1.0	15	2.95	0.73	0.35	0.32	40.04	48.38
1.0 to 2.0	9	4.71	0.71	0.46	0.49	38.95	44.73
2.0 to 5.0	3	3.18	0.48	0.48	0.59	56.67	49.07
> 5	4	6.43	0.28	0.94	0.8	30.84	53.9

Source: CPHEEO, Manual on Municipal Solid Waste

Table 6. *Chemical Composition of MSW in Indian Cities / Towns in percentage.*

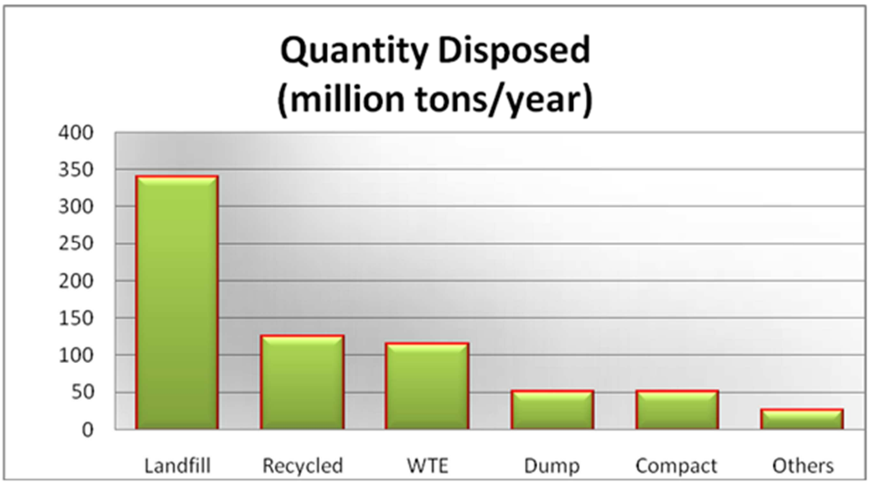
Population range (in million)	No. of cities surveyed	Moisture	Organic matter	Nitrogen as Total Nitrogen	Nitrogen as Total Nitrogen	Phosphorous as P_2O_5	C/N	Calorific value in kcal/kg
0.1-0.5	12	25.81	37.09	0.71	0.63	0.83	30.94	1009.89
0.5-1.0	15	19.52	25.14	0.66	0.56	0.69	21.13	900.61
1.0-2.0	9	26.98	26.89	0.64	0.82	0.72	23.68	980.05
2.0-5.0	3	21.03	25.6	0.56	0.69	0.78	22.45	907.18
> 5.0	4	38.72	39.07	0.56	0.52	0.52	30.11	800.7

Source: CPHEEO, Manual on Municipal Solid Waste

Table 7. *MSW Disposal Methods by Income (million tonnes).*

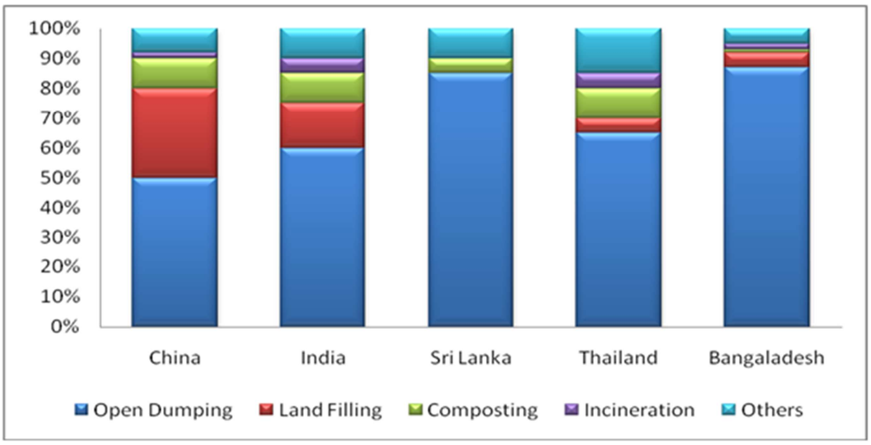
Methods	High Income	Upper Middle Income	Lower Middle Income	Low Income
Dumps	0.05	44	27	0.47
Landfills	250	80	6.1	2.2
Compost	66	1.3	1.2	0.05
Recycled	129	1.9	2.9	0.02
Incineration	122	0.18	0.12	0.05
Others	21	8.4	18	0.97

Source: World Bank: What a Waste: Asia



Source: World Bank: What a Waste: A Global Review

Fig. 2. *Total MSW Disposed of Worldwide.*



Source: C. Visvanathan et al, 2003[44]

Fig. 3. *MSW Disposal Methods in Asian Countries (%).*

3.5. Solid Waste Leachate Contamination

The main environmental problem of waste dumping sites is the potential risk of groundwater pollution. Waste placed in landfills or open dumps are subjected to either groundwater underflow or percolation from precipitation. The disposed solid wastes gradually release its initial interstitial water and some of its decaying by-products enter into water bodies moving through the waste deposit. Such liquid containing innumerable inorganic and organic compounds is called 'leachate'. This leachate concentrates at the bottom of the landfill and infiltrates through the soil. In landfills without liners there might be percolation of different inorganic and organic chemical compounds to the unsaturated zone of the soil which may reach the saturated zone. The unchecked infiltration of leachate in the saturated zone is treated as the worst environmental impact of a landfill.

Leachates may consist of large amounts of organic hazardous contaminants including aromatics, halogenated compounds, pesticides, ammonia, acetone, benzene, toluene, chloroform etc. It is also rich in phenol, nitrogen, and phosphorus. Especially, phenolic compounds released into the environment are of high concern because of their potential toxicity. The compounds present in the leachate also consist of cresols and chlorinated phenols which can be assumed to be hazardous even in small fractions. Also leachate from a solid waste dumping site is normally found to contain major inorganic elements like chloride, sulphate, calcium, magnesium, potassium etc.

Due to migration of leachate, soils have been polluted with heavy metals like lead, copper, zinc, iron, chromium, manganese, nickel, and cadmium and these heavy metals in solid wastes lead to grave problems because they cannot be biodegraded. Soils are regarded as the ultimate sink for heavy metals released into the environment.

Consequently, environmental management and the controlled discharge of waste products from anthropogenic activities are becoming a thrust area to regulatory bodies, researchers, environmental advisory agencies and policy-makers all over the world. Since the contaminants persist for a long time in the groundwater which adversely affects the groundwater quality, it has become an imminent study area for social causes.

3.6. Solid Waste Leachate Studies

The objective of this paper is to review and analyse the groundwater contamination due to non-engineered, indiscriminate solid waste disposal with a view to control groundwater contamination to the maximum possible extent. This review may motivate researchers and engineers to apply and develop new techniques, methodologies and policies enabling better understanding of solid waste management and groundwater contamination attenuation for a better and pollution-free world. The following few important studies pertaining to groundwater contamination due to MSW leachate were considered for the review.

1 A field study was demonstrated (Magda M. Abd El-Salam et al., 2015) [1] to study the impact of landfill leachate on the groundwater quality at Alexandria region, Egypt. Two lined landfill sites El-Hammam (13 cells) and Borg El-Arab (7 cells), along with two nearby monitoring wells were chosen for the study. Sampling was conducted once in two months for leachate and bimonthly for groundwater for a year. 12 Physio-chemical parameters and 8 heavy metals were analysed. The BOD5/ COD ratio (0.69) indicated that the leachate was un-stabilized and biodegradable. It was also perceived that groundwater in the vicinity of the landfills did not have severe contamination, although certain parameters viz. Electrical Conductivity, Total Dissolved Solids, Chlorides, Sulphates, Mn and Fe exceeded the limits. The results of Physio-chemical analyses of leachate confirmed that its characteristics were highly vacillating with severe contamination in organics, salts and heavy metals. The results confirmed that continuous monitoring of the groundwater was a must.

2 A field study demonstrated (Awaz, B.M., 2015) [2] the pollution potential of leachate and its impact on groundwater in Kirkuk Sanitary Landfill Site, in the north-eastern part of Iraq. To assess the groundwater contamination, samples from pre-treatment basin, post treatment basin and leachate pond were examined for physio-chemical characteristics (pH, EC, TSS, TDS, BOD, COD, Cl, SO_4, PO_4, NO_3 and NO_2) and heavy metals (Cu, Pb, Mn, Cd and Ni). Similar analysis was done on two monitoring wells around landfill site. The Leachate Pollution Index (LPI) was also evaluated. The results indicated high levels of Sulphate (SO_4), Phosphate (PO_4), Nitrate (NO_3), BOD and COD in the monitoring wells, indicating the migration of leachate into the groundwater. Analytical results of leachate samples revealed the early acidic biodegradation stage of Kirkuk landfill. The high LPI value of 6.651 was recorded for leachate before treatment, evincing that leachate treatment was necessary to minimize the levels of contamination.

3 A field study was attempted (Ismail Yusoff et al., 2013) [3] to assess the pollutant migration at Ampar Tenang landfill site, Selangor, Malaysia. The main environmental problem of waste dumping sites in Malaysia was the potential risk of groundwater pollution and the subsequent influence on surface water quality. Five exploration boreholes were drilled upto30 m depth to monitor groundwater quality and water level. Three raw leachate samples were collected from the drainage system within and around the landfill site. Similarly three river water samples were collected before and after the leachate entered the Labu river while five groundwater samples were collected. In total, 31 physio-chemical, biological and heavy metal

parameters were analysed. The observed concentration of chlorides in the groundwater within 75 m of the radius of landfill facility was observed to be in agreement with the simulated concentration of chloride in groundwater. Fe and Ni concentrations were above the permissible discharge limits of 1.0 and 0.075 mg/L, respectively. The average concentration for all the examined heavy metals was moderate. In contrast, with the exception of Fe, Ni, As, Cd, Pb, and Cu, all the other analysed heavy metals were below the permissible range. High concentrations of Cl, Ni, Cu, Zn, Mn and Pb were observed in the leachate. Water samples from groundwater, river water and leachate revealed that the landfill site was highly contaminated with organic pollutants indicated by high COD values. It was found that the contaminants including the heavy metals migrated both vertically and horizontally from the source point. The results clearly indicated that contaminants were poorly contained and were entering the wider environment. Hence revamping of the dumpsite was warranted in order to identify suitable remedial measures.

4 Leachate plume was defined (Deize Dias Lopes et al., 2012) [4] using groundwater and geophysical sampling methods in order to evaluate groundwater contamination at Londrina, Brazil. After performing a topographic survey with 12 monitoring borewells, the leachate plume was identified. Groundwater samples were analysed during dry and wet seasons for BOD, COD, pH, electrical conductivity, alkalinity, TKN and heavy metals. Electro resistivity method was used to define the shape of plume contamination. The highest values of electric conductivity and alkalinity corresponded to the wells located in the leachate contaminated zone. Even with seasonal variations, BOD values were low but COD values were higher upto 40 times the values of BOD. The concentrations of Ni, Zn, Cd and Cu in the groundwater were below the limits established by the potable water quality standards, except for Pb whose concentration in groundwater was higher.

5 The concentration of heavy metals was studied (S. Kanmani et al., 2012) [5]in the soil samples collected around the MSW open dumpsite, to understand the heavy metal contamination due to leachate migration from an open dumping site at Ariyamangalam, Trichy, India. Solid waste characterization was carried out in old and new solid waste dumps. The field study constituted 12 soil samples from 4 locations at top surface, 1.5 m and 3m depth. The Physio-chemical and heavy metal parameter concentration in the municipal solid waste, solid waste leachate and soil samples were analysed. The heavy metal concentration were found in the following order 1) Solid waste: Mn>Cu>Pb>Cd, 2) Leachate: Pb>Mn>Cu>Cd and 3) Soil: Mn>Pb>Cu>Cd. The presence of heavy metals in soil samples indicated that there was appreciable contamination of the soil by leachate migration from an open dumping site.

6 Four similar pilot-scale landfill reactors with different composite liners provided alternatively, were simultaneously studied (Gamze Varank, et al., 2011) [6]for a period of about 540 days to investigate and to simulate the migration behaviours of phenolic compounds and heavy metals (Pb, Cu, Cr, Cd, Zn, Ni) from landfill leachate to the groundwater at Odayeri Sanitary Landfill, Istanbul, Turkey. The four lined landfill reactors were viz., 1) R1: Compacted clay liner, 2) R2: Geomembrane +compacted clay liner, 3) R3: Geomembrane +compacted clay liner +bentonite liner +compacted clay liner and 4) R4: Geomembrane +compacted clay liner +zeolite liner +compacted clay liner. Municipal solid wastes were disposed in the reactors. To monitor and control anaerobic degradation in the reactors, variations of parameters like alkalinity, pH, chloride, conductivity, TOC, COD, TKN, ammonia and alkali metalswere investigated in leachate samples. The results exibited that about 35–50% of migration of organic contaminants and 55–100% of migration of inorganic contaminants (heavy metals) to the groundwater could be effectively reduced with the use of bentonite and zeolite materials in landfill liner systems. The experimental results of this study demonstrated that the release of these chemicals from landfill leachate to the groundwater might be potentially significant.

7 The characteristics of municipal solid waste dumped, was investigated (Arun Kanti, et al., 2010) [7] to evaluate the environmental quality in and around the landfill site at Mathkal, Kolkatta, India. The field study was conducted for 11 sampling borewell locations and 7 surface water locations in and around the dumpsite. The physio-chemical properties of the landfilled waste varied differently with organic matter content. Leachates were tested for measuring Cr, Cd, Ni, Mn, and Pb and physico-chemical parameters like pH, COD and hardness. The important relationships among these parameters were established and statistical evaluation viz., Factor and Correlation Analyses of the results were performed. Cl, SO_4 and NO_3 were negatively correlated with heavy metals which clearly showed that metals are not bio-degradable. The results from Factor Analysis were in agreement with the basic idea of water quality in and around the landfill dumpsite which related to the presence of heavy metals. High concentrations of Pb, Cd and Zn were found in groundwater. Also adjacent water bodies were polluted. The moderately high concentrations of heavy metal in groundwater, showed that the groundwater quality has been greatly affected by leachate percolation.

8 Field and laboratory studies have been carried out (Bahaa-eldin E. A. Rahim, et al., 2010) [8] to investigate the impact of municipal landfill leachate on the underlying groundwater at Ampar Tenang site, Malaysia. The solid waste was disposed of directly into

an open natural soil structure. This situation was made worse by the shallow water table. Six exploration boreholes were drilled upto 30m depth for study purposes from where 40 raw leachate samples were collected in and around the dumpsite, while 36 groundwater samples were collected from each borehole. The high ionic balance in certain boreholes revealed highly contaminated leachate migration in groundwater. Elevated concentration of nitrate, chloride, nitrite, ammoniacal-N, iron, sodium and lead measured downgradient indicated that the contamination plume has migrated further away from the site. In most cases, the concentration of these contaminants together with high sodium percentage and sodium absorption ratio were shown to be appreciably higher than the limits of safe water for both domestic and irrigation purposes, respectively. Large variation in EC among the boreholes indicated leachate migration. All heavy metals were below permissible limits except Fe, Cd, Pb and Cu. Highest TDS value was recorded near the active dumping area and the lowest value recorded at the upslope of the site. High Na percentage (60%) and SAR ratio(>4) were found in all boreholes except borehole 1.

9 The quality of groundwater around a municipal solid waste disposal site was verified (P. Vasanthi et al., 2008) [9] at Perungudi, Chennai, India. Field study was carried out from 16 open wells at various locations in and around the dump yard. In order to study the effect of seasonal variation on groundwater quality, physio-chemical analyses were carried out on water samples collected at intervals of 3 months for a period of 3 years. The study had revealed that the groundwater quality did not conform to the drinking water quality standards. The effects of dumping activity on groundwater were shown most clearly by high concentrations of total dissolved solids, electricalconductivity, total hardness, chlorides, COD, nitrates and sulphates. pH values of leachate varied from 6.8 to 8. Leachate collected from the site showed presence of heavy metals like Cd, Cr, Cu, Pb, Zn and Fe. The contaminant concentrations inclined to become lower, during the post monsoon season and increase, during the pre monsoon season in most of the samples.

10 Leachate and groundwater samples were collected (Suman Mor, et al., 2006) [10] from 12 sampling sites within 1.5 Km of landfill site at Ghazipur landfill site, New Delhi, India, to demonstrate the possible impact of leachate on groundwater quality. The dumpfill height varied from 12m to 20m. Concentration of various physio-chemical parameters including heavy metals like Cd, Cr, Fe, Cu, Ni, Pb and Zn and microbiological parameters like total coliform (TC) and faecal coliform (FC)) were evaluated in groundwater and leachate samples. Moderately high concentrations of Cl, NO_3, SO_4, NH_4, Phenol, Fe, Zn and COD in groundwater, likely indicated that groundwater quality was significantly affected by leachate passage. Further they verified to be the tracers for groundwater contamination. The spatial effect on the wells from the pollution source was also investigated. The groundwater quality improved with the increase in depth and the distance of the well from the pollution source. The presence of TC and FC in groundwater warned about the groundwater quality and thus rendered the associated aquifer unreliable for domestic water supply and other uses.

11 A hydrogeological and geochemical monitoring of the two principal aquifer systems developed below the landfill was identified (Dimitra Rapti-Caputo et al., 2006) [11] at Ferrara Province, north Italy. Water samples from 30 wells exploiting unconfined aquifer were collected and analysed. Secondly 4 borewells were built in the confined aquifer system for studying groundwater resources. Several stratigraphic columns and penetrometric tests have been conducted in order to reproduce in detail a lithological and hydrogeological model. Temporal variations of leachate for Al, Cr, Pb, Rb and Zn were observed. In the unconfined aquifer high concentrations of K, Na, Cl, SO_4, Cr, Ni, Co, Mo and Sr were found. In the confined aquifer relatively high values of some ions and heavy metal concentration have been observed. High values of EC along the flow-line indicated degradation of unconfined aquifer.

12 The leachate impact from sanitary landfills on groundwater was evaluated (Kazumasa Mizumura, 2003) [12] at Kanazawa city, Ishikawa, Japan. A field study was conducted by drilling boreholes at 7 points in and around the dumping yard. The chloride concentration in the ground, soil and river waters were investigated because chloride ion was nonreactive and produced no precipitation. The experimental result indicated the flow process of the leachate as most of the leachate plume was discharged into the river, and the balance percolated into the ground, chiefly through the different geological layers. The effect of the rice field was much greater than that of the landfills in the concentration of the Cl ion in the ground which was considered to be caused by fertilizers and agricultural chemicals. The concentration of Cl ion showed higher values near the river into which the leachate plume flowed.

13 Sanitary landfill leachates belonging to different stabilization stages were systematically sampled. More than 100 samples were collected seasonally and analysed for a period of 2-3 years. 20 of the most commonly examined pollution parameters were determined (A.A. Tatsi, et al., 2002) [13] at Thessaloniki, north Greece. Selected important relationships between these parameters were defined and statistical evaluation had been carried out. The composition of leachates varied widely, depending especially upon their degree of stabilization and season, representing the consequence of different climatic

conditions. All parameters examined showed appreciably higher values with fresh leachates. Mn, Ni, CU, and Cr showed lesser values, while Fe, Mg, Zn and Ca showed higher values. pH tended to increase gradually with time from slightly acidic towards alkaline values in leachate that was older, and therefore more stabilized. Toxic metal concentrations were found to be relatively low in 'fresh' leachate samples and even lower in the old ones. Statistical evaluations were also performed. Parameter ratios COD/BOD, VS/TS were also evaluated. BOD/COD varied from 0.5 to 0.2. Correlation analysis was performed for possible relationship among the parameters.

14 A field study was performed (William J. Weber et al., 2002) [14] using four lined landfill test cells (9m x 6m x 1.8m) to characterize leachate from land-disposed residential construction waste at Alachua County, Florida. Leachate samples were collected and analysed for a number of water quality parameters over a period of 6 months. No volatile or semi-volatile organic compounds were detected at elevated levels in the leachate. Inorganic ions were shown to be responsible for the bulk of the pollutant mass leached. Ca and SO_4 were the predominant ions in the leachate, consequent to the disintegration of gypsum. The concentrations of several leachate constituents were observed to exceed water quality standards. These constituents included Al, Ar, Cu, Mn, Fe, SO_4 and TDS. Ar was the only chemical which exceeded the primary water quality standard. The arsenic was concluded to result from chromated copper arsenate - treated wood. The potential risk of impact on groundwater was examined by comparing the observed constituent concentrations with the water quality standards to estimate the amount of dilution and attenuation needed in the groundwater so that a water quality limit would not be exceeded. The water quality standard exceeded by the greatest magnitude was Mn followed by Fe.

15 A field study was initiated (Despina Fatta et al., 1999) [15] using two leachate trenches and six testing wells near the vicinity of AnoLiosia landfill, Athens, Greece. 57 samples were collected monthly from each of the leachate trenches and 39 samples from each of the well. The experimental results showed that most of the parameters analysed in the leachate samples such as colour, electrical conductivity, TS, COD, NH_3, PO_4, SO_4, Cl, KC, Fe and Pb were found to be in high levels. The organic load was quite high since the COD concentrations were in the range of 3250– 6125 mg/L. In addition, the low BOD/COD ratio, indicated that the majority of this organic matter was not easily biodegradable. The groundwater near the landfill site was termed as not potable and not suitable for irrigation, since most of the physical and chemical parameters analysed – such as Colour, Conductivity, DS, Hardness, Cl, NH_3, COD, K, Na, Ca, Fe, Ni and Pb exceeded the permissible limits. Further, the application of the hydrologic evaluation of landfill performance (HELP) model was studied for the estimation of the yearly leakage from the base of the landfill after the final capping. The contamination movement was towards south-west and eastern directions.

16 A field investigation was made (D. Fatta et al., 1998) [16] by collecting leachate at 3 points near the dumpsite for 5 years at AnoLiosia landfill, Athens, Greece. 207 samples were collected and changes in their quality over a period of time were investigated for Physio-chemical parameters and heavy metals in leachate and groundwater. The results showed that the leachate contained high organic and inorganic polluting loads. The COD ranged between 3812 and 6489 mg/L. The organic load was not easily biodegradable as BOD / COD ratio was less than 0.2. The high chloride concentrations constituted a serious threat to the aquifer. Ammonia was also found in high concentration (1350 mg/L). Lead and iron were found to be high while other metals showed lower values. Statistical evaluation for correlation was performed for 23 variables. EC values were high and had good correlation with SO_4, PO_4, Na, Cu and Cr.

17 To investigate the field disposal conditions an experiment was conducted (Ambarish Ghosh et al., 1998) [17] at Kolaghat Thermal Power Station, West Bengal, India, using 6 numbers of leachate apparatus consisting of fly ash, lime and gypsum in various proportions to simulate recycling conditions as closely as possible. With proper proportioning of the mix, and adequate curing, the values of hydraulic conductivity in the order of 10-7 cm/s were achieved. Addition of lime and gypsum decreased hydraulic conductivity. Cu, Fe, Mg, Ni and Zn were below the allowable limits, whereas the concentrations of As, Cd, Cr, and Pb were above the allowable limits but below threshold limits. Hg was above the threshold limit.

4. Wastewater

4.1. Wastewater Management

There is not always sufficiently good quality water available to meet demands for agricultural, domestic and industrial use. There is always water shortage in all countries around the world, where water scarcity on the national level is seemingly contradicted by the local occurrence of large amounts of domestic wastewater. Generally, wastewater is liquid waste that is removed from residential, institutional and commercial establishments. About 80% of the water discharged from cities is wastewater and 80% of which is effluent disposed to the environment with or without treatment. Consequently, groundwater and surface water qualityproblems have become serious and increasing worldwide.

The major challenge to water quality management is due to treated, partially treated, and untreated wastewater from urban and rural settlements and industrial establishments. As the adoption of freshwater for non-agronomical activities produces wastewater, the quantum of wastewater has been ever-increasing with rapidly growing population, urbanization, improved living standards and economic growth. The practice of less freshwater allocation to agronomy more freshwater allocation to non-agronomical sectors and increasing use of urban wastewater, is expected to continue and intensify, especially in water starved countries.

Therefore, agriculture will increasingly rely on alternative water resources, such as wastewater produced by non-agronomical activities in urban and peri-urban areas. But the majority of towns and cities have no sewerage system and sewage treatment facilities. Many cities have expanded and do not have the capacity to handle large quantum of sewage. Management of sewage is worse in smaller towns. The sewage is either directly discharged into water bodies or in open fields. Municipal wastewater can be recycled or may be given some form of terminal treatment before its employment on land for groundwater recharge and agricultural purposes.

Despite the importance of wastewater in groundwater recharge, irrigation, industrial utilisation etc., information regarding the quantity of wastewater generated, treated and used at national scale is either unavailable, limited or outdated in numerous cases. Therefore, information regarding wastewater generation, treatment and use is crucially important for policy decisions in order to develop action plans aiming at wastewater treatment and fruitful use of wastewater in agronomy, groundwater recharge and industrial purpose for environment conservation and health protection.

The issues regarding wastewater generation, treatment and use will intensify in future, with environmental issues, public awareness, quality and quantity of wastewater generated, increasing population, water scarcity economic growth, etc. So the primary concern is the removal of wastewater from urban areas and its reuse for irrigation where infiltrated water is poorly monitored. In the recent years, increase in the quantity of secondary wastewater (SWW) originating from wastewater treatment processes has resulted in significant disposal problems. Land application of SWW is considered a viable management practice because it provides further filtering and biological treatment of the partially treated wastewater through the soils for recharging local water resources. It is true that irrigation was primarily a convenient and relatively inexpensive method of disposing of wastewater, but times and standards have changed.

4.2. Wastewater Generation, Treatment, and Use at Region and Country Scales

Based on World Bank economic classification of countries [35] [36] it is found that in high-income countries on an average 70% of the generated wastewater is treated, then comes upper-middle-income countries (38%), lower-middle-income countries (28%), whereas in low-income countries only 8% of the wastewater generated is treated.

4.2.1. North America

In North America the estimated annual volume of wastewater produced is about 85 km^3, of which 61 km^3 is treated [36]. The annual use of treated wastewater accounts for 2.3 km^3, which is only 3.8% of the wastewater treated in the region. Eventhough, 75% of the wastewater produced is treated, only a fraction is used in agricultural or industrial sectors [36].

4.2.2. Latin America

Only about 20% of wastewater produced is put into treatment in the Latin American countries. In 8 of 15 Latin American countries, less than half the population is subjected to wastewater collection and treatment systems [36]. Although, the population with improved sanitary conditions in the region is 81% in urban and 57% in rural areas, more than 140 million residents do not have improved sanitation facilities [36]. Further, rapid urbanization without sanitation facilities has caused major pollution problems in this region. The urban population is projected to further increase by 130% in 2025 and by 166% in 2050, thus placing additional pressure on Government to provide improved sanitation facilities and to manage urban wastewater to protect health and the environment [36].

4.2.3. Europe

Around 71% of the wastewater generated in Europe is treated, partly due to the public awareness, environment policies and technological advancement as European Union is ready to invest significantly on wastewater treatment systems [36]. Also, the legal and regulatory bodies play a crucial role in wastewater management systems.

4.2.4. Russian Federation

The volume of wastewater treated annually in the Russian Federation is about 14 km^3. About 28% of wastewater is treated as per norms, while the balance is discharged into the water bodies with partial treatment [36]. The major factors for poor efficiency of wastewater treatment plants are inadequate management where 60% of the treatment plants are overloaded and 38% are with old treatment methods which have been in operation for more than 30 years [36]. Fiscal and resource allocation are required for efficient management. Besides, improvised technological methods for wastewater treatment are the need of the hour.

4.2.5. Middle East and Africa

The estimated annual volume of wastewater produced is 22.3 km^3 in the Middle East and North Africa regions [36]. Of which 51% (11.4 km^3/year) is treated. The efficiency of wastewater treatment is varying and the treatment plants do not have the capacity to accommodate the large quantum of wastewater resulting due to the increasing urban population [36]. Nearly 51% of the treated wastewater is used for irrigation. Among 48 Sub-Saharan African countries, complete information regarding wastewater production, treatment and use is available only for 3 countries. Most wastewater goes without treatment in Sub-Saharan Africa, where water pollution triggers the spread of waterborne diseases. In most cases, the wastewater used for agriculture is polluted [36].

4.2.6. Oceania

About 45% of the 450 projects in Oceania are based on agriculture where there is extensive use of wastewater [36]. In Australia, an estimated 0.35 km^3/year of treated wastewater is utilised [36]. This quantum contributes 19% of the wastewater treated in the country and about 4% of the total water supply. Agriculture is the major area gaining from wastewater use in Australia. In New Zealand, wastewater is used to water golf courses and for industrial applications, but the volume involved is small [36].

4.2.7. Asia

Only about 32% of the wastewater generated in Asia is treated, largely due to the lack of treatment facilities [36]. The most common hurdle in Asia is the inadequate financial resources, lack of proper environmental policies, their employment and the shortage of qualified man-power in the field of wastewater management [36].

By and large the information regarding reporting, data collection and updation in many countries are not upto the mark. Therefore, technical and policy efforts should be emphasised globally in order to improve better data collection, enhance existing programs and implement new methods on the part of national and provincial offices regarding wastewater generation, treatment and reuse.

4.3. Wastewater - An Indian Scenario

India is rich in water resources, having a network of as many as 113 rivers and vast alluvial formations with contain large quantum of freshwater. India accounts for 2.45% of land area and 4% of water resources of the globe but constitutes 16% of the world population. With the rapid increase of population in the country there is an ever-increasing demand for water in irrigation, domestic and industrial sectors but the available water resources in many regions of the country are getting emptied and the water quality has deteriorated. In India, water pollution occurs from three main sources: household sewage, industrial effluents and run-off from agriculture. The most significant environmental problem and threat to public health in both rural and urban India is inadequate access to clean drinking water and sanitation facilities.

India is in a transition state i.e. from developing to a developed country, thereby facing two major social problems, one being the lack of infrastructure and on the other, rapid rising of urban population. The present population (2015) is about 1280 million whereas in 2025 it will be 1420 million and in 2050 it will be 1620 million. The population growth of India since 1901 is depicted in Figure 4 [46]. The urban population in India has jumped from 25.8 million in 1901 to about 377.6 million in 2011 [46]. In other words, about 30% of the total population lives in urban areas. It is estimated that by 2050, more than 50 percent of the country's population will live in cities and towns, thus the demand for infrastructural facilities is expected to rise sharply, posing a challenge to urban planners and policymakers. This has thrown up two perpetual problems, viz. water scarcity and sewage overload. But civic services are not able to keep pace with rapid urbanization.

4.3.1. Water Availability and Use

Total utilizable water resource in India has been estimated to be about 1123 BCM out of which 690 BCM are from surface waters and 433 BCM are from groundwater, which is just 28% of the water derived from precipitation. About 85% (688 BCM) of water is used for agricultural purposes, which may raise to 1072 BCM by 2050. Major source for irrigation is groundwater [45]. Annual groundwater recharge is about 433 BCM out of which 212.5 BCM utilised for agricultural purposes and 18.1 BCM for domestic and industrial use. By 2025, demand for household and industrial usage may escalate to 29.2 BCM [45]. Thus water availability for irrigation is expected to diminish to 162.3 BCM. With the present growth rate of population which is approximately 1.77% per year, the population is expected to cross the 1.62 billion mark by 2050. Due to increasing population and all round development in the country, the average annual per capita freshwater availability has been diminishing since 1951 from 5177 m^3 to 1869 m^3, in 2001 and 1588 m^3 in 2010 [45]. It is expected to further reduce to 1341 m^3 in 2025 and 1140 m3 in 2050 [45]. Hence, the need of the hour is the development of a nation-wide strategy for efficient management of water resources through minimization of groundwater usage and maximization of wastewater recycling.

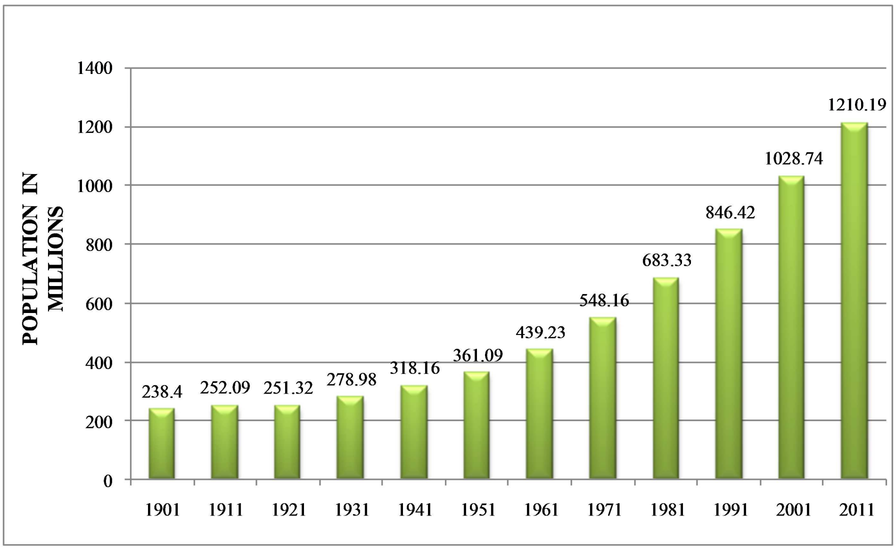
4.3.2. Status on Sewage Generation and Treatment in Class-I Cities (Including Metropolitan Cities) and Class-II Towns

With rapid expansion of urban limits and domestic water supply, quantity of gray/wastewater is increasing proportionately. Discharge of untreated or partially treated sewage into surface and groundwater is the most important water polluting source in India. Out of about 38000 MLD of sewage generated, treatment capacity exists for only about 12000 MLD. In a number of cities, the existing treatment capacity remains underutilized while a lot of sewage is discharged without treatment in the same city. The salient features of the sewage generation and treatment in Class-I Cities and Class-II Towns [37] are given below:-

- There are 498 Class-I Cities (having more than 1 Lakh Population)
- There are 410 Class-II Towns (having population between 50,000 and 1,00,000)
- The sewage generated in Class-I Cities is estimated to be 35558.12 MLD
- The sewage generated in Class-II Towns is 2696.70 MLD
- Class-I Cities generate 93% of total wastewater
- Total sewage treatment capacity of Class-I Cities is

reported 11553.68 MLD, which is 32% of the sewage generation.

- Out of 11553.68 MLD sewage treatment capacity, 8040 MLD is treated in 35 Metropolitan Cities i.e. 69%. This indicates that treatment capacity of balance 463 Class-I Cities is only 31%.
- Total sewage treatment capacity in Class-II Towns is 233.7 MLD which is 8% of the total sewage is generated from Class - II Towns.
- The projected wastewater generation will be 120000 MLD by 2051 in urban areas.
- The projected wastewater generation will be 50000 MLD by 2051 in rural areas.
- There are 269 STPs in India of which only 231 are operational.
- The existing treatment capacity is 21% of present sewage generation
- Per capita wastewater generation in Class - I Cities and Class - II Towns forming 72% of urban population in India has been estimated to be around 98 LPCD



Source: www.iipsenvis.nic.in

Fig. 4. *Population growth of India.*

Thus, the above scenario indicates that in future years, there will be a two-pronged problems viz., reduced fresh water availability and escalated generation of wastewater on account of population explosion, urban migration, inadequate treatment capacity and industrialization. So, there should be need-based programs and strategies to devise new water and wastewater policies, giving equal importance to both augmentation of water supply and development of wastewater treatment facilities, recycling, recovery, recharging, and storage. In future the urban water supply and wastewater treatments will be interdependent as the treated wastewater will be the source to downstream cities from upstream urban areas.

4.4. Effect of SWW on Soil

Wastewater treatment works use micro-organisms to break down effluent. The growth of these organisms removes nutrients from the effluent, thereby rendering it suitable for land irrigation. Conventional strategy for disposal of SWW typically includes land application which means disposal on land, is the most economical one, as SWW disposal is one of the major components in operation and maintenance of wastewater treatment plants. However potential hazards associated with SWW include the presence of pathogens, nitrate contamination, toxic heavy metals and persistent toxic organics. There is increasing concern about the presence of these pollutants in SWW, in particular regarding their agricultural land application and passage through the food chain, because of the reported increase in mutagenicity and persistence of some compounds like PCBs, PAHs and chlorobenzenes in soils. As a result of land application of SWW many different organic compounds may exist, all of which will react differently when applied to soil, depending on their individual properties, their concentrations in SWW , and also their characteristics, location, use and type of soil on which the land application occurs.

Contamination of soil by heavy metals through SWW land application poses a great challenge. Nevertheless, understanding the distribution and spatial variability of heavy metals has received little attention in long-term SWW land application. Therefore, anthropogenic activities like land application of SWW require particular attention for predicting quantum, frequency and types of ecosystem processes on input of SWW into the soil. Heavy metals are not thermodegradable or biodegradable and can concentrate in soil and sediments over time. Although the levels of heavy metals in domestic effluents are generally low, long-term application of domestic effluent has been shown to increase the amount of heavy metals in soils. The accumulation of Pb, Mn, Ni and Co in the soil appreciably raised after wastewater land application, and such concentration decreased with the depth. It is reported that there was significant increase in pH throughout the soil profile. Also P, Na, Ca and Mg increased in the upper profile.

4.5. Effect of SWW on Groundwater

From the viewpoint of the water cycle, groundwater can be treated as a renewable source, but from the angle of freshwater resource or ecology the groundwater may not be seen as a renewable source if it is polluted. Discharging partially treated wastewater into the soil, causes pollution therefore wastewater treatment is necessary to enhance overall water availability and conserve water resources. The long term use of land application as a disposal method of partially treated wastewater may result in groundwater pollution. When large quantities of SWW are applied to the soil which acts as filters for heavy metals, toxic and other hazardous substances, the same may be adsorbed and retained. When the capacity of soil to retain these materials declines due to continuous loading of SWW, the soil properties may change and in turn soil may release these materials into the groundwater.

Thus the contamination of groundwater through leaching of SWW land application is one of the most prevalent pathways through which toxic constituents migrate to the groundwater. Contaminants of SWW are categorized as: Disease causing microorganisms, essential plant nutrient elements, dissolved minerals, toxic chemicals and biodegradable organic matter.

Notably aquifers and their associated springs systems are exposed to nitrate contamination from various anthropogenic activities like SWW land application. Elevated nitrate-N and chloride concentrations have been reported in groundwater. Nitrate contamination of groundwater is typically a result of nitrogen movement into the unsaturated/vadose zone or saturated zones. In particular, large amounts of nitrogenous-fertilizers and poor utilization efficiency may initiate leaching of nitrate thereby polluting the groundwater.

If groundwater nitrate levels exceeded the drinking water standards SWW land application appears to have a negative impact on groundwater quality. In conventional wastewater treatment facilities substantial amount of heavy metals remain in the partially treated effluent if special advanced treatment is not conducted. Thus, long term effects of land application with SWW might include pollution of groundwater and soil with heavy metals. Other impacts of treated wastewater in agriculture include possible contamination of crops by pathogenic bacteria, organic and inorganic pollutants, which may lead to health hazards.

4.6. SWW Leachate Studies

The objective of this paper is to assess the impact of short-term and long-term wastewater application on land with a view:-

- To examine the effects on soil and groundwater properties due to wastewater land application.
- To evaluate and quantify the short-term and long-term effects of treated/partially treated wastewater application on groundwater and soil.
- To formulate land application management strategy.
- To assess the feasibility of mass balance technique for wastewater land application/disposal in relation to soil and groundwater quality.
- To assess the elemental leaching behaviour of SWW applied to soil and groundwater.
- To determine what proportion of the elements present in the soil can be removed by leaching.
- To study the impact of leaching of SWW land application and its effect on the aquifer spatially and temporally.
- To improve the efficiency wastewater treatment facilities based on assimilation capacity of soil.
- To assess the economic return from reuse of water and nutrients.
- To examine water conservation, groundwater recharge, crop production, recovery of nutrients from partially treated wastewater etc.

This review may initiate technocrats, bureaucrats, lending agencies like World Bank, financial experts, urban planners, infrastructure developers, politicians and policy makers to frame strategies in order to improve wastewater treatment, management, distribution and use, for millions of people who depend directly or indirectly on groundwater for domestic, recharge, industrial and agronomical purposes. The following few important cases pertaining to groundwater contamination due to wastewater land application were considered for study and review purposes.

1 Dairy waste lagoons being point sources were responsible for groundwater contamination due to different nitrogen-species, pathogens/microorganisms and chloride (Cl). A field study was attempted (S. Baram, et al., 2014) [18] to determine the past and future impacts of such lagoons on regional groundwater quality in the Beer-Tuvia region, Israel. Spatial statistical analysis methodology for distribution of Cland Total Nitrogen (TN) in the saturated and the vadose (unsaturated) zones was applied. The mass balances showed that despite the small surface area covered by the dairy lagoons in this region (0.8%), leachates from lagoons significantly contributed (6.0% and 12.6%) to the total mass of Cland TN presented in the aquifer. The chemical composition of the aquifer and vadose zone water suggested that land irrigation in the region mainly contributed to Cl and TN levels in the groundwater. A low spatial correlation between the Cl and NO_3- N concentrations in the groundwater and the lagoons strengthened this assumption. Mass balance calculations, for the saturated zone of the entire area, showed that drying of the lagoons would decrease the salinization process and NO_3-N contamination of groundwater.

2 A field study was aimed (Mutewekil M. Obeidat et al., 2013) [19] to assess the groundwater pollution in the

area surrounding the Al Ramtha Wastewater treatment plant in north Jordan. The effluent was utilized to water clover in the area surrounding the treatment plant. Three hundred and eleven samples were analysed in the study, representing 12 wells and one spring emerging from the same aquifer. 12 Physio-chemical parameters were identified for the study. Nitrate concentration ranged from 1 mg/L to 366 mg/L, with an average of 79 mg/L. In total in 71% of the samples analysed nitrate concentration exceeded the threshold value for anthropogenic sources (20 mg/L). More than 50% exceeded the permissible limits. Hydrochemical analysis revealed that groundwater in the study area was fresh-brackish, and hard to very hard in composition. Groundwater chemistry evolved from Ca-HCO3 fresh water type to Na-Cl brackish water type, due to continuous anthropogenic activities. Temporal fluctuations and spatial variations of groundwater quality were also studied. Low concentrations were reported during rainy season and high concentrations during summer season. This could be attributed to the dilution effects by recharging water. The spatial distributions of EC, Cl, and NO_3 followed a single pattern with highest values for those wells located near the treatment plant. Cluster analysis was resorted to the wells with emphasis on nitrate concentration which resulted in 3 distinct clusters. Cluster 1 involved only one sample, Clusters 2 and 3 were comprised of 46.1% of the samples each. To conclude the most important factors which affected the contributed to groundwater pollution were 1) depth to groundwater table, 2) aquifer transmissivity (hydraulic conductivity), 3) lineaments density and 4) distance from treatment plant.

3 A field study was carried out (Faisal Iqbal et al., 2013) [20] to evaluate the land irrigation of untreated wastewater application in 2 peri-urban villages near Faisalabad, Pakistan. Untreated wastewater diverted from the feeding canal of the nearby Wastewater Stabilization Ponds was used for land irrigation. Soil and water samples were collected twice in a month with three replica of each sample. Samples were analysed for water quality parameters like pH, EC, TSS, Carbonate, TDS, Chloride, Bicarbonates and Nitrates. The concentration of elements (EC, TDS, TSS, Nitrates and Chlorides) was more than the threshold values that might be due to the sewage water. The bicarbonates, carbonates and heavy metals values were within the permissible limits in all groundwater samples because these elements retained in the soil.

4 A study was performed (Marwan Ghanem et al., 2011) [21] to determine the concentration of pesticides viz. Dichlorphenoxy Acetic Acids, Paraquat, Atrazineand MCPP (Methyl Chlorophenoxy Pro-Panioic Acid) in groundwater due to agricultural activity in addition to the concentration of trace elements emanating from industrial wastes in dumping sites. The study area was located in Jenin and Tulkarem in the northern part of the West Bank, Palestine. Fifty water samples were collected from groundwater wells from three sampling locations. Nitrate (NO_3) and Potassium (K) concentrations exceeded in shallow wells. The concentrations of pesticides in Jenin was evaluated to be higher than those in Tulkarem where the majority of the samples taken had concentration of10 μg/L. Concentrations of heavy metals including cadmium (Cd), iron (Fe), zinc (Zn), chromium (Cr) and copper (Cu) were within the permissible limits. In Tulkarem there was no significant pollution from the trace elements like Cd (20%), Pb (90%) and Cr (35%). On the contrary, in Jenin about 85% of the tested samples were polluted with Pb. It was demonstrated that the contamination was due to pesticides and not wastewater disposal, since most of the samples were free from pathogenic indicators.

5 A field study was reported (Alma Chavez, et al., 2011) [22] at Tula Valley which received untreated wastewater from Mexico City for agricultural irrigation, half of which infiltrated to aquifers from where drinking water was extracted. A study was carried out in three zones of the valley. Wastewater samples were collected from principal canal. Infiltrated water was sampled and analysed from 12 wells, 4 springs and 2 dugwells in both seasonsfor 1) micro organisms 2) organic micropollutants and 3) some basic physio-chemical salinity indicators. Wastewater contained high concentrations of faecal coliforms and somatic bacteriophages. Also Giardia spp. and helminth eggs were present. There was no difference between seasons. Concentrations of microorganisms in the infiltrated water were generally very low but 68% of faecal coliforms, 36% of somatic bacteriophages, 14% of *Giardia* spp., and 8% of helminth eggs (8%) were present in the sample. 16 organic micropollutants were studied which were often present at high concentrations in the wastewater. These micropollutants were generally absent from the infiltrated water except carbamazepine which presented in 55% of samples (upto 193 mg/L). There was no correlation between microorganisms and carbamazepine concentrations but highest concentrations of carbamazepine and boron coincided. Regarding salinity parameters TDS, TSS, EC, Cl and SO_4 were found to be high. They were higher in the dry seasons than the wet seasons. In the infiltrated water TSS was reduced, while TDS was similar to wastewater. Nitrates exceeded limits. Except Al and F heavy metals were not present. Nanofiltration was recommended for potability of water.

6 A study was initiated (S. Rezapour et al., 2011) [23] in the Urmia region of north-western Iran, where wastewater was utilised for agricultural purposes during past 40 years. 12 soil profiles were selected from wastewater irrigated and adjacent controlled sites in 2 landscapes. The study area was divided into 3 zones - upper, lower and middle slopes respectively.

Concentrations and spatial distribution of Zn, Cu, Cd, Pb and 4 Physio-chemical parameters viz. pH, EC, TDS and TH along the two investigated landscapes were determined to assess the impact of long-term wastewater irrigation and landscape properties with respect to heavy metal contamination. Disturbed and undisturbed soil samples were taken from upper, middle and lower slopes. pH of waste irrigated soil was significantly different from control soil with the exception of midslope. EC and TDS in the wastewater applied soil was significantly higher than control soil. $CaCO_3$ was significantly escalated in wastewater applied soil than control soil in lower slopes. The investigation showed that the average concentration of the heavy metals followed the order Cd <Pb< Cu < Zn, in the wastewater-irrigated soil and Cd < Cu < Zn <Pb in the control soils. On an average, in the control region, the wastewater-irrigated regions contained 3.0 (midslope) to 4.9 (lower slope), 2.7 (midslope) to 4.6 (lower slope), 3.3 (upper slope) to 4.1 (lower slope), and 1.7 (upper slope) to 2.6 (lower slope) times higher amounts of Zn, Cu, Cd, and Pb, respectively. Significant positive relationships were recorded between the heavy metals concentration and organic matter content. Despite the significant raise of heavy metal concentrations in the wastewater-irrigated soils compared with control soils, the concentrations of all evaluated metals were below the maximum accepted limits (Zn < 300 mg/kg, Cu < 100 mg/kg, Cd < 5 mg/kg, and Pb< 100 mg/kg), and classified as "not-enriched" to "moderately-enriched" categories when compared to the topsoil enrichment index. By and large the lower slope was investigated to be more contaminated with the heavy metals compared to the other positions.

7 A field study on the short-term effects of wastewater land application was conducted (Runbin Duan et al., 2010) [24] with a system designed by water-mass balance method at City of Littlefield wastewater treatment site in the Lamb County, Texas, USA. Most of the SWW effluent was applied to the city farm growing alfalfa, and Bermuda grass. 20 rectangular grids were laid where wastewater was applied and 16 lysimeters were installed to assess water-mass balance, nitrogen balance and salt balance. Water mass balance method has proved to be an effective methodology for a wastewater land application system to depose nitrogen at the municipal wastewater treatment facility. At the beginning and at the end of this study period soil samples were taken at different depths from soil surface down to 91 cm at the research site (54 m×18 m), and analysed for pH, total Kjeldahl nitrogen, nitrate–nitrogen, ammonia–nitrogen, electricalconductivity, sodium, calcium, magnesium and sodium adsorption ratio. In the case of total Kjeldahl nitrogen and ammonia–nitrogen, the top layer of soil contained appreciably higher concentrations than in lower layers of the soil profile. Nitrate–nitrogen, on the contrary, had no difference throughout the entire soil profile tested. In the case of the salts and the resulting sodium adsorption ratio tested, there were no notable differences in the concentrations found between the samples collected at the start of the tests and those collected after a year of wastewater application. The results showed that there was no negative change in soil chemical properties during the research period in this wastewater land application system constructed by water mass balance method.

8 About 260 geochemical, microbiological indicators such as faecal indicators, bacteria and human enteroviruses, pharmaceutical and other organic wastewater compounds, stable isotopes, nutrients, major ions, volatile organic chemicals, pesticides, and trace elements were used to evaluate the water-quality impacts of the land application of treated municipal wastewater from sprayfield in Upper Floridan Aquifer (UFA) in northern Florida (Brian G. Katz et al., 2009) [25]. Nitrate-N concentrations had increased from about 0.2 to as high as 1.1 mg/L in Wakulla Springs, a regional discharge point for groundwater during the past 30 years. A major source of nitrate to the UFA was from 64 MLD of treated municipal wastewater applied on a land area of 774 Ha. Concentrations of Nitrate-N, Boron, Chloride, were increased in monitoring wells and in samples from the sprayfield effluent reservoir at the sprayfield area. The sprayfield application was greatly effective in removing most studied organic wastewater, pharmaceutical compounds and microbial indicators. Carbamazepine was the only pharmaceutical compound exposed in groundwater from two sprayfield monitoring wells. Also carbamazepine was found in a far off well water sample where enteroviruses also were identified, indicating a likely influence from a nearby septic tank.

9 A field study on irrigation with municipal effluent and borehole water was made (Ali M. Hassanli et al., 2008) [26] from 2003 to 2005 for 25 months in which 14 tree species were irrigated. The study was conducted at the Marvdasht city sewage treatment site, in southern Iran. Forty-two plots were irrigated with treated municipal effluent. Totally 18 soil samples were taken before the experiment commencement and 54 soil samples taken on 3 occasions for which 19 Physio-chemical parameters were studied. The statistical results showed that the effluent had no negative effect on soil properties. The soil salinity was reduced from 8.2, 6.8 and 7.0 dS/m to 1.07, 1.12 and 3.5 dS/m in the soil layers 0–30, 30–60 and 60–90 cm, respectively. The SAR decreased significantly, on other hand organic carbon increased. The soil pH increased by 0.8 and 0.6 units in the layers 0–30 and 30–60 cm. A total application of 9,335 m^3/Ha of effluent with a nitrogen and phosphorus concentration of 7.9 and 10.3 mg/L added 73 and 101 kg of nitrogen and phosphorus to the

soil. Twenty-five months of irrigation with effluent caused a slight increase in soil bulk density and a slight decrease in mean permeability. The quality of the effluent water was slightly better than that of the borehole water at the experimental site. The major issue was faecal coliform which was much higher than 1,000 FC/ml. Thus application of chloride to reduce microbiological pollutants in this study was highly recommended. Thus, considering water scarcity in the study region, treated effluent water could be a good alternative for irrigation purposes.

10 The effects of NO_3 were investigated (Mohsen Jalali et al., 2005) [27] in Hamadan, western Iran. Fertilizers were applied throughout the agricultural regions of Hamadan to enhance crop production as Nitrogen (N) was vital for crops and microbial growth in large amounts by most arable and horticulture plants. Water samples for NO_3 analysis were obtained during summer 2000 from 311 wells. High nitrate (NO_3) levels had been attributed to leaching from the soil and into water systems. Nitrate concentrations in the well samples varied from 3 to 252 mg/L with an average of 49 mg/L. Results showed that out of 311 wells, 196 (63%) had levels less than 50 mg/L and 115 wells (37%) had levels in excess of the 50 mg/L of NO_3. Only 16% of water samples were classified as having a low risk to human health or environment. Regions of elevated NO_3 occupying northeast, central and some part of the south suggested the influence of regional land use patterns. Fertilizer application was suggested in the spring and summer and the number of applications should be minimum two, though a higher fertilizer application was favoured. The use of groundwater with elevated NO_3 would reduce the requirement of inorganic fertilizer applications.

11 An experimental field study (Vania Rosolen et al., 2005) [28] was conducted to evaluate the chemical characterization of soil due to land application of wastewater at Populina, in the north-western Sao Paulo State, Brazil. The experimental set up consisted of 4 treatment plots – 25m x 70m each and a nearby control plot. Pre-treated effluent was then disposed on the soil surface through perforated tubes. Composite soil samples were collected from control and treated plots. Chemical analyses were conducted for 32 elements viz. Ag, As, Al, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, K, La, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Sc, Sn, Sr, Ti, V, W, Y, Zn andZr. It demonstrated high BOD, COD, TOC and N values, while the majority of metals were below the detection limits. Soils from the treated field indicated high values for the vast majority of macro and micro-nutrients like C, N, P, K, Ca, Mg, Mo, Zn and Cu as well as for other elements, e.g. Ba, Sr, Na, Li, La, etc. when compared to control plot. Other elements analysed i.e. Ag, Be, Bi, Cd, Sb, Sn, W and Sc were found to be partially toxic. Typical soil elements viz. Ti, Al, Fe, V and Zr showed higher values at the control site. The environmental implications of domestic wastewater application to soil surfaces could be grave due to toxicity of elements in the treated soils. Therefore these areas were classified as polluted and required long-term monitoring and detailed investigations.

12 A field study was attempted (C. Tang et al., 2004) [29] to explore the groundwater contamination due to nitrates on account of wastewater irrigation in Shijiazhuang region, North China Plain (NCP). Untreated wastewater from the Shijiazhuang City basin had been utilized for agricultural purposes for decades to irrigate croplands through Dongming Canal in the study area. Excess irrigation water recharged the aquifer that was used as a domestic water supply source. In the study area, groundwater samples were taken from 27 wells whose depths ranged from 40 to 60 m. Physio-chemical parameters like pH, Electrical Conductivity (EC), Temperature, NO_3, Cl, SO_4, Na, K, Ca and Mg, HCO_3 and N were analysed. The EC decreased with distance from the wastewater canal. Concentrations of NO_3 in groundwater were highest in the area near the canal and decreased sharply away from it. NO_3 varied from 50 to 130 mg/L. But in the croplands irrigated by pumping wells, away from the canal, NO_3 concentrations were less than 35 mg/L. In a survey of 27 wells located in and around the aquifer's recharge zone, nitrate concentrations ranged from less than 24 mg/L to 125 mg/L. In general, in shallower wells nitrate concentrations were higher and only one observation exceeded 125 mg/L. It was found that substantially all the wells with less than 40 m depth have NO_3 concentrations exceeding 50 mg/L. Cluster analysis was used to distinguish the spatial distribution of nitrates resulting from the wastewater. It was found that values of $\delta^{15}N$ ranged from +5 to +13‰, and dominantly from +7 to +11‰. Due to excess nitrate, treatment of wastewater prior to irrigation and careful irrigation management were recommended.

13 An experimental study was tried (Ahmad A. Ghosn et al., 2004) [30] in Kuwait to study the effect of freshwater, treated sanitary and industrial water on soil collected from 3 different agricultural sites. The experiment consisted of 9 columns of 120cm x 4.5 cm diameter each with sampling ports at depths of 30, 60, 90 cm. Samples were collected for one year and analysed from influent, effluent and sampling points. The environmental parameters investigated included total organic content (TOC), total Kjeldahl nitrogen (TKN), pH, dissolved oxygen (DO) and total hydrocarbon content (THC). The increase in permeability factor was noticed in industrial and tertiary treated wastewater over freshwater. Marked variations in soil were noticed for pH, DO, TKN, TOC and THC. These variations were attributed to the interactions between soil pore water, soil and influent wastewater used in this study. The results also indicated that the

investigated parameters were within the allowable limits suitable for the reuse of tertiary treated sanitary and industrial wastewaters for agricultural and irrigation purposes.

14 An experimental column study was conducted (Mohammed M. Al-Subu et al., 2003) [31] near the city of Nablus in Palestine. The study was aimed to simulate heavy metals viz. Pb, Cu and Zn ion adsorption on soil from two locations - Salim and Deir Sharaf and in leachate. For each soil, three approaches were adopted. These treatment approaches represent simulation periods for 2, 10 and 20 year periods in triplicates in order to recommend whether these soils were suitable for wastewater application, based on the simulation results. The experimental setup consisted of PVC columns (20 Nos.) of 4" diameter and 2m in length. Soils were analysed for Cl, CO_3, Na, K, Mg, Ca, Cu, Zn, P, Pb, total dissolved salts (TDS), EC, organic matter content, pH and physical properties. The results of soil chemical analyses demonstrated that EC and TDS were low for both soils, which indicated that neither soil was saline. The concentrations of Ca, Mg, K, Na, Cu, Zn, Pb, P, Cl and NO_3 were found to be low and below the acceptable limits of agricultural soil. The soil bulk density was high due to shrinkage. However, specific gravity of soil was typical. The two soils were found to have similar chemical and physical properties thus presented similar response to simulation experiments. Results of simulation experiments showed an increase in the lead, copper and zinc concentrations in soil and in leachate. Lead, copper and zinc concentrations increased with soil depth and duration of application of wastewater. The amount of heavy elements in leachate was also dependent on the simulation period. However, no notable difference in the concentration of heavy metals was found in leachate from the two soils. It was concluded that continuous monitoring of wastewater, soil and groundwater qualities were essential for reuse of wastewater application based on the simulation results.

15 The leaching behaviour of heavy metals was determined (K. Fytianos et al., 1998) [32] from aerobic stored sewage sludge brought from wastewater treatment plant of Thessaloniki, Greece using standard leaching test and various extracting solutions. The metals of interest were Pb, Cd, Zn, Cr, Cu, Fe and Mn because of their toxicity. Leaching was affected by parameters like liquid to soild (L/S) ratio, contact time, pH, type of leaching agents, and particle size. The test utilised the L/S ratio from 5 to 100. For most values of L/S tested, the percentage of leached amounts for the examined metals followed the order Mn< Fe <Pb< Zn < Cd at L/S = 20. At L/S >=40, the leaching order was Fe>Zn>Mn>Pb>Cd which was in agreement with initial metal concentration in sludge. As pH decreased, metal concentrations measured in the leachate also increased. In general, EDTA showed the greatest mobilization ability then comes NaOH, followed by HCL and H_3PO_4 acid solutions and water. Particle size distribution had practically no effect on Cd, Mn, and Pb leaching from sewage sluge. However in Fe, Zn, and Cu a decrease in leaching was observed with increasing particle size.

16 A field study (Neil J. McNab et al., 1997) [33] was demonstrated to determine the pollution effects of land application of sewage sludge from a waste treatment plant at Hammarsdale near the coastal city of Durban, South Africa. The activated sludge treatment process at the STP produced sludge which, after dewatering, was transported for land disposal. 8 suitable soil sampling sites were identified in the up, middle and down slopes respectively, in the sludge disposal land area. Soil sludge mixture samples were collected at the top 10cm and at a bottom depth of 90-100cm in the soil profile. Also water from boreholes and containment dam were sampled monthly. 11 Physio-chemical and physical parameters were studied. The heavy metal concentrations of the sludge produced had long been a matter of concern, especially the higher concentrations of Hg. Investigations of the land disposal site revealed that Hg was present in the upper topsoil (0-10 cm), and only very low concentrations were present in the subsoil. Analysis of the groundwater data revealed statistically that lower concentrations of a number of pollutants were noticed in the downslope aquifer in relation to the upslope aquifer, which would be affected by sludge disposal activities. The investigation directed on the movement of Hg, N and other elements through the soil profile into surface and groundwater resources, for identifying suitable crops for cultivation at the site which could also be used as a sludge disposal facility.

5. Conclusion

In this paper, the review was mainly concentrated on groundwater and soil contamination due to two anthropogenic activities viz., 1) non-engineered, unscientific solid waste dumping and 2) indiscriminate SWW application on land in the name of land irrigation and groundwater recharge with a view to control groundwater contamination to the maximum possible extent and to assess and quantify the short-term effect, long-term effect and leaching behavioural impact of treated or partially treated SWW application on soil and groundwater spatially and spectrally. An overall picture on MSW generation, composition and disposal, also wastewater production, treatment and usage on Global, Regional (Asia) and Country (India) levels, was given. But the main focus was on groundwater contamination due to MSW and SWW leachates. An outline of results of laboratory and field studies extracted from a wide literature survey, was presented. By and large, all the studies evinced that the soil and groundwater were invariably contaminated due to these anthropogenic activities. Importantly most of the studies revealed that the contamination due to solid waste dumping and SWW land application were taking place separately, which means both the contaminations do not happen simultaneously in the same place. But a unique situation prevails at Puducherry, India, where the co-disposal of both MSW and SWW takes place at the same site simultaneously, thereby contaminating the groundwater at this location concurrently. Presently, a field investigation is underway to study the combined effect of these two polluting factors. Based on the current investigation suitable remedial measures will be thought of.

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