Environmental Science

Ramesha Chandrappa
Diganta Bhusan Das

Solid Waste Management

Principles and Practice

Springer

Environmental Science and Engineering

Environmental Science

Series Editors

Rod Allan
Ulrich Förstner
Wim Salomons

For further volumes:
http://www.springer.com/series/3234

Ramesha Chandrappa · Diganta Bhusan Das

Solid Waste Management

Principles and Practice

Springer

Ramesha Chandrappa
Karnataka State Pollution
Control Board
Biomedical Waste
Church Street
Bangalore 560001
India

Diganta Bhusan Das
Chemical Engineering Department
Loughborough University
Loughborough LE11 3TU
UK

ISSN 1431-6250
ISBN 978-3-642-28680-3 ISBN 978-3-642-28681-0 (eBook)
DOI 10.1007/978-3-642-28681-0
Springer Heidelberg New York Dordrecht London

Library of Congress Control Number: 2012938705

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

The authors dedicate the book to their families and colleagues

Preface

Ideally, a theory and a practice should be the same. However, when it comes to reality, theory differs from practice.

Every year nearly one-third of the world's population dies due to commucable diseases. On the other hand, many countries spend more than one-third of their annual expenditure on armed forces without realising that the threat to their community is more within the nation.

While most of solid waste management is designed by literates and experts, a major part of the solid waste is managed by illiterates or the least literate or non-expert. Hence, there will always be shadows between the aspiration and realty—the reason that many solid waste management projects fail. While international consultants prepare volumes of manifests for hazardous waste transportation, illiterate drivers ship hazardous wastes with these manifests without knowing what to do with them.

While international agencies fund many waste management projects, corrupt politicians may seek a share in the amount spent toward such a project. In addition, there is also an inherent culture of citizens in many developing countries throwing waste on the streets. While the third world struggles to get rid of waste from the immediate neighborhood, some developed countries may add to the waste by shipping waste from their countries in the name of charity or other guise.

Solid waste management needs more common sense rather than the solution of complicated partial differential equations and financial plans.

In spite of many lacunae, innumerable efforts have been made in the past few decades to do much for the Earth. Although waste management has not developed the way some other streams of science/engineering have grown, there are people and agencies who are working within their own limitations which have helped make progress in this area.

Once we dig out and use all the possible resources on the Earth we would definitely turn to waste for recovery of resources—a practice which is now proven to be profitable in the case of extracting precious materials from waste from electrical and electronic equipments rather than from the ore.

Considering the above issues, an attempt is being made by us to minimize the knowledge gap in print and on field after working more than a decade in the field and surveying more than 300 literatures. We have made an attempt to touch almost all the important aspects of solid waste in this book while keeping in mind both the theory and practice. We have also tried to bring wholesomeness to our effort by discussing problems across the world instead of sticking to a single country.

We are most grateful to Ms. Agata Oelshlaeger of Springer-Verlag GmbH for the continuous encouragement and support right from the beginning till the publication of this book.

We acknowledge the help of Ms. K. P. Akshatha, Mr. Satish Garje, and Mr. Amar Yeshwanth of Karnataka State Pollution Control Board (KSPCB), Bangalore, India for their help in word processing.

The photos shared by Mr. K. M. Lingaraju, Mr. M. N. Yoganand, Mr. Ramesh D. Naik, Mr. D. P. Mahendra of KSPCB, Mr. Krishnegowda of Apollo Hospital, Banaglore, Mr. D. K. Nagaraj, and Mr. Guruprasad of Semb Ramky Pvt. Ltd., Bangalore and Ms. K. Rachitha were of great help. Support extended by Dr. B. Nagappa of KSPCB for the literature collection helped to cover many points in the book.

Courtesy and knowledge extended by Mr. V. R. Joshi of K. G. Nandini Enterprises, Bangalore during a visit to their WEEE processing unit were greatly helpful in completing the book.

Our acknowledgments would be incomplete without mentioning the name of Ms. P. Archana of KSPCB, Thambidurai Solaimuthu, and Agata Oelschläger of Springer whose association has helped in a great way in completing this book.

Ramesha Chandrappa
Diganta Bhusan Das

Contents

Abbreviations

3R	Reduce, Recycle and Reuse
ABS	Australian Bureau of Statistics
ACM	Asbestose Containing Material
AD	Ano Dominy or Anaerobic Digestion
ADB	Asian Development Bank or African Development Bank
AFP	Active Fire Protection
AIDS	Acquired Immunodeficiency Syndrome
APO	Asian Productivity Organisation
ASR	Automotice Shredder Residue
BaO	Barium Oxide
BARC	Bhaba Atomic Research Centre
BBMP	Bruhat Bengaluru Mahanagara Palike (Metropolitan Corporation of Greater Bangalore)
BC	Before Crist
BF	Blast Furnace
BFS	Blast Furnace Slag
BMW	Biomedical Waste
BIS	Bio-Intelligence Services
C&D	Construction and Demolition
CaO	Calcium Oxide
CBA	Cost Benefit Analysis
CCl_4	Calcium Tetra Chloride
CEA	Cost Effectiveness Analysis
CFC	Chloro Flouro Carbon
CH_3COOH	Acetic Acid
CH_4	Methane
CHNS	Chorbon, Hydrogen, Nitrogen, Sulphur
Ci/Kg	Curie/kg
CIDA	Canadian International Development Agency
CNS	Central Nervous System

CO_2	Carbon Dioxide
CPHEEO	Central Public Health and Environmental Engineering Organisation of India
CRT	Cathode Ray Tube
CSIR	Council for Scientific and Industrial Research
CTC	Carbon Tetra Chloride
CWC	Clean Washingdon Centre
DCC	Dhaka City Cooperation
DMP	Disaster Management Plan
DRS	Deposit Refund System
DSNC	Department of Sanitation Newyok City
DTI	Department of Trade and Industry
DTI	Department of Trade and Industry of the UK
DW	Disaster Waste
EBS	Engineered Barrier System
ECDGE	European Commission Director General Environment
EDA	Emergency Declaration Area
EEA	European Environment Agency
EEE	Electrical and Electronic Equipment
EH&S	Environment Health and Safety
EIA	Environmental Impact Assessment
ELV	End of Life Vehicle
EMP	Environment Management Plan
EoL	End of Life
EPA	Environment Protection Agency of the USA
EPHA	Environmental Public Health Act
EPP	Emergency Preparedness Plan
EPR	Extended Producer Responsibility
EU	European Union
FHNW	University of Applied Sciences Northwestern Switzerland
FMD	Floating Marine Debris
FML	Flexible Membrane Liners
GCL	Geosynthetic Clay Liner
GDP	Gross Domestic Product
GESAMP	Group of Experts on the Scientific Aspects of Marine Pollution
GHG	Greenhouse Gases
GI	Gastro-Intestine
GPS	Global Positioning System
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Technical Cooperation)
H_2O	Water
H_2S	Hydrogen Sulphide
HC	Hydrocarbons

HCl	Hydrogen Chloride
HHP	Household Hazardous Product
HHV	Human Herpesvirus
HHW	Household Hazardous Waste
HIV	Human Immunodeficiency Virus
HLS	School of Life Sciences
HLW	High-level Wastes
HOD	Handing Over Document
HSE	Health and Safety Executive of the UK
HSLT	High Speed Low Torque
IAD	Ion Assisted Deposition
IAEA	International Atomic Energy Agency
IATA	International Air Transport Association
IEC	Institute for Ecopreneurship
ILO	International Labour Organisation
ILW	Intermediate Level Waste
IMDG	International Marine Dangerous Goods
INS	In-situ Leach
IPCC	Intergovernmental Panel on Climate Change
ISL	In Situ Leach
ISWM	Integrated Solid Waste Management
IVD	Ion Vapour Deposition
IWB	Itinerant Waste Buyer
JICA	Japan International Cooperation Agency
K_2O	Potassium Oxide
L	Litre
LCA	Life Cycle Assessment
LCD	Liquid Crystal Display
LDAR	Leak Detection and Repair
LDC	Less Developed Country
LFG	Land Fill Gas
LILW	Low and Intermediate Level Wastes
LILW-LL	Low and Intermediate Level Wastes-Long Lived
LILW-SL	Low and Intermediate Level Wastes-Short Lived
LLW	Low Level Waste
LSHT	Low Speed High Torque
LWD	Large Woody Debris
LWP	Limited Work Permit
mCi	Millicurie, 1/1000 of a curie
MCi	Megacurie, 1,000,000 times a curie
MEIP	Metropolitan Environmental Improvement Programme
MFA	Material Flow Analysis
MgO	Magesium Oxide

MoEKoC	Ministry of Environment, Kingdom of Cambodia
MRF	Material Recovery Facility
MRI	Magnetic Resonance Imaging
MSDS	Material Safety Data Sheet
MSW	Municipal Solid Waste
N_2O	Nitrous oxide
NA	Not Applicable
NaO	Sodium Oxide
NEERI	National Environmental Engineering Research Institute
NEP	Natural Edge Project
NFC	Nuclear Fuel Cycle
NGO	Non-governmental organisations
NH_4OH	Ammonium Hydroxide
Ni-Cd	Nickel-Cadmium
Ni-Cr	Nickle-Chroimum
NiMeH	Nickel Metal Hydride
NMRS	Nuclear Magnetic Resonance Spectrometer
NO_2	Nitrogen Dioxide
NORM	Naturally Occurring Radioactive Materials
NORM	Naturally Occurring Radioactive Waste
NOx	Oxides of nitrogen
NWM	Nuclear Waste Management
O_3	Ozone
°C	Degree Celcius
ODS	Ozone Depleting Substance
OECD	Organisation for Economic Co-operation and Development
OPC	Ordinary Portland Cement
OPCW	Organization for the Prohibition of Chemical Weapons
P&T	Partitioning and Transmutation
PBDE	Poly-Brominated Diphenyl Etters
PbO	Lead Oxide
PCDD/Fs	Polychlorinated Dioxins and Furans
PDF	Packaging Derived Fuels
PDR	Peoples Democratic Republic
PEF	Process Engineered Fuel
PFA	Pulverised Fly Ash
PFT	Permission To Test
PMF	Powder Metal Fuel
POHC	Principal Organic Hazardous Constituents
POST	Parliamentary Office of Science and Technology
PP	Polypropelene
PPE	Personal Protective Equipment
PPF	Paper and Plastic Fraction
PPF	Passive Fire Protection
PRC	Pneumatic Refuse Collection

PS	Polysterene
PTW	Permit To Work
Pu^{+3}	Plutonium (III)
Pu^{+4}	Plutonium (IV)
PVC	Poly Venyl Chloride
RA	Risk Assessment
RCT	Reinforced Concrete Trenches
RDF	Refuse derived fuel
RDW	Reactor Decommisioning Waste
REF	Recovered Fuel
RFID	Radio Frequency Identification
RSS	Royal Scientific Society
RTS	Reservoir Triggered Seismicity
SA	Sustainable Assessment
SBA	Sustainable Business Associate
SCN	Safety clearance Notice
SEA	Strategic Environmental Assessment
SHG	Self Help Group
SiO_2	Silicon dioxide
SLF	Substitute Liquid Fuel
SLT	Stone-Lined Earth Trenches
SMS	Steel Melting Shop
SNF	Spent Nuclear Fuel
SoEA	Socioeconomic Assessment
SOP	Standard Operating Procedure
SPW	Solid Petroleum Waste
SRS	Sealed Radioactive Sources
SST	Sea Surface Temperature
SWM	Solid Waste Management
TBBPA	Tetra Bromo Biphenol-A
TH	Tile Hole
TRU	Transuranic
TRUW	Transuranic Waste
TSDF	Treatment, Storage and Disposal Facility
TTD	Tirumala Tirupathi Devastanam
TWRF	Tsunami Waste Recovery Facilities
UC	Uropean Community
UK	United Kingdom
ULB	Urban Local Body
UN	United Nations
UNEP	United Nations Environment Protection Agency
UNU	United Nations University
USA	United States of America
USACE	U.S. Army Corps of Engineers
USEPA	United Stares Environment Protection Aency

USFA	United States Fire Administration
VFA	Volatile Fatty Acid
VLLW	Very Low Level Waste
VOC	Volatile Organic Compounds
VRF	Volume Reduction Factor
WEEE	Waste from Electical and Electroic Equipment
WTE	Waste to Energy
ZnO	Zinc Oxide

Chapter 1
Introduction

Solid waste was a problem even before water and air pollution issues attracted the notice of human civilisation. Problems associated with solid wastes can be dated back to prehistoric days. Due to the invention of new products, technologies and services, the quantity and quality of waste have changed over the years. Now, the waste characteristics depend not only on people's income, culture and geography but also on the economy a society undergoes and situations like disasters to which the society may be subjected to.

The twentieth century is recognised as the *American Century* and the twenty-first century is recognised as the *Asian Century* and, it seems everybody wants to earn 'as much as possible' (Ramesha et al. 2011). After Asia the developing Africa could take the central stage of development in the coming years. Development does not come without environmental burdens and generation of waste is one among them. Waste in recent times has become a topic of extensive attention in academic and popular literature (Tim 2009). Waste is conventionally defined as unwanted material at the point of generation which does not have immediate use. Problems due to waste exist where there is a human inhabitants (UNEP 2004). As the name suggests, the term *solid waste* is used for waste which is solid. When governments took the responsibility of solid waste management originally, they bothered only about the waste generated from household and commercial activities. However, anthropogenic activities produce waste materials that are frequently discarded as they are considered useless. Some of the wastes are usually solid, and they are considered as useless and unwanted. But many of these waste substances can be reused and can be a resource for an industry. Indeed waste management is one of the most important problems of our time as development and subsequent use of materials generates enormous quantity of wastes.

In recent years many countries have passed laws with respect to municipal solid waste (MSW) management making urban local bodies (ULB) the obligatory organisation to manage solid waste. In many places the services of ULBs are poor

R. Chandrappa and D. B. Das, *Solid Waste Management*,
Environmental Science and Engineering, DOI: 10.1007/978-3-642-28681-0_1,

in terms of efficiency and satisfaction ending up in problems of health and environmental degradation of the solid waste.

Under the Environmental Public Health Act (EPHA) passed in 1968 in Singapore, ‘‘waste’’ includes:

(a) *Any substance which constitutes a scrap material or an effluent or other unwanted surplus substance arising from the application of any process*; *and*
(b) *Any substance or article which requires to be disposed of as being broken*, *worn out*, *contaminated or otherwise spoiled*, *and*
(c) *Anything which is discarded or otherwise dealt with as if it were waste shall be presumed to be waste unless the contrary is proved.*

“Municipal solid waste” is a term usually applied to a collection of wastes produced in urban areas. The US Environmental Protection Agency (US EPA) (2008) defines *municipal solid waste* as:

> the materials traditionally managed by municipalities, whether by burning, burying, recycling, or composting.

As per the Municipal Solid Wastes (Management and Handling) Rules, 1999, in India:

> “municipal solid waste”includes commercial and residential wastes generated in a municipal or notified areas in either solid or semi-solid form excluding industrial hazardous wastes but including treated biomedical wastes;

The quantities and characteristics of waste generated in any region are functions of the lifestyle and living standards of the region’s citizens and the type of the region’s natural resources. Excessive quantities of waste are generated from a society from inefficient production processes, and low durability of goods as well as unsustainable consumption of resources (Nicholas 2003). Due to the varying degrees of development in different countries, it is difficult to generalise or standardise solid waste management as in corporate sector. Solid waste management involves understanding of existing waste management practice as well as adoption of new methods to overcome existing practices. While higher income regions have been known for ‘use and throw’ habit generating huge quantity of waste. Lower income regions use and reuse the resources available to maximum extent and hence generate lower quantity of waste. Other factors contributing to varying waste quantities and qualities are climate, economy, frequency of disaster, mindset of the people, and any others.

Ditches, where solid wastes are collected, were the main reason for epidemics in Europe in 1348 and 1665 (Alice 2008) which can be observed in developing countries now (Fig. 1.1). In order to overcome epidemics England passed an order in 1578 to eradicate plague compelling householder with a pump or a well to pour water down the gutters in the street and householders were required to sweep the mud/filth of the street and out of the gutters. As shown in Fig. 1.2 people even throw waste into unused wells poisoning the groundwater.

Fig. 1.1 Solid waste dumped in an open drain

Fig. 1.2 Water contamination of groundwater due to indiscriminate throwing of solid waste into a well

In developed countries wastes are generally carefully regulated and tracked through well developed record-keeping systems. But a developing country may not have sufficient people and resource to carry out a detailed record keeping. In spite of the good knowledge of constraints developing countries also make legislation in line with that of developed countries and sometime the legislations may be just copies of existing legislation elsewhere.

Lack of clear definition, roles, responsibility, and quality data has made the treatment and disposal problematic in developing world. Copying solid waste disposal models of developed countries like hauling to disposal site and land filling is leading to expenditure on transportation mostly by outsourcing to private agencies. The alternative model like segregation in yard nearer to point of generation is often discouraged to make business opportunity to waste transporting agencies.

1.1 Need for Solid Waste Management

The expenses for environmental management are multi-tiered, and future events are difficult to forecast with assurance. However, the risks in the future and associated costs can be minimized and eliminated by choosing appropriate preventive measures (Nicholas 2003).

Environment and human health can be affected by poor solid waste management. Over the years, solid waste management responses have been practiced all over the world like policies, regulation, and financial practices. The human population is likely to double between 1990 and 2015 with most of the growth occurring in less developed countries (LDC) and with the increased population there would be an increase in demand for efficient waste management practices. Waste is diverse in its origin and variety resulting in diverse impacts. The rapid change in technologies has resulted in dimensions of impact. The waste dumping in deserts, forests, streams, lakes, oceans, and other place has resulted in wide impacts leading to international and national legislations.

The needs for solid waste management are many. While it is sometimes carried for resource recovery, in other cases it could overcome problem of epidemic. Sometimes, it is carried out to avoid accumulation of hazardous substances which could lead to fire hazards. At other time it is carried out to avoid rodents and vectors. Irrespective of the reasons and methods it aims to restore the environment in which the inhabitants are comfortable.

With rising people, wealth and urbanization, it is a chief challenge for many nations to manage increasing quantity of solid waste. It must be further highlighted that reduction in Green House Gas (GHG), improved public health, safety and environmental benefits accrue from good waste management practices.

Figure 1.3 shows the impacts due to improper solid waste management. In a nutshell improper solid waste management has following impacts: (a) water and air pollution, (b) problems associated with bad odour, pests, rodents and stray animals, (c) generation of GHGs, (d) problems associated with aviation due to birds flying above dump site, (e) fires within the waste dump/land fill, and (f) erosion and stability problems in waste dump or land fill.

Historically, science and technology are based on new ideas, concepts, and their applications but in the past little emphasis is given on end of life cycle of the product and service. The term life cycle refers to period of product or service in society, and then death. Production of same product by different methods can have different impacts. For example foundry activity can be done either in cupola or induction furnace. The former generate large amount of air pollution and waste compared to induction furnace. Similarly sports activity in night will have more impact on environment as there is huge energy consumption in night compared to day. The packed food always generates more waste during manufacturing, transportation and use.

One way of reducing waste is to lower consumption and another way is to use clean technology. Poor countries adopt ‘dirty technology’ keeping their inability to

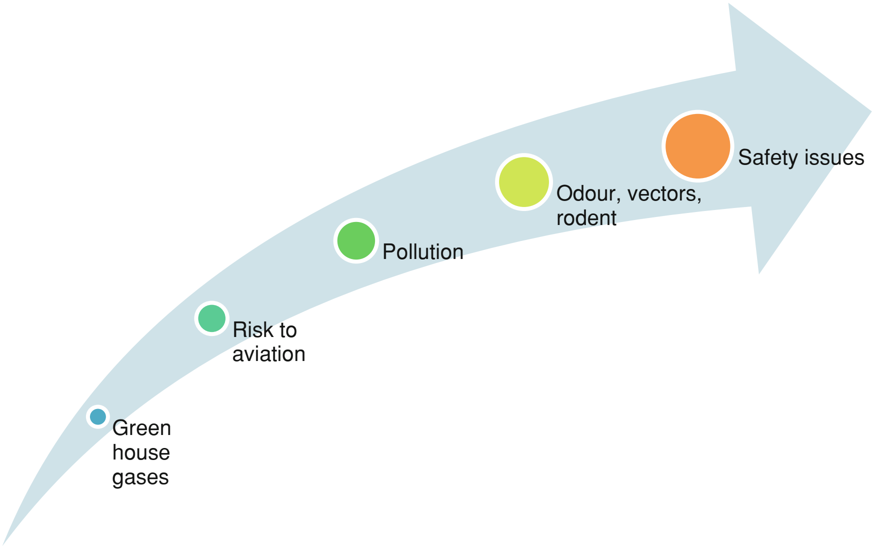

Fig. 1.3 Impacts due to improper solid waste management

spend towards cleaner technology. Whereas the rich countries adopt 'clean technology' but use a lot of packaging. As a result there is huge imbalance in the resource consumption and waste generation among various nations.

1.2 Importance of a Sound Solid Waste Management

In the developing nations, waste management regularly emerges as a problem which endangers public health and the environment. Waste management in developing countries seems to have a low priority as they are more bothered about issues like hunger, health, water, unemployment and civil war. Hence millions of people in the developing countries are living without an appropriate waste management system. In these countries uncontrolled waste dump is a huge danger for the environment and population due to contamination of the water and soil.

The organic fraction the waste not only attracts rodents and vectors, it also forms foul odours as well as unsightliness. Uncontrolled or inefficiently managed waste can contaminate water, air and soil. Many workers who handle waste and individuals who live near or on disposal area are infected with worms, gastrointestinal parasites and other related organisms (Cal Recovery Systems 1982). Sound waste management not only reduces the risk of commutable diseases, it also reduces toxicity of food and water due to entry of heavy metals and other chemicals. Solid waste management would also reduce resource depletion due to unnecessary mining, energy consumption and pollution problems during

Fig. 1.4 Bulky waste

manufacturing of new product. Proper recycling or reusing would add conservation of species due to unnecessary clearing forest and vegetation above the mineral resources.

Improper waste would also suffocate many species due to entry of material like plastic covers into food chain. The entry of toxins into food would also mean damage to ecology. The combustion in dump yards and other places not only add to pollution it will also add to GHGs. The loss of manpower due to acquired sickness due to improper waste disposal is difficult to estimate.

As would be discussed in subsequent chapters, the proper management would improve safety of waste handlers as well as general public. Proper solid waste management would also add revenue to local body by reducing unnecessary expenditure.

Population explosion and economic growth have resulted in increasing quantities of solid waste in urban areas. In most poor countries, the increasing quantities of waste have beleaguered local governments' ability to cope efficiently. In many of the developing countries, infectious wastes and toxic wastes are not segregated from other waste exposing the waste collectors to a variety of risks.

The solid waste is not always uniform throughout the year. It often changes from place to place and time to time. Figure 1.4 shows bulky waste generated during road widening which cannot be hauled by the truck which collects solid waste from streets and households. The uprooted trunk needs special cranes or it has to be made into pieces at the uprooted point. In either the case waste can be used as resource by using wood for furniture or for construction. Figure 1.5 shows art created by using waste from End of Life Vehicle (ELV)s. Such practices add not only to the efficiency of waste management process but also the economy of the country.

Another example for variation in waste quantity in the span of a year is shedding of leaves in spring which contribute to dry leaves. The festivals would

Fig. 1.5 Waste transformed into an art form

often generate greater amount of waste in markets and shopping areas. Riots and disasters would not only disrupt rhythm of solid waste management, they also add to new type of waste to the existing waste stream. The boom and recession cycles of economy would also affect the waste management by changing the type and quantity of waste.

In an attempt to speed up the industrial development, developing country may fail to manage solid waste. Such a failure invites a stern consequence afterwards in the form impact on the environment, public health and safety.

The indiscriminate disposal of waste is just not restricted to land or water. It may sometime stick to trees as shown in Fig. 1.6 affecting the aesthetics of the area and health of the tree.

Waste disposal can also lead to accident and traffic disruption as shown in Fig. 1.7 wherein the people have thrown the waste at the centre of the road as the civic authority have failed to place proper collection system in place. This picture which was taken from a lower income residential area in Delhi, India, is mainly due to the location of shops/houses very close to kerb side. In order to keep their premises clean the waste generators throw waste as far as possible from their property.

It is also interesting to know that pilgrimage centres and holy places will have unique situations calling for tailor made solution for the situations. Tirumala

Fig. 1.6 Waste on a tree

Fig. 1.7 Waste at the middle of a road

tirupathi devastanam (TTD) netted an income of 1,130 million rupees through 'e-auctioning' of human hair in the year 2011. Approximately ten million people shave their hair as an offer to deity, Lord Venkateshwara, in accomplishment of their prayers every year (Shukla 2011).

Another interesting situation wherein the data about waste generation is not available and secrete is from armed forces of all countries. Worldwide arms sale totalled 40.4 billion in the year 2010 (Thom 2011). It is not known how much the waste weapons and bullet are generated while testing and practicing usage of weapons are disposed off.

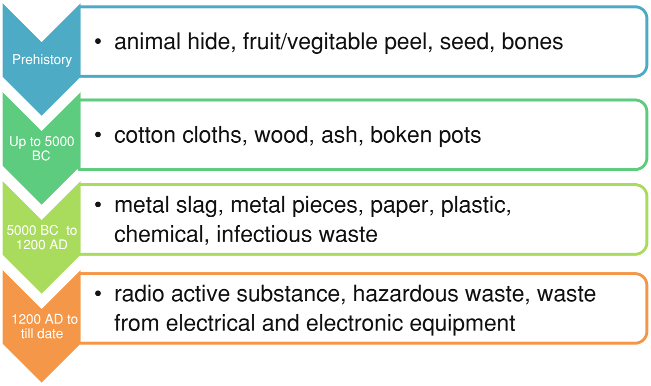

Fig. 1.8 Addition of new waste components over time

1.3 Change in Characteristics in Quantity and Time

Archaeological studies have shown layers from periods of prosperity and waste generation rates can be correlated to many indicators of prosperity (Bingemer and Crutzen 1987; Bogner and Matthews 2003; Mertins et al. 1999; OECD 2004; IPCC 2000; Richards 1989; Rathje et al. 1992a; US EPA 1999).

The plague, cholera and typhoid influenced monarchies and changed the populations of Europe. Europeans used to throw their domestic waste out of the window to the street through window and some still do so in the developing world. Figure 1.8 shows new components added to waste stream over the time. With innovation and development in science new products and business was added to the world. As a result the characteristics of waste changed from purely organic waste in prehistoric time to waste with radioactivity as on date.

Solid-waste generation rates depend on affluence and population, but data are questionable or deficient for many nations. Using data from 1975 to 1995, Bogner and Matthews (2003) developed models for per capita waste generation for developed and developing nations. As per Bogner et al. (2007) approximately 900 million tons of waste was generated globally in 2002 and Monni et al. (2006), indicated about 1250 million tons of waste generation in 2000 globally.

Per capita product and packaging waste increased by two folds between 1960 and 2005 while the per capita generation of food scraps and yard trimmings remained moderately constant in the USA (Sheehan and Spiegelman 2010). The quantity of metals in municipal solid waste of the USA changed from 12.3 % in 1960 to 7.7 % in 1996, whereas fraction of plastics changed from 0.4 % in 1960, to 9.4 % in 1996. Further, garden wastes declined from 22.7 % in 1960 to 13.4 % in 1996 (Franklin Associates 1998).

1.4 Waste Management in Pre-Industrialization Era

The history of solid waste is intricately bound with the history of civilisation given its omnipresent nature and visibility. For the last two million years humans generated little [please check] solid waste. The rate of garbage accumulated in the ancient city of Troy was estimated to be 1.4 million tons per century (Rathje 1990). The Roman practice of dumping solid waste in the streets caused considerable quantities of waste to be carried along the rainwater runoff.

Waste generated in pre-industrialization era was less toxic, low in quantity and easily biodegradable. The waste management prior to industrialization could be explained as below:

Human beings might have begun wearing clothing between 100,000 and 500,000 years ago. The people of the Indus Valley Civilization used clothing of cotton (which is now major component in urban solid waste) between fifth millennium BC and fourth millennium BC. Mohenjo-Daro city in the Indus valley had houses with rubbish chutes and Harappa City had toilets (Melosi 1981). With civilization, solid waste became an important issue. Human population of the world changed from one million in the year 10000 BC to 5 million in the year 5000 BC. Waste dumps were established away from settlements around 8000–9000 BC to avoid wild animals, insects, and odours (Bilitewski et al. 1997). The Minoans (lived around 3000–1000 BC) covered waste with layers of soil (Priestley 1968; Wilson 1977). By 2100 BC cities on the island of Crete had trunk sewers (Melosi 1981; Vesilind et al. 2002). The Neolithic revolution was the initial point for the transition from nomadic communities to settlement. During this period, the concept of solid waste management was not evolved. Waste removal was done randomly at convenience individuals could dump waste wherever they felt like dumping.

Very few records exist related to solid waste management prior to 3000 BC (Matthew 2009). The first documentation of solid waste management occurred in Athens, Greece during 500 BC and the city of Athens structured the first municipal dump where people were required to dispose the solid waste at least one mile away from city walls (Matthew 2009). The cities on the island of Crete had trunk sewers connecting homes in 2100 BC (Melosi 1981). In the Egyptian city of Heracleopolis (founded about 2100 BC), the wastes from “non-elite” section were ignored and waste from elite and religious sections were collected and disposed (Melosi 1981).

Metallurgy evolved between fifth and sixth millennium BC, and making of alloy began around 3500 BC during the Bronze Age. Around 1200 BC, the world witnessed the beginning of the Iron Age. Metallurgy brought with them an array of slag and scrap materials.

Archaeological studies reveal municipal dump in Athens Greece (Wikipedia 2011) during 500 BC. Municipal dump is established in ancient Athens (bfi-salinas 2011) during 400 BC. The first landfill was commissioned in Knossos Crete during 3000 BC (Ace disposal 2011; Matthew 2009). In the fifth century BC Greek