NaWaTech

Compendium of Natural Water Systems and Treatment Technologies to cope with Water Shortages in Urbanised Areas in India

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Compendium of Natural Water Systems and Treatment Technologies to cope with Water Shortages in Urbanised Areas in India

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Foreword

Access to adequate and clean water is an important environmental, social and economic issue. The supply of adequate water in the ever-growing urban areas is a challenge for the local government. Population growth, relocation of human resources from rural to urban areas, limited fresh water sources in urban areas and increase in the per capita water consumption has posed additional challenges for the local governments.

Natural Water systems and Treatment Technologies (NaWaTech) is a three-year collaborative project under 2011 India-European Union Call for Proposals on Water Technology, Research and Innovation approved by the Department of Science and Technology, Government of India and the European Commission.The purpose of the project is to cope with water shortages in urbanised areas in India in an attempt to demonstrate the effective use of natural water treatment systems by shifting the approach from the conventional end-of-pipe to an integrated water management. The NaWaTech concept is based on optimised use of surface water supply, rain water, storm water and grey / black water flows by treating each of these flows via a modular natural system taking into account the different nature and degree of pollution of the different water sources.

CSIR-NEERI along with the 6 other Indian Consortium Partners and seven European partners from five different countries aims to develop an approach to including (i) interventions over the entire urban water cycle; (ii) optimisation of water use by reusing wastewater and preventing pollution of fresh water source; (iii) prioritisation of small scale natural and technical systems, which are flexible, cost-effective and require low operation and maintenance.

This Compendium of Technologies of the natural water systems and treatment technologies to cope with water shortages in India is an attempt of NaWaTech Team to identify appropriate water and wastewater treatment technologies most efficient and effective for the conditions prevalent in Indian subcontinent. The Compendium will be useful in designing and implementing the listed technologies in the field. Factsheets consist of technical, scientific, operational, financial aspects and relevance of implementation of the technologies in India compared to rest of the world. It would help decision makers to zero-in on the most appropriate technology based on site-specific requirements.

The Compendium of technologies will be a useful reference tool for various stakeholders such as builders, engineers, decision makers, water resources professionals, entrepreneurs and sociologists.

Contribution made by various experts in preparing the Compendium is gratefully acknowledged.

Dr. Satish R. Wate
Director, CSIR-NEERI, Nagpur, India

Foreword

NaWaTech proposes an integrated approach to tackle the Indian challenges in urban water management. This integrated approach comprises (i) interventions over the entire urban water cycle (considering wastewater and freshwater both as integrated part of water resources); (ii) optimisation of water use by reusing treated wastewater and preventing pollution of freshwater sources; (iii) prioritisation of small-scale natural and technical systems, which are flexible, cost-effective and require low operation and maintenance. The NaWaTech systems approach aims towards sustainable implementation with systems that are operated on a long-term. We therefore consider the whole water cycle as well as operation and maintenance from the very beginning.

In the NaWaTech Compendium we describe natural treatment systems and compact treatment options that cover the whole water cycle and have high potential to be successfully applied in India. We have compiled experiences on using these technologies from all over the world and from India. A NaWaTech system can be compiled using these technologies. Having a multi-barrier approach in mind, separated collection and treatment of waste streams facilitates achieving the required water quality for the reuse application.

With the NaWaTech compendium we hope that we can inspire practitioners to start thinking out of the box towards new integrated solutions and thus contributing to solve the Indian water and sanitation problems.

Dr. Günter Langergraber
Scientific Coordinator NaWaTech EU

Index

Abbreviations

Ø= diameter
Θ=Arrhenius temperature coefficient
€= Euro
ABR: Anaerobic Baffle Reactor
AEW: Aerated Engineered Wetland
AF: Anaerobic Filter
ASP: Activated Sludge Processes
BCM: Billion of cubic metre
BF: Bank Filtration
BMC: Bombay Municipal Corporation
BOD: Biochemical Oxygen Demand
BOOT: Build-Own-Operate-Transfer
CAA: Constitutional Amendment
CDM: Clean Development Mechanism
cm: centimetre
CGI: Corrugated Galvanised Iron
COD: Chemical Oxygen Demand
CPCB: Central Pollution Control Board
CPHEEO: Centre for Public Health and Environmental Engineering Organisation
CSE: Centre for Science and Environment
CWC:Central Water Commission
CWs: Constructed Wetlands
DEWATS: Decentralised Wastewater Treatment System
DWWM: Decentralised Wastewater Management
DWWS: Decentralised Wastewater System
EFB: Eco-Filtration Bank
FAB: Fluidised Aerated Bed
FAO: Food and Agriculture Organisation
FC: Faecal Coliform
f/M Food to microorganism ratio
FPU: Final Polishing Unit (pond)
FRB: French Constructed Wetland
FWS: Free Water Surface
GAP: Ganga Action Plan
GDP: Gross Domestic Product
GRIHA: Green Rating for Integrated Habitat Assessment
GoI: Government of India
GW: Ground Water
GWP: Global Water Partnership
h: hour
ha: hectare
HCW: Hybrid Constructed Wetland
HF: Horizontal Flow
HRT: Hydraulic Retention Time
HUASB: Hybrid Upflow Anaerobic Sludge Blanket
IGBC: Indian Green Building Council
inh: inhabitant
JNNURM: Jawaharlal Nehru Urban Renewal Mission
KSPCB: Karnataka State Pollution Control Board
km: kilometre
L: litre
LMC: Ludhiana Municipal Corporation
LPCD: litre per capita per day
m: metre
m^2: square metre
m^3: cubic metre
mm: millimetre
Mm^3: Million of cubic metre
MAR: Managed Aquifer Recharge
MBBR: Moving Bed Biofilm Reactor
MBR: Membrane Bio Reactors
MF: Microfiltration
mg: milligram
Mha: Million hectars
MLD: Million Litres per Day
MLSS: Mixed Liquor Suspended Solids
MoEF: Ministry of Environment and Forest on India
MoUD: Ministry of Urban Development of India
MPN: Most Probable Number
MRTP: Maharashtra Regional Town Planning Act
n.y.: no year mentioned
NaWaTech: Natural Water Technologies
NCWR: Non-Conventional Water Resources Programme
NF: Nano filtration
NRCD: National River Conservation Directorate
NUT: Nephelometric Turbidity Unit
NUSP: National Urban Sanitation Policy
OLR: Organic Loading Rate or Sludge feeding
O&M: Operation and Maintenance
PAH: Polynuclear Aromatic Hydrocarbons
PMC: Pune Municipal Corporation
PPCB: Punjab Pollution Control Board
PRI: Panchayati Raj Institutions
PVC: Plasticised Polyvinyl Chloride
RCC: Reinforced Cement Concrete
RO: Reverse osmosis
Rs.: Indian Rupees
RWH: Rainwater Harvesting
s: second
SAT: Soil Aquifer Treatment
SBR: Sequencing Batch Reactor
SDB: Sludge Drying Bed
SRC: Short Rotation Coppice
SRT: Solid Retention Time
SS: Suspended Solids
SSF: Sub-Surface Flow
SSWM: Sustainable Sanitation and Water Management
STP: Sewage Treatment Plant
t: ton
TKN: Total Kjeldahl nitrogen
TSS: Total Suspended Solids
UASB: Up-flow Anaerobic Sludge Blanket
UF: Ultra filtration
ULB: Urban Local Body
UN: United Nations
UNICEF: United Nations Children's Fund
USD: United State of America Dollars
UV: Ultraviolet Light
VF: Vertical Flow
VS: Volatile Solids
WHO: World Health Organisation
WSPs: Water Safety Plans
WSP: Waste Stabilisation Pond
WWTPs: Wastewater Treatment Plants
YAP: Yamuna Action Plan

Introduction

Providing adequate water supply and sanitation, particularly in urban areas, is a challenging task for governments throughout the world. This task is made even more difficult due to predicted dramatic global changes. Population growth, urbanisation, increasing industrialisation, climate change and a steep increase in water consumption are putting pressure on urban water resources. In order to cope with water shortages in urban areas, there is a need for a paradigm shift from conventional end-of-pipe water management to an integrated approach. This integrated approach should include several actions such as: (i) interventions over the entire urban water cycle (considering wastewater and freshwater both as integrated part of water resources); (ii) optimisation of water use by reusing wastewater and preventing pollution of freshwater source; (iii) prioritisation of small-scale natural and technical systems, which are flexible, cost-effective and require low operation and maintenance.

Natural water systems, such as manmade wetlands, sub-soil filtration and storage via soil aquifer treatment and bank filtration, are key technologies that make use of natural gifts for water purification and wastewater treatment. In addition, compact technical systems such as SBRs and MBRs have made a great progress in the last years. As of now, they can absorb highly and widely varying pollution loads, buffer seasonal fluctuations in the availability of water and can be integrated into the urban planning as green infrastructures. In Europe, these systems have been developed for many years and their potential for the application in developing and newly industrialised countries is widely accepted and encouraged. However, before these systems are merely transferred to places such as India, an indigenisation and adaptation process to the local conditions has to take place, considering different environmental conditions, such as climate, pollution loads, urban settings and socio-organisational issues.

Taking these facts into account, the project NaWaTech "Natural Water Systems and Treatment Technologies to cope with Water Shortages in Urbanised Areas in India" was created. This Indian-European research and development initiative aims to explore, assess and enhance the potential of natural and compact water and wastewater treatment systems in order to improve their performance and reliability to cope with water shortages in India. These systems shall realise the effective management of municipal water resources, water supply and sanitation services, and the municipal water cycle as a whole in urbanised areas of India. Separated collection and treatment of wastewater fractions shall thereby facilitate achieving the required water quality for the reuse application with the optimal technology. Having a systems approach in mind, all aspects of the urban water cycle are considered. Additionally, NaWaTech considers operation and maintenance from the beginning as key to ensure sustainable long-term operation of the systems.

The Compendium of NaWaTech Technologies is an effort to pinpoint and describe water and wastewater technologies that could enable the sustainable water management in Indian cities.

The first chapter presents a historical perspective of the water management in urban India, with a thorough description of the ancient and current practices. Furthermore, this chapter presents an explanation of the different locales that compose an Indian city, with its different characteristics, challenges and opportunities for the implementation of an optimised approach for water management. A complete description of the Environmental Policies, Frameworks and Guidelines focussing on water and wastewater management is found at the end of the first chapter.

The second chapter of the Compendium describes the NaWaTech approach, based on an optimised use of different urban water flows by treating each of these flows via a modular natural system, taking into account the different nature and degree of pollution and intended reuse.

Acknowledging the lack of a holistic approach in current water management practices, that considers water within a system rather than in single treatment units, the third chapter presents the "urban water cycle". This describes the different steps through which water flows in a human context, including source, purification, distribution, municipal use, wastewater collection, treatment and reuse/recycle. Understanding the urban water cycle and the different technologies to optimise each of its steps is of key importance to enable an improved management of water, and therefore the NaWaTech Compendium and the presentation of its selected technologies is based on the cycle approach.

Following this logic, the fourth Chapter presents a set of 23 technology factsheets describing the design and construction principles, operation and maintenance, costs, advantages and disadvantages of each separate technology within the cycle. Furthermore, each factsheet presents an overview of the application of each technology in Europe and other cities of the world with specific case studies that could be replicated in the Indian context. The experiences in Indian cities are also described at the end of each factsheet, indicating the maturity of the technology in the country as well as list of projects, which serves as reference for further implementation under the challenging conditions of Indian cities.

The fifth Chapter is a thinking-piece of the challenges confronted by practitioners when implementing a NaWaTech system, including social, administrative, financial and technical issues.

Chapter 6 illustrates the application of the Sustainability Criteria for the implementation of specific NaWaTech Technologies, developed by the NaWaTech consortium in a previous work package. This tool shall empower practitioners in the Indian Urban context to assess the sustainability of their concepts and individual technologies case-specifically.

The Compendium of NaWaTech Technologies is intended as a reference for water professionals in charge of planning, designing and implementing sustainable water systems in the Indian urban scenario, based on a decentralised approach. This does not aim to be an engineering manual for the detailed design and construction, and the objective of the NaWaTech consortium is to inspire practitioners, igniting the shift from the conventional end-of-pipe thinking to intelligent practices to come up with sustainable solutions to the water and sanitation crisis in urban India.

This piece of work is the result of a joint effort of the specialists of the NaWaTech consortium, including CSIR – National Environmental Engineering Research Institute (CSIR-NEERI), Technology Transfer Centre Bremerhaven (ttz Bremerhaven), Institute of Sanitary Engineering and Water Pollution Control of the University of Natural Resources and Life Sciences Vienna (BOKU University), GEMMA - Group of Environmental Engineering and Microbiology of the Universitat Politècnica de Catalunya·BarcelonaTech, Indian Water Works Association (IWWA), Pune Municipal Cooperation (PMC), Maharashtra Jeevan Pradhikaran (MJP), Shrishti Eco-Research Institute (SERI) and Ecosan Services Foundation (ESF), and the SMEs seecon international gmbh, Viraj Envirozing India Pvt. Limited (VEIPL), BioAzul S.L., IRIDRA S.R.L and Kre_Ta gbr.

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Chapter 1

Water Management in Urban India

Water Management in Urban India

Photo by Barreto Dillon 2012.

Varad Shende
Ecosan Services Foundation (ESF)

Introduction

The ever-expanding water demand driven by the world's growing population and economy, combined with the impacts of climate change, are already making water scarcity a stark reality in many parts of the world—and with it humanity is witnessing severe damage to livelihoods, human health and ecosystems. The callosity of the situation is severed most upon developing economies, which are lost in the 'growth and progress' paradox of urbanisation. For e.g. India, which is home to 16% of the world's population, has only 2.5% of the world's land area and 4% of the water resources (Ernst and Young, 2011). Hence, there is an urgent need for efficient water resource management through enhanced water use efficiency and wastewater recycling. Water crisis is particularly very severe in highly populated urban areas and it is going to be further aggravated with world becoming increasingly urban as pointed out by the World Commission Report on Environment and Sustainability by 2020 (Kodarkar, 2007). The following chapter presents an overview of the current water management in the urban Indian scenario. It begins with a historical perspective of water use through ancient times. Next the degrading pattern of urban infrastructure in India correlating the callous 'development' with the inability of the city to cope with the growing citizens' demands will be highlighted. Finally the various policies and legislations drafted by the State in this regard will be revealed to stress the need for an alternative approach to water management in urbanised India.

The Rich Wisdom of the Ancient Past – A Historical Perspective

Indigenous and Ingenious Water Harvesting...

Fig. 1.1 : The stone bunds erected at Dholavira (Harappa Civilisation) forming a reservoir to conserve rainwater. Source: [Accessed: 10.07.2013]. http://www.shunya.net/Pictures/WesternIndia/Gujarat/Dholavira/Dholavira03.jpg

From times immemorial, a great importance has been attached to water, which is clearly evident upon a glance through the water culture of ancient civilisations of Greek, Rome, Egypt and the Indus Valley. Focusing on the Indian sub-continent, a long history of urbanisation dating back to 3000 B.C. i.e. the Indus Valley Civilisation can be seen. One can note that water is an integral part of Hindu beliefs and customs and it is always given a sacred position in the centuries-old civilisation of India. The civilisations originated and flourished on the banks of the sacred rivers and the influence of the rivers is reflected in all aspects of life; in the hymns of the holy texts, epics and great works of Vedic scholars (Nair, 2004). An interesting case study was presented of 'Dholavira', a major site of the Indus Valley civilisation, dating back to the third millennium BC, which was discovered in the 1960s. "The city suffered from various issues; arid area (average annual rainfall of 260 mm), no perennial sources of water like lakes or rivers and brackish and saline subterranean water. Its inhabitants, therefore, collected the monsoon runoff flowing down the flanking streams of the Manhar and Mansar by raising stone bunds across them at suitable points to divert the flow of water into a series of reservoirs that were dug out in the sloping areas between the inner and outer walls of the Harappan city. Also a network of drains crisscrossing the citadel was laid out to collect rainwater, showing that water harvesting was clearly the way of life" (Narain, 2006).

Managing the Waste...

Ancient wisdom on wastewater management is potent enough to put many of today's water management architects to shame. Quoting Lofrano and Brown (2010) "The Indus Valley Civilisation was far advanced in wastewater management. A sophisticated and technologically advanced urban culture is evident there. Even, as early as 2500 BCE, Harappa and Mohenjo-Daro included the world's first urban sanitation systems as did the recently discovered Rakhigarhi as did the recently discovered Rakhigarhi (Webster, 1962). Houses were connected to drainage channels and wastewater was not permitted to flow directly to the street sewers without first undergoing some treatment. First, wastewater was passed through tapered terra-cotta pipes into a small sump. Solids settled and accumulated in the sump, while the liquids overflowed into drainage channels in the street when the sump was about 75% full. The drainage channels could be covered by bricks and cut stones, which likely were removed during maintenance and cleaning activities. This most likely was the first attempt at treatment on record".

Fig. 1.2 : Sanitary drain at Lothal, Indus Valley. The smoothened and joined brickwork made an intriguing yet efficient waste water treatment system discharging waste into the main sewer. Source: [Accessed: 10.07.2013]. http://www.sewerhistory.org/images/w/wam/loth_wam10.jpg

Towards a Community Managed Approach...

This ancient knowledge was carried forward, and at other times modified, but their use continued. However, the local community rather than the king was responsible for management and maintenance of these harvesting structures. In spite of a wide range of geographical and climatic diversity, from the Himalayas in the north to the arid deserts of Rajasthan in the west, in each and every nook, corner and community, distinct water harvesting methods were practiced. Some of these ingenious water harvesting and conservation techniques are mentioned below (adapted from CSE, n.y.):

Fig. 1.3:The Kund of Rajasthan. Source:[Accessed: 10.07.2013]. http://againsttheflowfilm.com/wp/wp-content/uploads/2011/12/Kundi-photo.jpg

- **Paar :** This was a common water harvesting practice in the western Rajasthan region, where the rainwater flows from the agar (catchment) and in the process percolates into the sandy soil. In order to access the rajani pani (percolated water) kuis or beris are dug in the agor (storage area, usually 5 m to 12 m deep). Normally 6 to10 of them are constructed in a paar.
- **Johads :** Small earthen check-dams capturing and conserving rainwater to improve percolation and groundwater recharge.
- **Kund :** Or kundi looks like an upturned cup nestling in a saucer. These structures harvest rainwater for drinking, and dot the sandier tracts of the Thar Desert in western Rajasthan and some areas in Gujarat. Essentially a circular underground well, kunds have a saucer-shaped catchment area that gently slopes towards the centre where the well is situated. A wire mesh across water-inlets prevents debris from falling into the well-pit. The sides of the well-pit are covered with (disinfectant) lime and ash. Most pits have a dome-shaped cover, or at least a lid, to protect the water. If need be, water can be drawn out with a bucket. The depth and diameter of kunds depend on their use (drinking, or domestic water requirements).
- **Ahar :** This is s a catchment basin embanked on three sides, the 'fourth' side being the natural gradient of land itself. Ahars were also used to grow a rabi (winter) crop after draining out the excess water that remained after kharif (summer) cultivation.
- **Bhandaras:** Check dams built across rivers. A traditional system found in Maharashtra, their presence raises the water level of the rivers so that it begins to flow into channels. They are also used to impound water and form a large reservoir. Where a bandhara was built across a small stream, the water supply would usually last for a few months after the rains.

Children of Rome or Children of Edo?

So, what happened to all these brilliant water management systems? For one, population explosion associated with urbanisation and growth of huge cities overreached the capacity of these ancient technologies pushing for end-of pipe solutions. Second, some practices followed in ancient times set precedents for the coming generations.

As Sunita Narain rightly concludes in 'A tale of two cities', - "The water culture of people is an important indicator of their level of civilisation. Take the two ancient cities, Rome and the town of Edo, which grew into the mega-metropolis of Tokyo. The people of Rome brought their drinking water with the help of long aqueducts, which today are regarded as architectural marvels of the bygone Roman civilisation. But the people of Rome lived on the banks of the river Tiber. They didn't need to bring water from afar. Unfortunately, they did not know to dispose of their human wastes and like the modern Western civilisation they ended up polluting the river, thus being forced to go far in search of clean water. This makes Roman aqueducts not a symbol of intelligence but one of great environmental stupidity. On the other hand, Edo, which too was situated on several streams, ensured that all its human wastes were collected and returned to the farmlands. Its neighbouring rivers remained clean and it tapped its water from them through an extensive piped water supply. But today we are all children of Rome and not Edo. We have turned our backs to our water-bodies and if we don't have money to clean our mess, then we will have nothing but polluted waters" (Narain, 2002).

The 18th Century Urban Water Management – Case Study of Pune
(Adapted from SGI, PMC, H_2O Pune, n.y.)

Tracing the evolution of water management in big Indian towns up to the British rule, the emulation of such principles is seen. A deeper focus on Pune (Poona), Maharashtra validates the point. Pune is known to have existed since the 9th century A.D, and is situated on the leeward side of the Sahyadri Mountain Range at the confluence of the Mula and Mutha rivers. However, in the 18th century, Pune became the political power centre of Indian subcontinent, since it was the seat of Peshwas (Maratha Empire's Prime Ministers). Thus, it gradually transformed itself into a large urban town and to accommodate for the increased urbanisation, Peshwas had to make certain important changes in the topography and herein traces of the brilliance of ancient water management wisdom are found. The Ambil Odha (rivulet) was dammed in 1755 creating a reservoir, which is today known as the famous 'Katraj Lake' located 10 km south of Pune city. Nanasaheb Peshwa developed an ingenious water supply system comprising huge ducts (earthen duct 8 km long) and underground tunnels originating from Katraj Lake to the historic Shaniwarwada Fort (Peshwa Palace) opening out at roughly 125 places as a series of water tanks (hauds) along the way. Some of these, such as the Kala Haud and the Nana Haud, are still functional i.e. receive water directly from the Katraj Lake even after 250 years! Importantly, during this urbanisation process environmental and aesthetic visions were not ignored. World-renowned architect and urban planner Christopher Benninger notes "A major stream, the Peshwa Nala, was rejoined with the Ambil Odha channel creating a chain of lotus ponds, cooling pools and pleasure gardens, employing dams and sluices along this network. The system was able to supply approximately 2.9 million litres of water per day to practically the whole of Pune, then without the need for motors and pipelines and the water was used for potable purposes and bathing". Today however, it is not potable due to pollution and sheer ignorance and lack of maintenance by the authorities. Reminiscent of the Roman planning, however, amongst these impressive aqueducts, "the only lacunae seems to have been the sewerage system that was ill-conceived, dumping human affluent into street-side gutters, all gathering into an appropriately named 'gandha-nala (bad water) channel, polluting the Mutha river! This seems to be the only lesson our city fathers have harvested from the past!" (Pune Mirror, 2010).

Fig. 1.4: The Hajari Karanje (thousand outlet fountain) in the historic ShaniwarWada Fort. This fountain received water through underground aqueducts directly from the Katraj Lake 10 km away.[Accessed: 10.07.2013]
Source:http://travelzunlimited.blogspot.in/2010/11/shanivar-wada-pune-photo-feature.html

British Rule to 21st century India...

"It is important to note that ancient Indian rulers rarely built water harvesting structures themselves. They instead created fiscal systems to encourage communities to build and manage water systems. This changed with the coming of the British rule into India. In their desire to rule, administer and maximise their revenues from this rich land, the British steadily changed the land and water tenure systems, which gradually but systematically lead to the destruction of community based resource management systems, bringing about a birth of the irrigation and public works bureaucracy" (Narain, 2006). Also Britain itself had faulty practices. "The principle employed was to assume 'the solution of pollution is dilution' of which the Bazalgette sewer system in London, 1865 is an example. Through a series of collection sewers and pumping stations wastewater was conveyed from the streets and discharged to the Thames River. There was no understanding of assimilative capacity in the river and no understanding of the need to remove pollutants prior to discharging to the river" (Lofrano and Brown, 2010).

In taking over the British precedent after independence, Indian local governments have completely ignored ancient wisdom and have forgotten to acknowledge that the conventional sewer system was developed at a time, in regions, and under environmental conditions where the priority was mainly to remove liquid wastes and dilute excreta from cities. Quoting Bracken et al. (2007), "Today with increased population pressure, changes in consumer habits and increasing pressure on freshwater and other resources, this human waste disposal system is no longer able to meet the pressing global needs. In the light of dwindling natural resources, there is a need to reassess the functioning of conventional sewage collection and treatment stems.

The motivation and inspiration behind end-of-pipe systems needs to be reassessed from a historical perspective and in the light of technological advances". The above conclusions, though stated in a different context, are very wise and can be equally applied to the urban Indian scenario and all that's going wrong with it.

'The India Story' - a Paradox...

India's Gross Domestic Product at purchasing power parity could overtake that of the United States by 2045. During the next four decades, Indian GDP is expected to grow at an annualised average of 8%, making it potentially the world's fastest-growing major economy until 2050 (PricewaterhouseCoopers, 2011). However, currently housing some of the richest billionaires in the world, India is also home to 400 million people who are living below poverty line, roughly 37% of its population and are poorer than the poorest people in Sub-Saharan Africa (BBC, 2010). This is clearly a paradox and in spite of giant leaps towards emerging as the one of the most sought after investment markets, India still has a lot of ground to cover on the provision of basic life necessities for the population. Some of the major problems faced currently in urban India which reflect upon concerns for the future are highlighted below:

The Urban Population Explosion...

India's population, according to the 2011 census, has been listed at a staggering 1.22 billion (approximately 17% of the world's population) and has added roughly 180 million people in the last decade (GoI, 2012c). Obviously, these overwhelming figures have had a profound effect on meeting global and national goals for water service provisions. Although, most of the countries, including India, are on track to achieve the Millennium Developmental Goals in 2015 for drinking water provisions, the goal focuses on 'access' to improved drinking water facility, without really evaluating the quality of the water and other parameters. Not surprisingly, a WHO report states that roughly 900,000 Indians die every year by drinking contaminated water or breathing polluted air. On the sanitation front, the 2012 Progress Report on Drinking water and Sanitation Joint Monitoring Programme of UNICEF & WHO commented on the global sanitation trends between 1990 and 2010 and noted that even today more than 50% of people in India, 814 million to be precise, lacked access to improved sanitation. Embarrassingly, 626 million of these Indians resort to open defecation, which accounts for 60% of the open defecation practiced in the whole world, making India a capital-of-sorts for open defecation (WHO/UNICEF, 2012). The global trend of urbanisation is discernible in India as well and to discard above statistics as a 'rural phenomenon' would be far away from reality since roughly 30% of the Indian population, corresponding to 377 million people live in urban areas (GoI, 2012c).

Fig. 1.5:Trains in Mumbai everyday carry a lot more people in risky manners than their capacity due to the huge population explosion and inadequate infrastructure.
Source:[Accessed: 10.07.2013]
http://unsettledcity.files.wordpress.com/2011/01/train-block-wr-may-2006-2.jpg

Pressure on Urban Infrastructure

There is tremendous pressure on civic infrastructure like water supply, sewerage and drainage, solid waste management and with a population growth rate of 31.8%, urban areas of Indian are already facing sanitation and water crisis. India today has 53 urban agglomerates each with 1 million plus population and the urban areas of India contribute to more than 60% of the GDP of the country. In spite of this, 7.87 % of urban households did not have access to latrines and therefore defecated in the open, 8.13% of urban households used community toilets and 19.49 % used shared latrines, according to the Census of 2001(GoI, 2012c). Also approximately 50% of population in India lives in unhygienic situations. Among the 370-odd million urban residents in India, 206 million (58.8 %) urban households do not have access to a drainage network, only 102 million (29 % of the urban population) are connected to septic tanks, and 60 million (17%) use pit or vault latrines. In general, it can be stated that more than 37% of the total human excreta generated in urban India is unsafely disposed and such type of unrestricted wastewater discharge into the open has resulted in contamination of 75 % of all surface water across India (MoUD, 2008). It has been found in a study that there is no Indian city that receives 24x7 (24 hours during the 7 days of the week) piped water and in most cities less than 50 % of the population has access to piped water, the report paints a grim picture of the deteriorating water supply situation. For instance, even the national Capital Delhi loses as much as 40-70 % of its water due to physical and financial leakages. Data suggests that water supply is available for 2.9 hours per day across cities and towns (India Water Review, 2012). Recently Bangalore topped the list of cities with maximum water losses and Pune's Superintendent Engineer agreed "Of the total water Pune Municipal Corporation received from the dams, 5% is lost during filtration process while 25% is lost due to leakage in the tanks and pipelines''. It is also reported that while the PMC claims it has installed flow meters at water treatment plants and knows exact amount of water it lifts from the dams, there are 60 tanks to store the processed water but only 15 have meters.

Such carelessness in attitude is one of India's major undoing (DNA India, 2012). "With around 102 million septic tanks and 60 million latrines (World Bank, 2010) and the projected improvement level to be achieved in sanitation sector of the country, it is intriguing to observe that India lacks national septage management guidelines/policies". Centre for Public Health and Environmental Engineering Organisation (CPHEEO) have published "guidelines for septic tank design, construction, installation and O&M but in practice the central, state and local governments fail to enforce these guidelines and requirements, like desludging at regular intervals. The overflow from the tanks finds its way into any nearest waterways or land surface and pollutes it. The effluent and sludge from septic tanks are often rich in phosphates and nitrates. The effluents lead to saturation of surface soil and water bodies with nutrients posing a threat of eutrophication to the surface waters. In the absence of any consolidated septage management practices, all these improved sanitation facilities will continue to degrade surface water bodies and groundwater resource. The state of services reflects the deterioration in the quality of city environments" (CSE, 2011). Water management is very intrinsically linked to overall functioning of the ecosystems including land, air, flora, fauna and thus failure of urban water infrastructure noted above has serious consequences on rest of the ecological parameters of the urban scenario as well.

Growth of a City – Pattern and Concerns.

Many issues associated with urban India are the rate of growth of the cities as well as the pattern of the growth. Traditionally India, being an agrarian economy, invested attention in the village as its core integral unit bypassing the needs of upcoming cities. However, in the wake of globalisation and free market, cities have seen swarming of hordes of people, since they offer to fulfil dreams of the youth from all around the country. According to Census 2011, the number of towns in India increased from 5,161 in 2001, to 7,935, and more than 90% of the increase was due to growth of 'census' towns, that is, growth in agglomerations in the urban peripheries and rural areas, which do not have any urban governance structures, such as municipalities or corporations. These towns do not have the required urban infrastructure in terms of housing, roads, water, sanitation etc. In this light, some typical territory expansion patterns are observed, which are in part responsible for the many of the water and sanitation issues the city faces. Described below are the typical locales of a city with an example of Pune, Maharashtra:

Fig. 1.6:The old city area of Pune called Tulshibaug. Note the prominence of shops overarching the roads as well as the housing societies in the background. Source: http://discoveringpune.com/tulshibaug-pune/. [Accessed: 10.07.2013]

- **Old city – Historical dwellings:** This is the origin of a city, the first settlements and dwellings. Usually, the birth of any civilisation starts with a water source i.e. a river. The essentials of a society like the market place, important political cultural locations, initial employment opportunities etc. are all concentrated in this small place. After exploiting this initial market, the city moves on to expansion of its territory and spreads to less dense lucrative locales. In case of Pune, the core part of the old city called 'Peths' constitute this cluster of the initial habitations developed along the Mula-Mutha river. From old historic buildings, close knit communities, market places and shopping streets, this represents an extremely dense and crowded locale. Although extremely dense, this part of the city houses ancient families and is thus the beholder of the city's historic past. The problem of overcrowding, lack of maintenance of centuries-old infrastructure (like the water ducts of Peshwa Pune discussed above), lack for space for deploying any new infrastructure based project, very low floor space index are some of the problems faced by this section of the city.
- **Newer settlements –The New Urban Middle Class:** This constitutes the area immediately outside the periphery of the city with wider streets, larger building complexes, a higher floor space index, new constructions, middle-class to affluent families, better water service provisions, etc. This part of the city houses individual societies and thus there is less community initiative at work. This locale can usually showcase small-scale individual projects, like rainwater harvesting for a single society.
- **New Townships – Mini Cities:** As the urban infrastructure of the city improves, more jobs are created and gradual expansion of the city takes place. Nearby locales, which were independent villages earlier, are acquired by the corporation and the space is used for building self-sufficient townships or micro cities. These townships are home to mostly the migratory population with well-placed jobs as well some native population from the interior of the city. Since the construction of such townships is a land intensive venture, it is ensured that they make every bid to be closer to the 'green building' parameters. Some salient features of such townships include use of solar panels and other energy reducing devices, water harvesting, green spaces and parks, water treatment on site through a STP, water reuse for gardening, flushing etc., together with a range of capacity-building and awareness raising initiatives related to the environment. Taking the case of Pune, various such townships like Magarpatta City, Nanded City, Amanora, among many others, have come up in the last few years within a radius of approximately 20-25 km from the core city.

- **Slums** : This is the worst outcome of unbundled urbanisation. The rapid growth of urban population is an outcome of huge migration of population, mostly from rural areas and small towns to big towns. Other reasons are inclusion of newer rural areas in the nearest urban settings and natural growth of urban population. Many of these migrants are illiterate and live hands-on with meagre earnings they receive. Thus, they end up only adding considerably to the population of poor people in the city. The recent population census results reveal that 80 million people out of the 370 million urban-dwellers are poor. Significant public health and environmental costs are imposed on them. The 42.6 million of people living in slums in cities and towns are forced to subsist in overcrowded conditions, often polluted and with a lacking of basic civic amenities like clean drinking water and sanitation facilities. In 2002 the percentage of notified and non-notified slums without latrines was 17 % and 51 % respectively (MoUD, 2008). A total of 54.7 % of urban slums have no toilet facility and most free community toilets built by state government or local bodies are rendered unusable because of the lack of maintenance (Barreto Dillon, 2013).

Fig. 1.7:Dense crowded unhygienic conditions of slum in the financial capital of India, Mumbai.
Source:[Accessed: 10.07.2013]
http://592f46.medialib.glogster.com/media/a32ee3808da5092638c0530c7a30ffc9f
419c807e5d637817d1adef3fa666af5/slum-mumbai1a.jpg

While the other locales represent opportunities for newer approaches of implementation of water infrastructure, the real cause of concern is the proliferation of the slums and living conditions of the urban poor. Along with health and environmental hazards, the growth of slums also account for institutional roadblocks. There is abundant water and energy theft since most slums do not have registered water and electricity connections. Usually, the number of persons per toilet seat in a slum might run into many hundreds and this lack of access to sanitation has huge sociological ramifications. To top this, entire slum communities are developed alongside rivers, pipelines, etc. and are responsible for pipeline damage and contamination causing additional burdens to the Urban Local Bodies.

Overuse and Contamination of Groundwater...

India is the largest user of groundwater in the world. It uses an estimated 230 km^3 of groundwater per year - over a quarter of the global total. As per a World Bank report (2010), groundwater use has been steadily increasing in India over the last 4-5 decades, and supports around 60 % of irrigated agriculture and more than 80 % of rural and urban water supplies. However, groundwater resources are being depleted at an alarming rate. As per assessment carried out by Central Ground Water Board in association with the State Ground Water organisations in 5723 groundwater assessment units (i.e. blocks, mandals, talukas etc), the number of over-exploited, critical and semi critical assessment units is roughly 29% per cent (over-exploited - 839, critical - 226, semi-critical – 550). To make matters worse, whatever water is present is at the risk of contamination and the situation is deteriorating rapidly. By 2025, an estimated 60 % of India's groundwater blocks will be in a critical condition (World Bank, 2010). Moreover, a 2003 survey of 1,000 locations in Kolkata found that 87% of water reservoirs serving residential buildings and 63% of taps had high levels of faecal contamination and presence of toxins like arsenic, a shocking revelation (Engel et al.,2011).

Growing concerns for the future...

In the future, Indian cities will play an even more critical role. According to a study carried out by the McKinsey Global Institute, urban India will generate 70% of new jobs created until 2030, produce around 70% of the country's GDP in 2030 and around 85% of total tax revenues. This incredible growth and the proliferation of employment opportunities will be a powerful magnet, increasing the urban population from 360 million in 2012 to 590 million in 2030, corresponding to 68 million-plus cities (Barreto Dillon, 2013).
But are the Indian cities equipped to handle such a massive exodus of population? An independent study notes, "by 2030, water demand in India will grow to almost 1.5 trillion m^3, driven by domestic demand for rice, wheat, and sugar for a growing population, a large proportion of which is moving toward a middle-class diet. Against this demand, India's current water supply is approximately 740 billion m^3. As a result, most of India's river basins could face severe deficit by 2030 unless concerted action is taken, with some of the most populous—including the Ganga, the Krishna, and the Indian portion of the Indus—facing the biggest absolute gap" (Addams et al., 2009). Indeed, another study by the World Business Council for Sustainable Development in 2005 projects India to be with over 40% fresh water stress by 2025 (Fry, 2006).

Currently, India has almost twice the number of people lacking in improved sanitation as compared to China and almost 50 times the number of people resorting to open defecation as compared to China (WHO/UNICEF, 2012). This fact is significant because the population of China is more than that of India. Therefore, pushing the entire onus of urban problems to increased population is not entirely accurate. Clearly faulty policies and / or lack of management and governance are responsible for the callous situation today and are issues of grave concern for the decades to come. If the current state of mismanaged development continues, a horrifying picture of un-liveable Indian cities is no longer a mere nightmare. Have the legislative and the executive tried hard enough to avert this disaster? What steps have been take at the legislative level in this regard? These and some other aspects of important policy making with respect to the water and sanitation sector are elucidated below:

Looking from the Top – Policies, Frameworks and Guidelines

Water and sanitation find place in the state list of the Seventh Schedule of the Constitution. Thus, each State manages and administrates water policy and its implementation individually, with the central government extending a more facilitating role and supporting financial activities through the Five Year Planning Process. There is a complex group of institutions at the national level and in every state with different responsibilities related to water and sanitation management.

The responsibility for water supply and sanitation at the central and state level is shared by various Ministries. At the central level three Ministries have responsibilities in the sector: The Ministry of Drinking Water and Sanitation is responsible for rural water supply and sanitation; the Ministry of Housing and Urban Poverty Alleviation and the Ministry of Urban Development share the responsibility for urban water supply and sanitation. States may give the responsibility to the Panchayati Raj Institutions (PRI) in rural areas or municipalities in urban areas, called Urban Local Bodies (ULB). At present, states generally plan, design and execute water supply schemes (and often operate them) through their State Departments (of Public Health Engineering or Rural Development Engineering) or State Water Boards. Discussed below are some of the crucial interventions at the policy level to help alleviate the urban water management mess through various legislations that have tried to improvise on the fault lines:

The 74th Constitutional Amendment (CAA, 1992) and the Jawaharlal Nehru Urban Renewal Mission (JNNURM 2005)

Realising that a very rigidly centralised approach was doing no good to provision of basic necessities to all it citizens, a landmark step in decentralisation and division of responsibilities was taken via the 74th Constitutional Amendment Act in 1992. This amendment increased the work jurisdiction of ULB's and gave them constitutionality. It requires the State Governments to amend their Municipal Laws in order to empower ULB's "with such powers and authority as may be necessary to enable them to function as institutions of self governance" and provides a basis for the State Legislatures to transfer various responsibilities to Municipalties and to strengthen municipal-level governance. Accordingly, several State Governments have amended their Municipal Laws by bringing them in conformity with the Constitutional provisions. Since water and sanitation provisions form an extremely crucial interface of urban governance, it was expected that this move would solve various issues related to urban water and sanitation infrastructure. However, while State Governments ratified the 74th CAA, they found it difficult to implement its provisions in totality, since functional devolution to ULBs has not been supported by adequate transfer of revenue sources. The ULB's financial autonomy has been undermined, as they have to seek State Government approval for enhancement in tax rates and user charges beyond the limits mentioned in Municipal Laws. To tackle this issue, a massive city-reorganisation and modernisation scheme called the Jawaharlal Nehru National Urban Renewal Mission was launched by the Government of India in 2005. Spanning over 7 years and costing 20 billion USD, it is today the flagship poster mission for most of the city developmental framework. The thrust of the JNNURM reform is to ensure improvement in urban governance and service delivery so that ULB's become financially sound and sustainable. Implementation of the 74th Constitutional Amendment is a mandatory reform to be carried out at State level under JNNURM and one of its sub-missions is to strengthen urban infrastructure with a focus on water supply and sanitation, solid waste management, road network, urban transport and redevelopment of old city areas (MoUD, 2011).

National Urban Sanitation Policy
(Adapted from MoUD, 2008)

Besides facilitating the financial aspect of governance, to realise its goals, the JNNURM formed an umbrella for implementation of various flagship missions seeking to fulfil the aims and aspirations of the urban population. With the aim of improving the sanitation situation in urban areas, the Government of India (GoI) sanctioned a policy paper prepared by the MoUD known as the National Urban Sanitation Policy (NUSP). This document outlines the following aspirational sanitation vision for Indian cities: "All Indian cities and towns should become totally sanitised, healthy and liveable and ensure and sustain good public health and environmental outcomes for all their citizens, with a special focus on hygienic and affordable sanitation facilities for the urban poor and women". The NUSP is a comprehensive framework that not only defines the specific goals to be attained, but also indicates how the GoI will be supporting the states in developing and implementing innovative strategies to accord priority to urban sanitation. In the NUSP, the GoI recognises that sanitation is a state subject and calls all State Governments in India to prepare State Level Sanitation Strategies and ULB's to prepare City Sanitation Plans.

Other Legislative Provisions and Authorities

(Adapted from Barreto Dillon, 2013)

Although the NUSP explicitly requires the ULB of a city to prepare the city sanitation plan and prepare water and sanitation strategies, there are various check points which the ULB's have to follow. Various statutory and parastatal bodies, as well as central legislations have been created, which provide the overall framework for the ULB's to act in. All the current legal provisions deal with diverse water, wastewater and sanitation services and have resulted in multiple bodies and jurisdictions in India. Some of these laying down specific norms standards and guidelines for water management of the country are:

- **The Water (Prevention and Control of Pollution) Act 1974; The Air (Prevention and Control of Pollution) Act, 1981:** Water and air pollution in India are regulated under these acts. The Water Act of 1974 made a constitutional provision for the formation of pollution control regulation boards, a need that was further strengthened by the legislative provisions of the Air Act 1981. As an outcome of the above legislations, the Central Pollution Control Board (CPCB) was established under the Ministry of Environment and Forest (MoEF) to control pollution in the country by generating relevant data, providing scientific information, rendering technical inputs for formation of national policies and programs and implementing various environmental legislations. The CPCB majorly plays a supervisory role with respect to actual implementation of the norms and standards, and it is the respective State Pollution Control Boards, who are responsible for the same. Under the act, the State Boards are provided with a wide range of powers from entry, inspection, emergency measures, etc. Each State Pollution Control Board has also set norms and standards for water and wastewater quality, which are in consonance with the national set of norms and everybody is required to adhere to the state norms or else invite penal strictures. Primary water quality criteria for designated best classes (for drinking water, outdoor bathing, propagation of wildlife and fisheries, irrigation and industrial cooling) have been developed by the Central Pollution Control Board. The major quality parameters focus on presence on coliforms in the water, the pH, quantity of dissolved oxygen, presence of various chemicals etc. among others (CPCB, n.y.). The drinking water standards have been set under the CPHEEO as recommended by the World Health Organisation. Also CPCB sets standards for quantity of service provision. For e.g., for domestic and non-domestic needs in cities with water supply pipes and sewerage system the municipalities must provide citizens with minimum 135 LPCD water.
- **The Environment Protection Act 1986:** The Environmental Protection Act was wider in its ambit. Under the act the central government is authorised to set new national standards for ambient quality of the environment and standards for controlling emissions and effluent discharges; to regulate industrial locations; to prescribe procedures for managing hazardous substances; to establish safeguard for preventing accidents; and to collect and disseminate information regarding environmental pollution. Schedule VI of the second amendment in 1993 lays down the national norms and standards for treated water quality with parameters like pH, turbidity, BOD, etc.
- **National Water Policy 2002:** To resolve the number of challenges that have emerged in development and management of water resources in India, the National Water Policy, laying guidelines on a range of topics under water management, was formulated in 1987. It was further revised in 2002 and includes guidelines on water resource planning, groundwater and drinking water quality, water zoning, conservation, public participation in water resource management, etc.
- **National Environmental Policy 2006:** Promotes conservation of national resources, protection of wildlife and ecosystems, prevention of pollution, reuse and recycling of wastewater, adoption of clean technology, application of 'polluter pay principle' and amendment in the existing law from criminal to civil suit provisions.
- **The Water (Prevention & Control of Pollution) Cess Act, 1977, as Amended:** Its aims include to charge cess on water consumption for polluting activities and to strengthen the Pollution Control Boards by providing financial support for equipment. Amendmentsin 1993 and 2003 included capacity building of technical personnel and promotion of water conservation by recycling.
- **Environmental Impact Assessment Notification:**The aim of the notification is to impose restrictions and prohibitions on the expansion and modernisation of any activity or new projects being undertaken in any part of India. This is done throughthis environmental clearance, accorded by the Central Government or the State Government.
- **Municipalities Act (e.g. Bombay Provincial Municipal Corporations Act):** Complete authority and jurisdiction over all urban amenities, including water Act or the Nagar Palika Act supply and sanitation with Municipality.
- **Town Planning Acts (e.g. Maharashtra Regional Town Planning Act, MRTP):** It gives the full jurisdiction to the ULB's to establish development and planning authorities having total jurisdiction on any developmental activity in the area.

Clearly providing 135 LPCD (and 200+ LPCD for metropolitan cities like Mumbai) to such an exorbitant population is no mean feat. Various problems associated with the so-called growth of a city like leakages, water theft, expansion into other territory and construction of new dams, loss of habitation etc. have been noted. In the above situation the city bodies have tried to use the various powers allotted to them for improving the water management crisis of urban India. Primarily they have, in different ways, tried to close the water and nutrient loop by adopting various measures ditching the end-of-pipe solutions.

Water Conservation Measures

The Ministry of Urban Affairs and Poverty Alleviation made Rainwater Harvesting (RWH) mandatory in all new buildings with a roof area of more than 100 m^2 and in all plots with an area of more than 1,000 m^2 that were being developed (Legislation on RWH, CSE 2013). Also a directive was issued to all the Urban Local Bodies for amending their building by-laws and making RWH mandatory under the JNNURM (Ministry of Urban Development, India). Accordingly in 2007, the BMC Mumbai made it compulsory for buildings with plot areas of 300 m^2 to have RWH system. Similarly 18 other cities like Chennai, Bangalore, Thrissur, Hyderabad, Pune and Nagpur have also made RWH mandatory for new constructions. Very recently, East Delhi has decided to join the bandwagon by making prerequisite for all households of 27m^2 or above (as against 84m^2 previously) to have water conservation facility (Deccan Herrald, 2013)

Groundwater Restrictions

The authority on groundwater regulations has been established by statute and is called The Central Ground Water Authority. Since water is a state subject, the Union Government has circulated a Model Bill to the States and Union Territories to enable them to enact suitable legislation for regulation and control of groundwater developments, which has been implemented by 11 states thus far. It has been divided into notified and non-notified areas and there are various norms and checks to regulate, control and manage groundwater abstraction and use especially for non-potable purposes. Considering the huge resource that rainwater provides, from time to time, the Government also launches various projects aimed at increasing the groundwater table by recharge. The latest in this sequence is the Master Plan for Artificial Recharge of groundwater in India, which also contains draft guidelines on measures to adopt for converting over-exploited blocks to safe blocks (CGWA, 2013).

Wastewater Treatment

The Environmental Impact Assessment Notification (2006) mentions all constructions with more than 20,000 m^2 area will need prior clearance permission, which includes an important component of wastewater treatment unit. To address shortfall in wastewater treatment, the Delhi Development Authority in March 2012 made it mandatory for any new group of housing, institutional and commercial building plans to have dual plumbing systems and a mini-sewage treatment plant within the premises. This initiative has been implemented in Karnataka with encouraging results.The Karnataka State Pollution Control Board (KSPCB) specifies that housing complexes that are in excess of 10,000 m^2 built up area or 50 flats need to have a sewage treatment plant on their premises and the flats should have dual plumbing. This allows the treated water to be put to non-human consumption use or secondary usage such as flushing, gardening, washing cars, etc. Along with this, KSPCB also stresses on rainwater harvesting in order to bolster the water table (The Pioneer, 2012). In 2011, Pune Municipal Corporation proposed a resolution to make mandatory for all constructions with more than 80 flats (new and old) to have an on-site wastewater treatment unit (TOI, 2011). Similarly, Jaipur too is in the process of initiating compulsory wastewater treatment units on site for all building complexes.

The Ganga Action Plan (2006)

The Ganga Action Plan of 1986 is one of the pioneer initiatives in India, which looked into implementing sanitation projects on a large scale. The main objective of this pollution abatement plan is to improve the water quality by interception, diversion and treatment of domestic sewage and toxic and industrial chemical wastes from identified grossly polluting units entering in to the River Ganga. The project implementation included infrastructure development with respect to network lines as well as treatment plants across five states of India focused on the towns situated in the banks of the River Ganga. Even after 27 years, the major targets envisioned by the project were not achieved. Most of the studies on these projects mention the lack of proper sewage collection streams as the major culprit. A number of STPs (sewage treatment plants) installed across the country are now running below their capacities. For instance out of the 17 STPs built in the city of Delhi, 7 have sewage inflow lesser than 50% of the capacity. According to the service level benchmarking assessment done by the Ministry of Urban Development across 28 cities, only 6 cities have marked coverage of sewerage collection networks above 75 % and the collection efficiency is above 75% only in 4 cities (MoUD, 2010). Hence, it is evident that the importance of appropriate sewer networks has to highlight in urban planning processes in order to receive benefits out of the sanitation projects.

Promoting ReuseApproaches

(Adapted from CSE, 2011)

In wake of the seriousness of the water crisis in India, as well as to substantially lift the pressure off groundwater abuse, many cities have started already implementing reuse solutions at the policy level. Since reuse of blackwater is a psychological hitch in many communities, mostly these interventions focus on greywater reuse. Some important landmarks in this respect are given below:

- **Delhi:** Govt. of India, by its notification made modification and additions in the building by-laws 1983 as under; Clause 22.4.2: All buildings having a minimum discharge of 10,000 litres and above per day shall incorporate a wastewater recycling system. The recycled water should be used for horticultural purposes. The above amendments have been endorsed by Municipal Corporation of Delhi and it is mandatory, if someone wishes to apply for water connection to the Delhi Water Board Authority they show proof of implementation of this recycling of wastewater.

- **Bengaluru :** Implementation of dual water supply system in all new layouts and apartment complexes has come up in the city. The builders of over 30 new apartment complexes coming up in and around the city have been asked to install dual lines for potable and recycled water for construction activities.
- **Rajkot:** In August 2009, the Corporation amended building by-laws, making mandatory the recycling and reuse of wastewater for the buildings. The use of potable domestic water for non-potable uses like car washing, gardening, construction purposes, landscaping, irrigation uses is forbidden by virtue of powers vested with government. Treated greywater is pumped to a separate tank on the roof, from where greywater will be supplied to toilets, garden taps, car washing taps, etc. This treated greywater may be used for groundwater recharge. Only water from toilets should be let in to sewerage.
- **Chennai:** The City Corporation Building's rules of June 2003 clearly mandated wastewater recycling. The amended rules state that only water from toilets must be the outlet to the sewer system. In case of ordinary buildings (ground-plus-one and residential buildings of four dwelling units), the greywater should be used for groundwater recharge after a simple organic filtration. In case of multi-stored apartments, recycled water should be used for toilet flushing.
- **Chandigarh:** The city had come out with by-laws on reuse of recycled water since 1990.

Good Policies, Bad Implementation?

It is clear that India is somehow trying to catch up lost ground. The above stated policy conglomeration clearly suggests a shift in the desire of the legislative to push for greener boundaries with respect to urban water and sanitation provisions. However, various loopholes in their implementation can be noted. The formal planning system has seen little change since independence, and most towns and cities rely on inflexible master plans, which are more often than not outdated by the time they are completed. Rigid development control norms, which are flouted at every step, and a weak governance system which can neither guide nor enforce, completes the sorry picture. Also, the number of policies, frameworks, agenciesand authorities working at both the State and Central levels create a muddle, since too many people are responsible and many fail to respond to accountability. Further key variables have prevented effective institutional development of the ULB's; inherent instrumentalities of the Constitutional Amendments, lack of will, apathy towards the life of its poor citizens, weak fiscal and management skills being chief amongst them. Merely applying for huge investments from the centre and state is failing. There is hardly any third party external audit to evaluate the efficiency of functioning of the ULB's. The ULB's across distinct sections and categories are plagued with similar inconsistencies like widespread corruption, lack of self-evaluatory mechanisms, an untrained and substantially inadequate workforce, lack of integrated planning and coordination between various co-acting subjects, etc. Although consumers bear the brunt of these inefficiencies, even the ULB's are not any better off themselves, as they are only able to recover 30-40 per cent of their operations and maintenance costs, leaving most to survive on Government (State / Central) subsidies to meet their O & M costs as well as capital investment. What emerges is a grim picture in dire need of rework. The ULB's must be made to see themselves as the smallest self-sufficient and very much accountable unit of citizen's right to basic provisions. However waiting for these critical issues faced by the institutional machinery to somehow be resolved on their own would be plain naive. In the meanwhile, it is very evident that a multi-disciplinary, decentralised, sectioned and community-involved approach is necessary if the water management crisis of urban India is to find a solution.

Final Remarks

Water conservation, treatment and reuse have a long history in India spanning a period of at least 5,000 years. Somewhere down the evolution course the Indian nation shifted from this course and adopted end-of pipe solutions. However it is evident, that such solutions are unfit for bearing the brunt of tremendous population explosion and associated problems of mass urbanisation. Although various policies have attempted to mellow the situation through introduction of various policies and enabling frameworks to arrest this deterioration, the Indian urban locale continues to be a picture of distress. Amongst other reasons, lack of inherent capacity of the governing municipal organisation is responsible for the ineffective implementation of such schemes. Clearly India needs alternative, integrated and a holistic approach, perhaps even multiple approaches. Maybe it is time to go back to basics, to ancient wisdom that worked so effectively and in consonance with the local communities. Surely demographics, climate patterns, hydrogeology of the continent, concepts and human behaviours have all changed. Therefore, blindly following former precedents would serve no purpose. But perhaps a revamped, remixed version of the community-led water management genius is what beckons India today.

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Chapter 2

The NaWaTech Approach

The NaWaTech Approach

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NaWaTech

Introduction

At present, urban settlements in developing countries are growing five times as fast as those in developed countries. As a consequence, today the urban population has exceeded the rural population of the world. In developing countries, urban population is predicted to grow from 1.9 billion in 2000 to 3.9 billion in 2030 (Brockerhoff, 2000). India is projected to become the most populated country by 2030, with an estimated population of 2.53 billion inhabitants (Census, 2001). About 30 % of India's people (almost 300 million) live in cities and towns generating over 60% of the country's GDP and 90% of government revenues (iGovernment, 2008). The rapid urbanisation and population growth and the lack of appropriate sanitation and wastewater treatment facilities result in water shortage, degradation of river, streams and aquifers and over exploitation of groundwater resources.

Fig. 2.1: Collapsed activated sludge wastewater treatment plant in Pandharpur, Maharashtra. Source: Barreto Dillon 2010

It has been demonstrated that the conventional approach to water management has serious inefficiencies, such as providing high quality drinking water for all domestic purposes, large piping systems difficult to construct and maintain, large quantities of drinking water to transport human excreta, dependency of extensive energy supply for advanced treatment system, production of large quantities of sludge and loss of useful elements with the sludge (e.g. phosphorus). It is thus clear that current models of urban water management and their corresponding infrastructure have already failed or are on the verge of collapse from the perspective of cost-efficiency, performance and sustainability.

In order to optimise the operation, and maintenance and technically cost-effectiveness of future urban water management systems, there must be a shift of paradigm from an approach with centralised mixed end-of-pipe solutions to the design of integrated urban systems. Such systems should optimise water use and reuse, minimise operation and maintenance and be flexible.

Natural Water Systems and Compact Treatment as Solution

Facing the challenges of future urban water management, natural water treatments show a high potential due to their flexibility and adaptability, cost-efficiency, and low requirements for building, operation and maintenance and energy supply. Natural treatment systems refer to systems that use natural capacities in soil and vegetation to absorb and retain water, and to take-up, transform, or otherwise treat pollutants in water.

Natural systems are much more convenient than the conventional wastewater plants during the operational phase, because they require less energy than conventional systems. Limited mechanical devices are used in these systems thus reducing the maintenance costs. In addition it was found that natural systems are generally efficient for the removal of most of pollutants. Finally and most importantly these systems are found to be very reliable even in extreme operating conditions. They can better absorb a variety of both hydraulic and pollution shocks and have the capability to adapt to new, different, or changing requirements, hence making them more robust and resilient systems.

Fig. 2.2: Natural system for managed stormwater collection, treatment and infiltration in Switzerland. Source: Heeb 2008

Natural treatments can be integrated in the urban scenario as flexible small-scale decentralised measures, such as infiltration devices or constructed wetlands for stormwater control and managed groundwater recharge. Thus, urban natural water treatment systems have a wide range of socio-economic and ecological services, including improved public amenity and health, flood retention capacity, groundwater recharge and drinking water supply.

In Europe, those systems have been developed for many years and their potential for the application in developing and newly-industrialised countries is widely accepted. However, the location of India and many developing and newly industrialised countries in warmer climatic zones sets different environmental conditions.

On the basis of a detailed inventory of natural treatment systems and compact treatment options, several promising axes have been identified:

- Wastewater and stormwater treatment and reuse for the managed aquifer recharge (MAR) (constructed wetland; SBRs & MBRs, soil aquifer treatment and aquifer storage and recovery);
- Stimulation of water retention and self-purification capacity of water resource via in-stream remediation using eco-hydrology principles;
- Improvement of surface water quality via bank filtration (lake or river bank filtration) for the generation (indirect) potable water; Secondary treatments for drinking water (sand filtration; membrane filtration; UV disinfection).

Previous experiences have shown that soil aquifer treatment (SAT) is a promising technology for the reclamation of stormwater and managed aquifer recharge. SAT technology involves infiltration of storm water or secondary effluent (pre-treated wastewater) through a recharge basin with subsequent extraction through recovery wells, and embodies both treatment, dominant in the vadose (unsaturated) zone, and storage within the saturated zone (aquifer) (Amy and Drewes, 2005). SAT in combination with both, advanced wastewater treatment system (e.g. activated sludge) or natural systems (e.g. constructed wetlands) has proven to be effective in many MAR sites (Reclaim Water, 2009; van den Hoven and Kazner, 2009). However, little is known about the parameters controlling them and implementing man made technologies for enhancing those attenuation processes is not yet a common practice.

Constructed wetlands (CWs) are low cost eco-technological wastewater treatment systems that in the past 30 years have been set up all over the world as an alternative to conventional mechanical intensive systems for the treatment of a wide range of wastewaters like municipal, industrial, urban run-off, leachate, agricultural, etc. CWs can remove a variety of substances (organic matter, nutrients, microbiological contamination, micro-pollutants, etc.) and have been used worldwide for a large number of applications (Ghermandi et al., 2007; Rousseau et al., 2008; Llorens et al.,2009; Seguí et al., 2009) including as a pre-treatment step before artificial recharge of groundwater bodies in China (Grosse et al., 1999; Perfler et al., 1999). They have been shown to be adapted in particular to urban areas for the small-scale decentralised treatment and storage of stormwater as well as the treatment of greywater or blackwater prior to SAT.

Fig. 2.3: Prototype of an integrated black water system UASB followed by a hybrid wetland in Barcelona, Spain. Source: UPC 2011

Bank filtration (BF) consists in the abstraction of water from aquifers that are hydraulically connected to a surface water body, which is in most cases a river system. It is based on percolation of the surface water through the ground into the aquifer enhanced by the pumping in drinking water wells close to the riverbank. During the percolation processes potential contaminants from the surface water are removed by filtration, adsorption, reduction and biodegradation (Chittaranjan et al., 2002; Tufenkij et al., 2002; Orlikowski et al.,2006). The capacity of self-purification depends mainly on flow velocity, hydraulic residence time and the covered distance determined by the permeability and the hydraulic potential in the aquifer. In Central Europe, BF has been a traditional, efficient and well-accepted method of surface water treatment for more than 100 years for public and industrial water supply (Grischek et al., 2002; Schmidt et al., 2003; Sharma and Amy, 2009).

Due to the easy implementation and little maintenance, an effective removal of pathogens, solids and toxins of algae from surface water can be achieved. Because of its capacity to buffer shock loads and extreme climatic conditions (i.e. floods and droughts), BF has been suggested to be a useful drinking water treatment for developing and newly-industrialised countries.

For India situated in tropical, semi-arid and arid climates zones, little is known about the performance, operation and maintenance of natural water treatment and infiltration system. Especially the higher temperature and organic solid load in the water is a parameter expected to substantially affect the sorption and biodegradation process in soil filtration systems due to lower oxygen content in the water and thus changing redox conditions.

Sequencing Batch Reactors (SBR) and Membrane Bioreactors (MBR) represent intensive water treatment systems that are able to effectively treat heavily contaminated water sources as stand-alone systems or in combination to the above mentioned natural, extensive systems. SBRs are a variation of the well-known activated sludge system where the natural degradation and conversion processes of water bodies are utilised. In contrast to the natural treatment systems presented above, SBR and MBR are designed to concentrate biological degradation on a small footprint enabling high performance by control of the different biological treatment processes. The advantages of SBR and MBR over natural systems like e.g. constructed wetlands lie in contrast to increased efforts that are required for operation. Beside investments in technical equipment the active aeration and filtration (in the case of MBR) result in higher energy demands, hindering the application for financial reasons or simply because of lack of power supply in many regions of the world. The maintenance of membranes (cleaning and replacement) also leads to increased costs and efforts. Last but not least, both systems require sufficiently trained personnel for operation and maintenance.

As reaction to the main shortcomings of these technologies, research and development has been concentrated on reduced energy demands and lower maintenance requirements. Especially when it comes to the applicability for developing countries, adaptation is needed for applicability. Low energy membranes, hydrostatic filtration and simplified reactor designs as well as the combination to anaerobic treatment have been successfully applied in various projects. Having the various water related problems of India in mind (rapid urbanisation, high population density, contamination of surface and wastewaters with various toxic compounds) the implementation of adapted SBR and MBR treatment (or combined as SMBR) is a vital part of the NaWaTech concept. For NaWaTech the potential application of SBR and MBR covers and wide range: from decentralised treatment systems to components of the recharge chain. The possible reason for their inclusion can be demand for water re-use at high quality requirements in the urban context, the improvement of the pre-treatment for BF or SAT or the targeted removal of trace contaminants (micro pollutants) that would pass the other stages. MBR systems have wide applicability for municipal and industrial wastewater treatment but also for agriculture, food production and even for potable water treatment. Hence, in the scope of NaWaTech SBR and MBR are seen as complementary components of the natural systems to enlarge the modular flexibility.

The NaWaTech Concept

NaWaTech stands for "Natural Water systems and treatment Technologies to cope with water shortages in urbanised areas in India". As an integrated approach, NaWaTech is based on the following axis:

- Interventions over the entire urban water cycle, which includes water sources, purification, distribution, use, collection, treatment and reuse.
- Optimisation of water use, by diminishing water use at home, reusing wastewater and preventing pollution of freshwater source;
- Prioritisation of small-scale natural and technical systems, which are flexible, cost-effective and require low operation and maintenance.

As shown in the Figure 2.4, the concept is based on optimised use of different urban water flows by treating each of these flows via a modular natural system taking into account the different nature and degree of pollution of the different water sources. Thus, it will cost-effectively improve the water quality of urban surface water and restore depleting groundwater sources.

Due to the multi-barrier approach, these systems are also able to treat heavily polluted water in order to reuse them and to supplement traditional sources to cope with water shortages today and in the future. The collected waters are treated in different steps by natural and technical processes at the surface or underground before they are reused to supply the urban population:

- Stormwater is collected and pre-treated in constructed wetland before being filtered through the soil and can be stored in the aquifer.
- Blackwater is treated anaerobically (producing energy and biogas) before being treated and collected in constructed wetlands together with or without the greywater. The effluent of these constructed wetlands will be either discharged to the surface water (if removal efficiency is satisfying) or reused for the urban agriculture or landscaping.

- Rainwater is collected on rooftops and either directly reused or fed into the aquifer.
- Surface water quality will be enhanced by in-stream and in-lake eco-hydrological systems prior to sub-surface passage and re extraction for the urban water supply.

In addition to that, a low-cost and viable post-treatment option could be used based on different steps (sand filtration, low-pressure membrane filtration or UV disinfection) depending on the required quality for service or potable water.

A NaWaTech system is integrated as green infrastructure into the urban scene providing additional socio-economic benefits including flood absorption and buffering of seasonal variability in the availability of water, recreational values for the urban population, space for animals and plants and improved air quality.

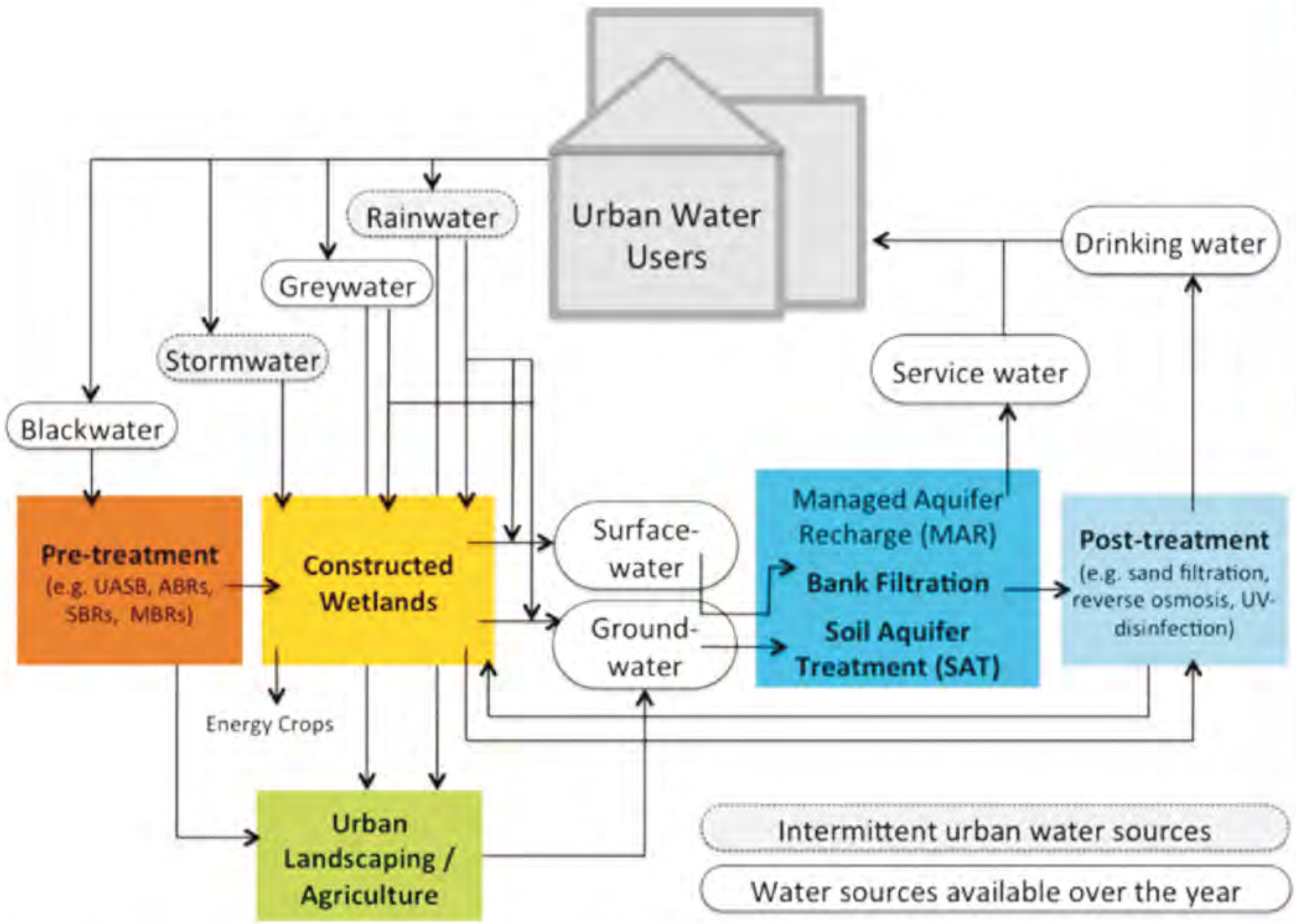

Fig. 2.4: The NaWaTech approach: every available water source is reused locally minimising the dependency from external freshwater sources and minimising the pollution of downstream water users.

This holistic approach minimises the urban water footprint and enhance the water security of the area, as the water cycle is closed at a local level. It also minimises the pollution of ecosystems and water sources for downstream users, as almost minimal amounts of freshwater get polluted and polluted water is treated and reused locally.

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Chapter 3

The Urban Water Cycle

The Urban Water Cycle


City of Mumbai, Maharashtra- India.Photo by Barreto Dillon 2012

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Introduction

The amount of water on earth is constant, travelling within the earth in a constant cycle through atmosphere, land and oceans. This global water cycle is significantly influenced by humans, as water is extracted, dams are built and kilometres of pipelines are constructed to meet the water requirements of a settlement. Particularly in urban areas the effects are immense, where more development and more concrete have severe consequences on the continuous process of evaporation, condensation, precipitation and infiltration of groundwater, producing the removal of natural vegetation drainage patterns, less evapotranspiration, less infiltration of rainwater and more run-off. Conventional urban water management practices try to meet water demands while conveying wastewater and stormwater away from urban settings. However, increasing scarcity and failures to meet the demands are changing the paradigm into systems with treated wastewater recycle and reuse. Therefore, the urban water cycle plays a key role in urban planning, as it aims for an innovative way of managing water within a city. This details the long journey of a drop of water from when it is collected for use in an urban community to when it is returned to the natural water cycle by reuse or recharge.

The 7 Steps of the Urban Water Cycle

The hydrological water cycle starts with precipitation, which reaches the land, where is taken up by plants and used by humans and animals. Part of the water evaporates to the atmosphere via evapotranspiration, other portion flows through riversto lakes and the sea and the rest infiltrates. Some of the precipitation is stored in the glaciers and after melting maintains fresh drinking water sources. Most of the water, after passing through different ecosystems, reaches the sea where it is again evaporated to continue the cycle. The sun is the ultimate energy source that keeps the water cycle working.

The urban water cycle can be thought as a small natural water cycle with artificial means of energy input and flow channels, but it is indeed also part of the natural water cycle. The urban water cycle starts with the abstraction of surface or groundwater, which is purified to render it potable for drinking water. Water is then transported to the points of use through a network of pipes and storage tanks. After used, the sewerage water is collected and transported through sewers, which also collect and transport rain and stormwater. Water then reaches the wastewater treatment plants, where the polluting substances are removed from the water to render it safe to be reused or discharged into the environment through recharge of natural aquifers.

The following sections describe thoroughly the 7 steps that compose the urban water cycle, as it is of critical importance to plan for water systems in urbanised areas with a holistic view of the water resources, taking into account each step and the various alternatives of both water inputs into and water outputs from urban catchments. Effective management of urban water needsa complete understanding of the impact of human activity on both the urban hydrological cycle – including its processes and interactions – and the environment itself. These human impacts, which vary broadly in time and space, need to be taken into account when defining strategies for an optimised urban water system, together with other environmental and socio-economic factors.

Water Sources

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Photos by Barreto Dillon 2012

Introduction

World's fresh water resources are facing increasing shortage, degradation and/or exploitation and efficient resource management becomes vital. This not only refers to the optimisation of water uses (e.g. through closing the water cycle), but also to the prevention of pollution of fresh water sources. Sound water resources management should consider the whole range of potential water sources (surface water, groundwater, harvested precipitation water or indirectly/directly reused storm- or wastewater (see Sub-Chapter Recharge), while keeping in mind the variety of final water uses (potable water, domestic and industrial service water, water for irrigation, water for urban landscaping, etc.). Ideally, development and management of water sources has to be linked and coordinated with those of land and land-related resources, building up a whole resource management structure as aspired in Integrated Urban Water Resources Management (Hassing et al., 2009). Ensuring the safety and applicability of water for the different uses is crucial – as poor management can pose tremendous risks to human health and the environment. Water Safety Plans (WSPs) can be used as risk management instrument encompassing all steps from source to consumer as proposed by Bartram et al. (2009). Depending on the source, resource access and extraction mode (and herewith also technological, socio-economical and infrastructural requirements) can vary significantly. Following a general overview on different kinds of sources and abstraction approaches below, selected NaWaTech approaches for water abstraction, namely (1) bank-filtration (2) rainwater harvesting and (3) retention basins will be described in more detail in subsequent factsheets. For describing general principles and processes below, contents of the Implementation tools for Water Sources of the SSWM Toolbox (Conradin et al., 2010) have been summarised. References beyond the SSWM contents have been are stated separately.

Principles and Processes

For getting an overview of principles and processes in relation to different water sources, it can be differentiated between surface water, groundwater and water obtained through harvesting precipitation. For each source, different technologies can be used for water extraction and, depending on source quality/quantity, evolving raw water qualities and quantities are varying. Also of high relevance in the context of water source management, are methods for artificial recharge of groundwater sources, which are described in more detail in Sub-Chapter Recharge and Reuse.

Category 1: Surface Water Sources

Conventional surface water sources are lakes, rivers and man-made reservoirs. However, although requiring huge purification efforts, even seawater can be used as surface water source. Typical processes taking an impact on availability and quality of surface water sources are precipitation on the one hand, and discharge, evaporation, evapotranspiration and subsurface seepage on the other hand. Inhibition of natural rehabilitation processes, deposition of waste, discharge of untreated waste water from domestic, industrial and agricultural uses as well as other point and non-point/diffuse pollutions pose severe risks to surface water sources and can result in critical pollution and eutrophication. Moreover, characteristic challenges in relation to surface water management are water use conflicts and over-extraction due to missing water allocation plans and inaccurate monitoring. Among the most commonly used surface water abstraction approaches are:

- **Abstraction from lakes and man-made reservoirs:** There are both natural lakes and man-made lakes ("reservoirs"). Reservoirs are artificial, usually formed by constructing a dam across a river or by diverting a part of the river flow and storing the water in a reservoir. Strong seasonal quality and quantity variations are characteristic for lake/reservoir water. When using lake water, it is essential that the amount of water extracted does not exceed the amount of water entering the lake.

Water abstraction can be based on simple (and temporary) means such as buckets, or may also rely on more sophisticated technology such as pumps (for transport into water trucks or to small-scale distribution networks) or even permanent water intake structures (for large scale extraction).

- **Abstraction from rivers or man-made canals:** Sediments and soil brought into rivers/canals through surface run-off (e.g. heavy rainfall) or (seasonal) changes in the river basin (e.g. snow melting) can have significant impact on river water quality and quantity. Extraction methods are similar to those of lakes, whereas location and design should protect against clogging and scouring and ensure the stability of the structure even under flood conditions.
- **Bank Filtration:** See factsheet on Bank Filtration (F3).
- **Sea-water abstraction:** Considering the fact that about 97% of the world's water resources are salt water (Gleick, 1993), the abstraction of sea water and subsequent desalination can represent another potential "water source", which can specifically become relevant in arid and coastal regions. However, high-energy consumption and investment costs as well as the production of highly concentrated salty water as a by-product are commonly named disadvantages.

Category 2: Groundwater Sources

Groundwater is water that is found underground in the cracks and spaces in soil, sand and rock (called "aquifer"). Aquifers typically consist of gravel, sand, sandstone, or fractured rock, like limestone. Groundwater flow velocity depends on the size of the spaces in the soil or rock and on how well the spaces are connected. The area where water fills the aquifer is called the saturated zone (or saturation zone). The top of this zone is called the water table. The groundwater table may be deep or shallow; and may rise or fall depending on many factors. Natural factors such as heavy rains or melting snow as well as artificial groundwater recharge can support the water table to rise. Heavy pumping of groundwater supplies on the other hand can cause the water table to fall. Groundwater not only represents about 31% of the world's fresh water sources (2.5% of total world's water) (Gleick, 1993), but also acts as long-term reservoir and buffer against shortages of surface water resources. While surface water sources and springs are directly exposed to human activities, groundwater sources are often protected through overlaying soil layers. However, when well digging/drilling is not done accurately, this might allow contaminants to enter the aquifer. Moreover, on the long-term, agricultural over-use can take a negative impact on the aquifer. Rehabilitation of contaminated aquifer is both costly and time-intensive. Over-use, seawater intrusion and severe pollution (e.g. with fluoride and arsenic) are some of the most prominent problems in groundwater management. Among common practices are:

- **Abstraction through springs:** Groundwater emerging from small water holes or wet spots ("springs" or "surface seepage") is one of the most easily accessible water sources, which in many cases can directly provide water of very high quality. Opportunities for spring tapping are limited to specific hydrological, geological and topographical conditions. Gravity springs occur in unconfined aquifers and can be prone to seasonal fluctuations as well as to contaminants entering the system from the surface. Artesian springs occur at confined aquifers and are characterised by large recharge areas, little to no seasonal fluctuations and the protection against contamination (by being covered with an impervious layer). Both kinds of springs require strict protection in the catchment zone and water quality monitoring.
- **Abstraction with dug-wells:** Hand-dug wells are the traditional and still most common method of obtaining groundwater in areas where the water table is rather close to the surface. A hole is excavated (mainly manually) until the groundwater level is reached. Depths of hand-dug wells range from shallow dug wells (about 5 m in depth) to deep dug wells (over 20 m in depth). Pumps or buckets can be used to extract inflowing groundwater. Although being a low-tech option, supervision and careful operation and maintenance are important especially in terms of accurate well protection. Capacity building on proper well management and community participation is essential. Moreover, rehabilitation of dug (or drilled) wells becomes necessary if operating wells fail to provide adequate water quality or quantity as the well becomes contaminated or clogged through natural processes or due to emergencies (e.g. floods, seawater intrusion, etc.). It involves the cleaning and disinfection of the well and sometimes the application of well development procedures. Eligible procedures range from very basic to quite sophisticated.
- **Abstraction through drilled wells:** A hole is drilled into a groundwater body and infiltrating water is then abstracted with the help of a pump. For wells ranging deeper than 50 m, manual drilling is generally no longer an option making mechanical drilling necessary. Technically, drilled wells can reach down to 200 m depth. Having a smaller diameter the yield of drilled wells can be smaller than those of dug-wells. Depending on the size (depth and diameter) and the hydrological conditions, drilled wells suit water supplies ranging from household use, small rural communities to urban areas with centralised supply systems ranging from simple to high-tech solutions. Even in case of low-tech variants, maintenance of the pump needs trained repairers and equipment. Similar as with dug-wells, well protection is vital. Strict attention has to be paid on the abstraction rate in order to prohibit over-use.
- **Conjunctive use:** This form of water abstraction combines the use of groundwater and surface water resources in two main usage phases, namely "recharge" and "recovery". During the recharge phase (when the water surface water level is high), the use of surface water is to be maximised and the recharge of groundwater can be enhanced artificially by surface and subsurface water recharge. During the recovery phase (dry season), water is drawn from groundwater resources. Conjunctive use requires appropriate management and coordination between all potential water users and therefore implementation is complex.

Category 3: Precipitation Harvesting

Precipitation harvesting refers to the controlled collection of precipitation (rain, fog, dew, snow, etc.) to complement water supply or supplement other sources when they are of low quality (e.g. brackish groundwater). It can range from simple low-tech variants requiring applicable on small-scale with only a minimum of specific expertise to more sophisticated systems at large-scale. Besides rainwater harvesting, this also refers to the use and storage of precipitation for agricultural uses. In general, harvesting systems encompass a catchment/collection area, a delivery system to drain collected water into a storage reservoir and an extraction or infiltration device (in case of groundwater recharge). Moreover, subsequent treatment might be necessary either before, during and/or after storage. Below are some examples of the most commonly used harvesting approaches:

- **Urban and Rural Rainwater Harvesting:** See factsheet on Rainwater Harvesting (F1)
- **Retention Basins:** see factsheet on Retention Basins (F2)
- **Bunds & Field Trenches:** These two approaches are among the most common techniques used in agriculture to collect surface run-off, increase water infiltration and prevent soil erosion. Their principles are comparably simple: by building bunds along the contour lines (bunds) or breaking the slope of the ground (field trenches), water runoff is slowed down, which leads to increased water infiltration and enhanced soil moisture.
- **Planting Pits:** For preventing water run-off, increasing infiltration and reducing erosion, holes are dug 50-100 cm apart from each other with a depth of 5-15 cm. Planting pits are most suitable on soil with low permeability, such as silt and clay and are applicable in semi-arid areas for annual and perennial crops.
- **Micro Basins:** Small pools are surrounded by stone walls and/or soil ridges on all sides to collect the rainwater and surface run-off. This allows storing rainwater and using it for small-scale tree and bush planting, enabling increased growth of plants if there is a moisture deficit.
- **Check Dams ("gully plugs"):** These structures are mainly built to prevent erosion and to settle sediments and pollutants. Furthermore, it is possible to keep soil moisture due to infiltration.
- **Controlled Drainage:** This approach is used for the reduction of short-term water related stress on plants, such as during flooding or drought.This method cannot supply enough water for longer water-scarce episodes and is therefore unsuitable for dry areas.
- **Sand Dams and Subsurface Dams:** A sand dam is a small dam built above ground and into the riverbed of a seasonal sand river. Sand accumulates upstream of the dam, resulting in additional groundwater storage capacity. Similar to sand dam, a subsurface dam obstructs the groundwater flow of an aquifer and stores water below ground level. Sand and subsurface dams are suitable for rural areas with semi-arid climate in order to store only seasonal available water to be used in dry periods for livestock, minor irrigation as well as for domestic use.
- **Fog Drip:** This is typically applied inarid and semiarid, rural regions for complementing other available water sources.As the wind blows the fog through specially designed nets (fog collectors), tiny droplets of condensed water form on the mesh. They are collected in a gutter and transported to a storage site.

Further Considerations

Source protection of surface water sources and ground water sources is recognised as the most suitable and cost-effective way to prevent the pollution of water sources and to limit (costly) purification measures to a minimum. However, due to the multiplicity of water users relying on one and the same resource, this can be a very complex task requiring the creation of an enabling environment including policies, a legal and institutional framework and its accurate enforcement. Moreover, availability of capacities and (human) resources in the community have to be ensured based on awareness raising, consideration of the economic setting and the creation of incentives. Water source assessments, water balance calculations and material flow analyses are tools within Integrated Urban Water Resources Management (Bartram et al., 2009), which can help to evaluate water and nutrient cycles in terms of their quality and quantity in order to better understand and manage resource dynamics. Permitting systems (in combination with allocation plans) can help to implement and monitor water allocation systems.

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Water Purification

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Photos by Barreto Dillon 2012

Introduction

Water purification is the major component ensuring the clean water supply to the population by treating the raw water from various sources, such as surface waters for large population and rainwater, stormwater and groundwater for households. Rivers, reservoirs, lakes and ponds are the major sources of water supply in cities and towns and open wells or tube wells (means aquifers) are the sources of water in rural India. Dams and reservoirs collect water from their catchments during the monsoon and store amply for the dry spells. Purification of such waters is critical when they are contaminated due to unscrupulous discharge of wastes emanating from rapid industrialisation, urbanisation and modern agriculture. Geogenic and anthropogenic chemo-biological contaminants can be treated by selecting technological solutions carefully to minimise the side effects of treatments. Rainwater harvesting in the urban settlements can be supplementary to tackle the water shortage problem where piped water supply cannot be provided sufficiently. Raw water quality available in India varies significantly depending on the geo-climatic conditions. In some regions of India, groundwater is contaminated with fluoride or arsenic, which need specialised treatment before use. In the piped water supply scheme, water distribution network plays vital role in the maintaining the quality of water. Lifeline supply of pure water in rural India is 40 LPCD (NRDWP, 2013), 135 LPCD for towns and cities with sewerage facilities and 150 LPCD for metro cities (CPHEEO, 2005).

Principles and Processes

Water resources are susceptible to contamination from the air, the ground, or from rocks and surface-sub-surface flows. Some of these contaminants, such as traces of certain elements, minerals or compounds, are not harmful to health, but others, such as pathogens, can be. Water quality must be acceptable and treatment methods suited to the community concerned. Community practices of good sanitation and hygiene increase the advantages of using improved water sources. Water quality issues such as high fluoride or arsenic or nitrates concentrations having serious health implications need advanced treatments, while turbidity is generally simple to deal with. Water treatment can be taken up at community or household level. Community water treatment systems are located at centralised locations to enable to provide safe drinking water to the household consumers. Water is termed as safe, potable if following some of the criteria are fulfilled (BIS, 2012):

Sr. No	Parameter	Concentration	Sr. No	Parameter	Concentration
1	pH	6.5 – 8.5	8	Iron, mg/L, Max.	0.3
2	Turbidity, NTU	1	9	Nitrates, mg/L, Max.	45
3	Total dissolved solids, mg/L, Max.	500	10	Total Kjeldahl Nitrogen, mg/L, Max.	1
4	Ammonia, mg/L, Max.	0.5	11	Phenolic compounds, mg/L, Max.	0.001
5	Anionic detergents, mg/L, Max.	0.2	12	Fluoride, mg/L, Max.	1
6	Calcium, mg/L, Max.	75	13	PAH, mg/L, Max.	0.001
7	Magnesium, mg/L, Max.	30	14	Thermotolerant coliforms, MPN/100 mL	Absent

There are many other parameters such as pesticides, heavy metals, radioactive substances to be treated depending on region-specific prevalence, occurrence in the water resources and their catchments.

Production of potable water (biologically and chemically safe water) is the primary purpose when designing water treatment plants adequately. Furthermore, these plants need to be operated skilfully with attention to the sanitary requirements of the source of supply and the distribution system. Ideally, the customer expects the followingcharacteristics of water: clear, colourless, pleasant taste, odourless, and cool temperature. Additionally, it should not be corrosive, or scale forming or staining. Consumers expect the desired quality of water delivered at the tap, not the quality at the community treatment plant. So, the utility operations should ensure that quality is not impaired during transmission, storage and distribution to the consumer, which means that the control point for the determination of water quality is the customer's tap. Storage and distribution system should prevent biological growths, corrosion, and contamination by cross-connections.

Treatment processes

The aim of water treatment processes is to remove contaminantsinwater or to reduce the concentration of such contaminants to make it fit for desired end-use. A conventional water treatment scheme consists of straining, aeration, chemical coagulation, flocculation, sedimentation, filtration and disinfection. Water treatment plants ensure their best feasible mechanism and operational status for appropriate drinking water production with least possible rejects and minimal routine management. Progression of treatment units in a water treatment plant mostly remains the same, i.e. having the principle objectives to remove turbidity and subsequently to kill pathogens. The first process in a water treatment plant is aeration to remove odoriferous gases and to oxidise some organic compounds. A coagulant (often alum) is thoroughly mixed with raw water. This water is then flocculated which enhances water-solid separation with rapid settlement. Flocculated water is then taken to sedimentation tanks / clarifiers for removal of flocs and from there to filters where remaining particles are removed. Filtered water is then disinfected and then stored in clear water reservoirs from where it is taken to water distribution system.

- **Micro-straining :** Removal of algae and plankton from the raw water sourced from natural water bodies like rivers and lakes or artificial like reservoirs.
- **Aeration :** Stripping and oxidation of taste and odour causing volatile organics and gases; oxidation of metals like iron and manganese.
- **Pre-oxidation and Mixing:** Use of oxidising agents to retard microbiological growth and destruction of colour imparting compounds.
- **Coagulation :** Use of coagulating agents (if water is highly alkaline then alum may used or if water is highly acidic then lime may be used) rapidly mixed in the water to facilitate destabilisation of colloidal solids and formation of pinhead floc.
- **Flocculation :** Aggregation of colloidal solids imparting turbidity and colour to the water leading the formation of settle-able flocs.
- **Sedimentation :** Gravity separation of suspended solids or flocs.
- **Filtration :** Removal of reminiscent particulate matter or flocs by passing through a single or multi-layered filter media.
- **Disinfection :** Destruction of disease causing microbes and multi-cellular organisms.
- **Softening :** Reduction of hardness of the water before use.

Treatment of Water

Water treatment processes usually combine a number of physical and chemical processes. Physical processes are dependent on gravity settling, aeration and filtration, where as chemical processes use coagulating or oxidizing chemical agents to enhance the performance of physical processes. Disinfection of water can be done by UV rays or using chemical disinfectants, such as chlorine or its compounds. This treatment is applicable to rainwater, stormwater, grey water, and treated water also. Extensive application of various processes can convert used water – wastewater into usable water again. Wastewater treatment can be divided into three – primary (which is mostly physical with or without chemical use), secondary treatment (mostly biological aerobic or anaerobic) and tertiary treatment to remove nutrients and microbial contaminants from the water to make it usable. This treatment is applicable to sewage and industrial effluents to make them recyclable for non-potable uses.

Conventional water sources such as dams and reservoirs and non-conventional water resources such as rainwater harvesting systems and storages are useful for centralised community water treatment-distribution system and decentralised household water purification respectively. Double piping or multiple collection or distribution piping systems can be adapted to keep the potable pure water separate from non-potable water used for toilet flushing, car washing, floor cleaning and watering the gardens depending on the quality of water required for desired use. Water sourcing from conventional or non-conventional resources and treatment can be optimised by reusing the treated wastewater for community green areas, urban agriculture and energy crops by facilitating equilibrium of urban water cycle.

The techniques/treatment units used for water treatment at household or community treatment plants are described as:

- **Microstrainer** is made up of a finely woven stainless-steel wire cloth (mesh-size 15 – 60 μm) mounted on a revolving drum somewhat submerged in the water. Water entering through an open end of the drum flows out through the screen, leaving suspended solids at the back.

Centrifugal force applied by the rotation of the drum acts on the bigger particles pushing them away from the screen thus preventing clogging and permitting substantially continuous operation. Microstrainers are used primarily to remove algae and plankton from the raw water sourced from rivers, lakes or rainwater harvesting storage ponds. Other mechanisms such as constant rate variable-head or immersed disc are used to avoid clogging of filter medium.

- Various types of **aerators** such as gravity, spray, diffuser, and mechanical are employed to remove the odoriferous substances and gases from the water. Gravity aerators require large area and may not be suitable for household water treatment. Spray aerators are not suitable unless the precaution is taken to avoid losses due to evaporation or wind carryover. Diffusers are suitable for both household and community water treatment plants. Mechanical aerators are energy intensive.Therefore the selection of aeration mechanism is based on the availability of land, uninterrupted electricity and wind kinetics.
- **Coagulation and Flocculation** is described as a physicochemical technique of blending or mixing (flash or rapid) of a coagulating chemical into a flow and then gently stirring the blended mixture to improve the particulate size and colloid reduction efficiency of the subsequent settling and or filtration processes. Various coagulating agents are used such as alum, lime, poly-electrolytes, sodium aluminosilicate to accelerate the settling of solids/flocs.
- In most conventional water treatments plants, the majority of the solids removal is accomplished by **sedimentation** as a means of reducing the load applied to the filters. Sedimentation basins are provided with inlet, settling, sludge storage or removal and outlet zones. Advanced mechanisms such as a centre feed clarifier, Spaulding Precipitator, Degremont Pulsator or tube settler techniques are used to improve the settling efficiency.
- **Filters** in water treatment are generally classified on the basis of filtration rate, driving force, direction of flow and filter media. Space footprint of slow filters (flow <10 $m^3/m^2/d$) is comparatively more than rapid and high-rate filters (flow 120-200 $m^3/m^2/d$). Backwashing of the filters is must, because of the clogging by solids. Community water filters are made up of sand, while household filters may have various types of membranes as filtration medium.
- Many a times, there are chances of presence of pathogens in water sourced from surface water. **Disinfection** of such waters using chlorination or ozonisation techniques is advantageous to curb the spread of epidemics of water-borne diseases. The concern about disinfection-by-products (DBP) is to be addressed while selecting the chemical agents. UV disinfection is also effective mechanism to eradicate pathogens from the water. In India, in most of the water treatment plants chlorination is used mostly as compared to ozonation and UV treatment for disinfection of water.
- After removal of suspended and biological contaminants, excess hardness should be removed by **softening** process. Some toxic components like fluoride and arsenic, mostly found in waters sourced from groundwater, are to be treated using specific chemical treatment having alum or lime one of the constituents for de-fluoridation or Nalgonda Technology. This technique can be also employed prior to sedimentation. Activated alumina is found to be useful in treating the water from hand pumps.

Other techniques that can be used **at the user point** are given below:

- If the water at the household tap is found with high turbidity, then it can be treated using **pinch of alum**. If there is doubt of bacterial contamination, then it can be treated with **hypochlorite solutions** available in the market. The other household technique of eliminating bacterial contamination is **boiling**. Some traditional techniques can also be used to purify water at the house such as the use of **drumstick powder** to remove turbidity and to some extent hardness, and the use of oscimum extract as disinfectant (Sundaramurthi et al., 2012).
- Small water treatment plants or household units can use various techniques such as **ion specific resins, membrane filtration, electro-dialysis, reverse osmosis and chemicals-materials** such as magnesia, fly ash, rare earth materials, bone char, tamarind gel and seeds, moringa powder etc. to remove fluoride, arsenic and other chemical contaminants of the water (NEERI, 2011).
- Use of **solar energy** to evaporate water and condense the same is a newly developing technique, which requires comparatively more area to yield clean water. Dew collection is also one of the options, where the surface and groundwater have high concentration of toxic contaminants and/or hardness and salts.

Some advanced techniques can be used to remove contaminants like nitrates, salinity and iron from the water which are listed below:

- Use of **strong anion exchange resins** charged with chloride, catalytic reduction, distillation, multi-effect distillation techniques is helpful in removing the contaminants from the water.
- **Vapour techniques** such thermal or mechanical compression, vertical tube, solar stills are found to be useful in desalination of salt waters.
- **Biological methods** such as biological nitrogen removal (BNR) using bacteria, phyto-filtration and wetland systems for absorption of nitrates and ecological disinfection of water are some attractive options.
- **Watershed management** is advanced ecological concept to procure clean water such as the world's largest unfiltered surface water supplies for New York City. This water supply system relies on a combination oftunnels, aqueducts and reservoirs to meet the daily needs of 8 million population (Strickland and Rush, 2013).

Further Considerations

Purification of water is a vital issue in controlling the outbreaks of diseases due to chemogens (chemical agents) or pathogens (biological agents). There are chances of contamination at every stage of collection, transmission, treatment, storage and distribution. Therefore, in addition to a centralised water purification unit, monitoring and correcting sub-units can be installed en-route in the distribution network after the storage tanks. Pure water lines can be kept separate from the sewerage lines or recycled lines to avoid any contamination.

Assurance of uninterrupted quality water supply is the need of the hour. Sourcing the water either from extra-urban or intra-urban surface or subsurface resources with watertight pipelines, low-energy high-efficacy of water treatment process, minimal loss in distribution network can be remotely controlled with programmed software to ensure timely and quality water supply at the tap of consumer. In the same manner, if the wastewater collection network is developed by minimising leakages and losses, this will be a prelude to recycling of treated wastewater for non-consumptive uses in the cities. This will be a close loop of water use and purification cycle in the community with natural resources for abstraction, transport, treatment, distribution and recycling facility.

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Water Distribution

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Introduction

A distribution system is composed by a storage reservoir and a pipe network that allows the transmission of treated water to the users. "The overall objective of a distribution system is to deliver wholesome water to the consumer at adequate residual pressure in sufficient quantity at convenient points and achieve continuity and maximum coverage at affordable cost" (CPHEEO, 2005). Because water distribution usually accounts for 40 to 70% of the capital cost of a water supply project, a proper design and layout is very important (CPHEEO, 1999). The basic requirements for the planning of the distribution system include functional requirements, such as geometrical considerations of pipes, and hydraulic requirements to maintain adequate residual pressure at the maximum demand (CPHEEO, 1999).

General Design Guidelines

Requirements of an Adequate Distribution System

A water distribution system is the physical works that deliver water from the water source to the intended end point or user. It is designed to deliver sufficient water quantity and quality to meet the requirements of the customer. Typically, this is achieved by way of pumps and motors, watermains, service pipes, storage tanks or reservoirs, and related equipment, in a closed system under pressure. The basic requirements of a system are (from Stauffer, 2011):

- Water quality should not deteriorate while in the distribution pipes.
- The system should be capable of supplying water to all the intended places with sufficient pressure head.
- It should be capable of supplying the requisite amount of water during fire fighting.
- The layout should be such that no consumer is without water supply, during the repair of any section of the system.
- All the distribution pipes should preferably be laid one metre from or above sewerlines.
- It should be fairly watertight to keep losses (e.g. due to leakage) to a minimum.

Parameters for the Design of Distribution Systems

In order to design a distribution system is important to know the following factors (adapted from CPHEEO, 1999):

- **Peak Factor:** When designing a water supply system it is not correct to take the per capita rate of water supply (135 LPCD in India) but to consider the fluctuation in consumption during the day. The hourly variation in consumption will indicate the different habits and customs of the population, for instance the cooking or bathing times. The peak factor for a population less than 50,000 is 3, which should be multiplied to the average rate of consumption.
- **Residual Pressure:** the distribution system should be designed for the following minimal residual pressure at ferrule points: single storey buildings 7 m, two storey buildings 12 m and three storey building 17 m.
- **Minimum PipeSize:** 100 mm is recommended for towns having a population up to 50,000 persons.
- **Layout:** the distribution layout should be such as to facilitate hydraulic isolation of sections, metering for assessment and control of leakage and wastage.

- **Elevation of Reservoir:** The staging height of the tank shall be such that, a minimum residual pressure of 12 m of water is maintained at the farthest/ highest point in the distribution system. The staging height of reservoir is normally kept at 15 m.
- **Location of Mains:** For roads wider than 25 m, the distribution pipes should be provided on both sides of the road, by running rider mains suitably linked with trunk mains.
- **Valves:** Sluice valves shall be located on at least three sides of every cross-junction and at every kilometer on long mains.

Planning and Design of Overhead Service Reservoirs

(Adapted from DWSSGP,2006)

The treated water shall be stored properly and then distributed through network of pipes by gravity. Elevated service reservoirs are the most commonly adopted structures for the above purpose, as they can be constructed at suitable locations. Furthermore, they allow for minimum interruptions of services caused by failures in pumps and help in reducing the size of the mains to meet the peak demands.

Parameters for the design of Overhead Service Reservoirs

Following are the parameters to be considered in design of such overhead water tanks.

- **Capacity and Location:** the capacity of the overhead tanks usually is calculated using the Mass Curve Method keeping in view the realistic availability of electricity and water supply hours.
- **Location:** The tank shall be located such that the minimum residual pressure at the remotest point is at least 12 m. If elevated lands are available at a reasonable distance, ground level reservoirs can be proposed for storage of water. If such location is not available, an elevated service reservoir can be proposed with staging such that it gives a minimum residual pressure of 12 m after counting for loss of head during peak hours due to simultaneous opening of the all the taps on the distribution system.
- **Structure and Shape:** The overhead water tanks should be made of Reinforced Concrete and can have shapes preferably circular type.

Design of Pipe Networks

Hydraulic Network Analysis

The hydraulic analysis of the pipe network is the building block for the design of a water distribution system and essentially involves the determination of the flow conditions associated with specified pipe sizes, the location and size of reservoirs and capacity of pumps (CPHEEO, 1999). The main requirement is to provide adequate residual pressure at maximum demand according to the hydraulic capacity of the system to ensure enough flow at the point of consumption. In order to carry out a hydraulic network analysis, a pipe network map corresponding to the road network should be prepared. The total length of pipe network is calculated and the estimated number of households for the design period is arrived at. From this data the households per running metre of network is calculated and hence the demand per running metre of the pipe network is calculated. The demand for each pipe section is arrived calculating from the end point as per the number of the households per running metre. The cumulative demand is calculated for each branch and for the trunk main. This demand is average demand, however, the network is to be designed for the peak flow. The pipe network is then analysed for the estimated demand using the suitable peak factor (adapted from DWSSGP, 2006). Several network modelling software packages are available for the designing of pipe networks.

Types of Pipes

(Adapted from Gur, 2011)

Pipes come in several types and sizes. They can be divided into three main categories: metallic pipes, cement pipes and plastic pipes. Metallic pipes include steel pipes, galvanised iron pipes and cast iron pipes. Cement pipes include concrete cement pipes and asbestos cement pipes. Plastic pipes include plasticised polyvinyl chloride (PVC) pipes. The type of material chosen for the pipes and accessories will determine the maintenance activities that will be needed, because of the typical diameters and its sensitivity to fouling and corrosion (Brikké and Bredero, 2003).

- **Steel Pipes:** These are comparatively expensive, but they are the strongest and most durable of all water supply pipes. They can withstand high water pressure, come in convenient (longer) lengths than most other pipes and thus incur lower installation/transportation costs. They can also be easily welded (Lee,n.y.).
- **Galvanised Steel or Iron Pipes:** Galvanised steel or iron is the traditional piping material in the plumbing industry for the conveyance of water and wastewater. Although still used throughout the world, its popularity is declining. The use of galvanised steel or iron as a conveyer for drinking wateris problematic where water flow is slow or static for periods of time because it causes rust from internal corrosion. Galvanised steel or iron piping may also give an unpalatable taste and smell to the water conveyed under corrosive conditions (WHO, 2006).
- **Cast Iron Pipes:** Cast iron pipes are quite stable and well suited for high water pressure. However, cast iron pipes are heavy, which makes them unsuitable for inaccessible places due to transportation problems.

In addition, due to their weight, they generally come in short lengths increasing costs for layout and jointing.

- **Concrete Cement and Asbestos Cement Pipes:** These are expensive but non-corrosive by nature. Their advantage is that they are extremely strong and durable. However, being bulky and heavy, they are harder and more costly to handle, install and transport (Lee,n.y.). Asbestos cement pipes are made with external diameters from 100 mm to over 1000 mm (Brikke and Bredero,2003).

- **Plasticised Polyvinyl Chloride (PVC) Pipes:** PVC pipes are non-corrosive, extremely light and thus easy to handle and transport. Still, they are strong and come in long lengths that lower installation/transportation costs (Lee,n.y.). However, they are prone to physical damage if exposed over ground and become brittle when exposed to ultraviolet light. In addition to the problems associated with the expansion and contraction of PVC, the material will soften and deform if exposed to temperatures over 65°C (WHO, 2006).

House Service Connections

The supply from the main pipeline to the individual houses is made through a house service connection. This consists of two parts (adapted from CPHEEO, 1999):

- **Communication pipe:** this runs from the street main to the boundary of the premises and is usually laid and maintained by the local authority at the cost of the owner of the premises. The water supply in a building system depends upon the intensity of pressure obtained in the street main and the hours of supply. A direct supply system will be possible only if the pressure near the premise is adequate to supply water for sufficient number of hours at the highest part of a building. This is recommended only if the number of floors in a building is not more than two. In cases, where the pressure in the street main is not sufficient to deliver water directly, the down-take supply system with ground level storage and boosting is adopted. In this case, separate overhead tanks should be provided for flushing and other domestic purposes. For the ground level storage, a capacity of 50 % of the daily requirement is taken. For overhead tanks directly receiving water from public mains, the capacity should take care of the total daily requirement.

- **Service pipe:** this runs inside the premises. Normally, galvanised iron pipes are used for service connections, because they have the advantage of low cost and high strength. However, they suffer from the disadvantage of short life in corrosive soils. Rigid PVC pipes, as well as high density polyethylene pipes are also coming into use, but they are damaged easily and soften at temperature above 65°C, and therefore cannot be used for hot water systems.

Further Considerations

Leakages generally occur at faulty pipe joints or when defects develop in the pipe bodies due to soil instability, corrosion of water pipes, traffic loading, poor quality of fittings and aging of components (adapted from Faure et al., 2011). These leaks, together with illegal connections, lack of metering and accounting errors, are the major component of water loss in developing countries. The longer the leakages remain unattended, the larger the economic loss suffered, as the wastage of water, energy and chemicals used for the purification step increases. Non-revenue water, which shows the difference between water produced and water reaching the consumption point, could reach 65 % in major Asian cities, having an average ration of 30 % (Mcintosh, 2003). In India, wastage from pipelines reaches 40 % (CPHEEO, 1999). In order to control leakages and preserve the quality of the distribution system, an entire programme for preventive maintenance and correct operation shall be developed within the service provider, strengthening the capacity of the staff and developing standard procedures for the correct assessment, detection and prevention of wastage of water from the pipeline system. "The objective of O&M of a distribution system is to achieve optimum utilisation of the installed capacity of the transmission system with minimum transmission losses and at minimum cost" (CPHEEO, 2005). O&M also allows preserving the hygienic quality of water and providing conditions for adequate flow through the pipelines. Key maintenance activities include (adapted from CPHEEO, 1999):

- **Waste Assessment and Leakage Detection:** a systematic waste and leakage survey and detection, followed by prompt corrective action is of importance in bringing about a reduction in the wastage. In residential areas with 24 hours supply is possible to assess the total wastage occurring when consumption is minimal, i.e. at midnight. The difference between the minimum night flow in the system and the accountable flow at midnight, divided by the average daily flow at midnight provides the percentage of waste in the area. Level of wastage upto 10 % may be considered as low, 10-20 % as average, 20-50 % as excessive and over 50 % as alarming. In intermittent supplies, only leakages related to water mains are assessed. This can be done in a zone by closing all the taps or by stopping the cocks in the house service connections. The waste survey procedure requires careful planning and preparatory work and a large amount of routine field survey and investigation. It consists on preparatory work (mapping of network, collecting statistics of connections, inspections and testing for isolation), waste assessment, leakage detection (only in areas with heavy leakages detected by visual determination on the surface, traversing the sub-zone in the night by sounding road or electronic leak locator) and correcting actions (prompt repairs of pipes and valves).

- **Cleaning of Pipes:** this is necessary because the carrying capacity of the pipes reduces due to growth of slimes, incrustations and deposits. Flushing with water at high velocity (90 to 120 cm/s) in one direction and letting it scape through a scour valve or hydrant can remove loose deposits of small size and microscopic biological growths.

Swabbing with a polyurethane foam of cylindrical shape of different diameters and a length of up to 60 cm sweeps out the loose and slimy layer adhering to the inside of the pipeline and the deposits carried away by the flowing water.

- **Protection against Pollution near Sewers and Drains:** a water main should be laid with at least 3 m separation, horizontally, from any existing or proposed drain or sewer line. In situation where water mains have to cross house sewers, storm drains or sanitary sewer, it should be laid at such an elevation that the bottom of the water main is 0.5 m above the top of the drain or sewer with the joints as remote from the sewer as possible.

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Water Use

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Photos by Barreto Dillon 2012

Introduction

Water is used in large amounts every day, serving different purposes. According to FAO and UN-Water, water use has been growing at more than twice the rate of population increase in the last century (UN-WATER, 2013). The use purpose will condition the selection of the water source and the treatment needed after use and collection. Human water use could be classified as agricultural use, domestic use and industrial use. With NaWaTech's focus on urbanised areas, this text concentrates in domestic use. In India, municipal water withdraw has increased 33 % from the year 2000 to 2010 (FAO, 2013). While the total population growth was 14 % between 2002 and 2011, urban population grew over 23 % (FAO, 2013), showing the importance and impact of water use management in urban areas.

The water use step will take place immediately after water distribution, and will be followed by collection and treatment. The same water can be used for many different purposes, there are many instruments that can lead to a more efficient water use. A combination of software and hardware tools is most adequate to achieve impact in efficiency. Hardware tools are devices such as low flush toilets, faucet aerators or leak detectors. Some examples of software tools are legal framework, media campaigns, water pricing or water restriction tools.

For describing general principles and processes below, contents of the Implementation Tools for Water Sources of the SSWM Toolbox (Conradin et al., 2010) have been summarised. These instruments are presented with more detail in the following sections.

Principles and Processes

Depending on the use, water with different qualities will be needed. This will condition the water source and/or the purification technology that can be used: for example, water for agricultural use can have an organic load that would be unacceptable for drinking purposes. The same applies to the wastewater generated: different uses will produce wastewater with different characteristics, and this will revert on different wastewater treatment needs. However, there is one common aspect of water use, whatever application: the fact that it should be minimised. It is estimated that by 2025, two-thirds of the world population could be under stress conditions caused by water scarcity (IFAD, 2013). Water use optimisation and management is critical to reduce the pressure on water resources and guarantee a safe and equal access.

In this chapter, some tools that can help reducing domestic water use will be described.

Hardware Tools

Hardware tools for water use minimisation are physical solutions that allow reducing water consumption. New technologies are coming to the market every year, but some well-proven options are described below:

- **Low flush toilets:** Toilets are by far the main source of water use in the home, with up to 30% of domestic water consumption (EPA, 2013). Low flush toilets typically use around 6 litre per flush. While there has been some debate on the ability of low flush toilets to totally empty the bowl (U.S. Green Building Council 2011 and Stauffer 2013) efficiency has improved dramatically since the 90´s.
- **Double flush toilets:** These are a variation of the flush toilets that uses two buttons or handles two flush different levels of water. Designed for light and heavy flushes, these toilets typically operate with a handle that can move up or down, or a two-button system. One direction or button will activate the lower flow flush, while the other will activate the higher flow flush.

- **Low flow faucet aerators:** Installing low-flow faucet aerators on faucets is one of the easiest and least expensive ways to save on both energy and water costs. They reduce the flow of water from the faucet without reducing the pressure.
- **Leak detectors:** such as the sonic leak-detection equipment, which identifies the sound of water escaping a pipe. They can include pinpoint listening devices that make contact with valves and hydrants, and geophones that listen directly on the ground. In addition, correlator devices can listen at two points simultaneously to pinpoint the exact location of a leak.

Software Tools

Software tools are instruments and set-ups which aim to change behaviour and attitudes from different actors involved (Conradin et al., 2010). Many software tools can be implemented to foster a more efficient water used, a few examples are presented below (from www.sswm.info):

- **Legal framework:** The legal framework is a powerful and crucial tool to support sanitation and water management on the local level, necessarily going hand in hand with the formulation or change of policies that guarantee access to safe drinking water.
- **Media campaigns:** There is a multitude of information published on water use. However, this information does not trickle down to all citizens, enabling them to step up. People receive information best when it is presented in a format that they can understand. Thus, a well-planned media campaign is an effective way to raise awareness and motivate change.
- **Water pricing:** Water tariffs are economic instruments that help tackling both challenges of providing water and to all citizens at an affordable price and the conservation of water resources. Proper water tariffs provide incentives to improve sustainable water and sanitation services and to use water resources more efficiently.
- **Water restriction:** Restrictions, rationing or full prohibitions are legal prescriptions that have a direct impact on the range of opened options, as they constrain/exclude certain ways of acting. They are tools that should only be used in combination with other measures: awareness raising, implementation of water-saving technologies etc. It is a tool to be used in situations of water scarcity, but does not guarantee a sustainable use of water in the long run.

Further Considerations

Water use is a fundamental step on the urban water cycle. Water is used for drinking, washing, cleaning, cooking, and growing food as well as many, many other things. The UN suggests that each person needs 20-50 litres of water a day to ensure their basic needs. It is critical that all key actors join forces to guarantee general access to safe water, in adequate quality for each use, and to use it in a rational and environmentally conscious way. Every measure taken to save water will contribute to reduce the pressure on natural resources and guarantee general access. A stable and well-defined legal framework is the first step to guarantee both the access in quantity and quality of water by the users, and an adequate treatment after use. Awareness rising amongst the users on the consequences of an inadequate water use, as well as available technologies and practices is also a key step for water use optimisation.

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Wastewater Collection

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Photos by Barreto Dillon 2013 and 2010

Introduction

A system of pipes used to collect and carry stormwater, wastewater and trade waste away for treatment and disposal is called the sewerage or the wastewater system (Nidirect, n.y.) The CPHEEO Manual on Sewerage and Sewage Treatment (2012) highlights the role of sewer systems as:

- Improvement in the environment by removing the sewage as it originates
- Preventing inundation of low lying areas that may be otherwise caused by not sewering
- Prevention of vector propagation by sluggish sewage stagnations
- Avoiding cross connections with fresh water sources by seepage

In cities classical sewer systems are laid down with cement concrete pipes below the surface of the road so as to avoid minimum interactions with the fresh water streams. However, the contemporary designs are more focussed towards building small networks and thereby avoiding big diameters of pipes used, avoiding infiltration and exfiltration effects on to the wastewater streams and also avoiding the below road position in order to avoid deep excavations (Mara, 1996).

Design Principles

The major parameters to be considered in designing sewer networks are the population served, population density and water consumption. The design period for conventional sewers is taken as 30 years, while the non-conventional ones should be designed for 15 years only (CPHEEO, 2012).

- **Flow:** theoretically, 100 % of the water supplied should get into the sewerage systems but due to physical conditions and consumption dynamics, it is often suggested to consider 90% of the per capita water supply. In dry and arid regions it can go to as low as 40%. Flow calculations are based upon the supply estimates released by CPHEEO equal to 135 LPCD for households.
- **Storm Runoff:** Even though the sanitary sewers are not expected to handle storm water, in locations where there is frequent rainfall, storm water flows are often considered in conventional sewer networks.
- **Industrial Effluents:** According to the local Pollution Control Board norm, the industrial effluents are not allowed to enter the sewer systems without treatment. Also, most of the Urban Local Bodies encourage and implement norms promoting reuse of treated water in a zero liquid discharge fashion. But in cities where uncontrolled growth has been observed, there can be multiple pockets where industrial effluents enter the sewer systems.

Technologies for Wastewater Collection

The sewer systems are designed based on the needs, available resources and physical conditions of the towns. There are many types of systems, some of which are listed below (adapted from CPHEEO, 2012 and Conradin et al., 2010):

- **Separate Sewers:** This system includes two separate lines: one for stormwater and another for domestic sewage and treated industrial sewage. The line for domestic wastewater is called as the foul sewer and the other is referred to as the storm sewer. The existing infrastructure in most of the cities uses these systems.
- **Combined Sewers:** Sewers that receive both storm water and the wastewater are referred as combined sewers. These are proffered in areas, which receive rainfall throughout the year as in other places this system will have variable flow velocities and water quality. These sewers are also ideally suited for resorts and private development.
- **Pressurised Sewers:** Pressure sewers are integral parts of conventional sewer systems. In undulating terrain and in areas where there is high water tables, it is often difficult to guide the flow by gravity sewage from establishments in the vicinity. Therefore, the sewage is collected in a basin fitted with submersible pump to lift and inject the sewage to a sewer on the shoulder of the roadway thus sparing the riding surface from the infamous digging for initial construction and repairs.
- **Vacuum Sewer System:** In vacuum sewer systems the conveyance is facilitated by vacuum maintained at the receiving end. A collection unit is installed for every house or for a small community, which is connected to the vacuum lines. The vacuum lines are opened at regular intervals to suck out the collected wastewater to the central connection units. The conveyance line of this system includes small diameter pipes and these can be laid just below the surface on road shoulders or pavements. The major disadvantage of such systems is the need of unfailing power supply.
- **Solids-free system:** A variant of the conventional systems, solids free systems are constructed to carry only the liquid components of the wastewater by gravity or pressurised systems. Every house or community is connected to a septic tank, which prevents the inflow of solids into the system. Solids–free systems also use low diameter pipes and can hence save a lot on the construction costs. But the system needs proper management to ensure timely maintenance of the interceptor tanks.
- **Condominial Sewer:** Simplified or condominial sewers are flexible, low cost designs, which are built along private lands or road shoulders ensuring shortest possible connection lengths and avoiding the design considerations needed for bearing traffic loads. These systems use conveyance lines of moderate diameters laid down at shallow depths at a flat gradient. These systems are best when designed for small communities and maintained by them.

Additionally, every network system has house connection components, manholes and junctions. These accessories are essential to ensure proper flow to the systems and for carrying out required operation and maintenance when it is required. The designs principles of these accessories vary with respect to the type of the network system selected but as these accessories are very high in number in every network, simplicity and robustness needs to be ensured.

While in the developing world new systems have to be built,sewer systems in developed countries are ageing. Water infrastructure is one of the most valuable assets held by cities and communities in developed countries around the world. Sewer-related assets typically comprise more than 60% of all water-related assets. Therefore the long-term conservation of this vast asset for future generations should be mandatory for communities. The means to finance the costs of replacement should be available out of the income from charges, but the actual cost of rehabilitation in most European cities presumes a disproportionate expected service life for sewers. However, all rehabilitation strategies and the models that support them depend greatly on the quality of structural sewer data and on the results of on-site inspections. Quality management, including optimised training of the personnel, is indispensable in carrying out the inspection programmes that deliver the basic information needed for rehabilitation activities (Ertl, 2006).

Final Remarks

Though wastewater collection systems play a vital role in the water cycle it is often found that it has been neglected in the planning process in many towns of India. This is evident from the service level benchmarking done in the major cities of the country. Looking at the density and the rate of urbanisation, India needs simple, low cost and robust network systems, which are tailor-made for the cities depending on the existing conditions prevalent there. Future implementations must be done with proper planning and strict quality control to ensure low operation and maintenance demands.

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Wastewater Treatment

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Photos by Barreto Dillon 2013 and 2010

Introduction

In the water cycle, perhaps sewage management is the most challenging and promising component that gives the opportunity to complete the water cycle and conserve the fresh water resources. It becomes more relevant when sewage management is carried out using ecologically sound treatment systems in order to achieve sustainable development. Before sewage management it is targeted, it is important to discuss first the composition of sewage, which comprises of black and grey water. Wastewater originating from toilet flushing is called as "black water" and the one generated from all other domestic applications viz. washing, cleaning, and bathing is referred to as "grey water". If black and grey waters are separated, the job becomes much easier. However, on large scale it looks impractical to separate the black and grey waters owing to financial, administrative and operational and many other difficulties. Therefore, in this article issues related to sewage management are discussed, which includes both black and grey waters.

Why Treat Wastewater?

According to the estimates of CPCB Delhi, about 38,000 MLD of sewage is generated in India (CPCB, 2009) of which only 35 % is treated, mostly up to secondary stage. Inadequate sewage management and sanitation cause significant damage to public health and urban environment and sizeable loss to the country's GDP. Incessant discharge of untreated sewage into water bodies has resulted in contamination of 75 % of all surface water across India (CPHEEO, 2012). Water pollution poses costly threats to the ecology, to aquatic life, and the fishing industry. Most importantly, pollution of freshwater bodies is inextricably linked to growing water scarcity, as polluted water is more expensive and unsafe to use directly (Hingorani, 2011). It has been envisaged that if the sewage generated in urban and semi-urban areas is adequately treated and reused for non-potable purposes (including gardening, toilet flushing, car washing, agriculture, industry, etc.) the demand on fresh water supply would be reduced substantially.

Principles and Processes

The type of treatment process to be implemented remains at the forefront of all the challenges since a large number of technology options are available for sewage treatment. The sole objective of any treatment option is to maximise benefits by incurring minimum cost. This is mainly based on factors such as economics of treatment, technical and administrative suitability. The technological option to be implemented depends on the site-specific conditions and can be selected using different criteria (see Chapter 6 for the NaWaTech Sustainability Criteria). Some of the prevalent treatment processes for wastewater treatment are discussed below:

- **Physical Processes:** Impurities that are removed physically by screening, sedimentation, filtration, flotation, absorption or adsorption or both and centrifugation.
- **Chemical Processes:** Impurities that are removed chemically through coagulation, absorption, oxidation-reduction, disinfection and ion-exchange.
- **Biological Processes:** Pollutants that are removed using biological mechanisms, such as aerobic treatment, anaerobic treatment and photosynthetic process (oxidation pond) (UNEP, 2004).

Primary Treatment Options for Sewage Treatment

- **Screens, Grease Traps and Grit Chambers:** They remove solids and grease and are beneficial for wastewater from households, canteens and certain industries. Short retention times prevent the settling of biodegradable solids. Grit and grease must be removed frequently (BORDA, 2011).
- **Septic Tanks:** This is a water-tight, covered receptacle for treatment of sewage. It receives the discharge of sewage from a building, separates settable and floating solids from the liquid, digests organic matter by anaerobic bacterial action, stores digested solids through a period of detention, allows clarified liquids to discharge for additional treatment and finally disperses and attenuates flows (CIDWT, 2009).
- **Imhoff Tanks:** It is a two-stage anaerobic system, where the sludge is digested in a separate compartment and is not mixed with incoming sewage. It is a compact and efficient communal system for pre-treatment of municipal wastewater from 500 up to 20,000 habitants. It removes about 30-40% of the organic matter of the raw wastewater (Hoffman et al., 2011).
- **Anaerobic Baffle Reactors:** They function as multi-chamber septic tanks. They increase biological degradation by forcing the wastewater through active sludge beneath chamber-separating baffles. All baffled reactors are most appropriate for wastewater with a high percentage of non-settable suspended solids and narrow COD/BOD ratio (BORDA, 2009). More information in factsheet F6.
- **Anaerobic Filters:** They combine mechanical solids-removal with digestion of dissolved organics. By providing filter surfaces for biological activity, increased contact between new wastewater and active microorganisms results in effective digestion. They are used for wastewater with a low percentage of suspended solids and narrow COD/BOD ratio (BORDA, 2009). More information in factsheet F7.
- **Upflow Anaerobic Sludge Blanket:** It is often used in warm climates for municipal wastewater treatment and for effluents with high organic loads. The influent enters at the base of the UASB reactor and flows upwards. Due to the high loading and special design, the anaerobic bacteria form sludge granules, which filter the wastewater biologically and mechanically (Hoffman et al., 2011). More information in factsheet F8.
- **Sedimentation Tank:** Settling of solid material out of a liquid, typically accomplished by reducing the velocity of the liquid below the point at which it can transport the suspended material; may be enhanced by coagulation and flocculation (CIDWT, 2009). They also allow for sludge to settle and thicken (Tilley et al., 2008).

Secondary Treatment Options for Sewage Treatment

- **Activated Sludge Process:** This process involves rapid mixing and aeration of the wastewater, either by mechanical surface aerators or a submerged compressed air system, to create optimal conditions for treatment. The system comprises of an aeration basin and a secondary clarifier (settling tank) designed to remove suspended microorganisms (flocs) prior to discharge. Active biomass is returned to the aeration tank (MoUD, 2008).
- **Trickling Filters:** An "attached-growth" system comprising a circular tank filled with a bed of crushed aggregate, cylindrical plastic or foam blocks. Wastewater trickles vertically through the filter and the biomass growing on the media removes organic matter under aerobic conditions (MoUD, 2008).
- **Waste Stabilisation Ponds:** WSP systems comprise a single string of anaerobic, facultative and maturation ponds in series, or several such series in parallel. In essence, anaerobic and facultative ponds are designed for removal of Biochemical Oxygen Demand (BOD), and maturation ponds for pathogen removal, although some BOD removal also occurs in maturation ponds and some pathogen removal in anaerobic and facultative ponds (Mara, 1987).
- **Rotating Biological Contactors:** A rotating biological contactor consists of a series of discs, which are partially immersed in the wastewater. As the discs rotate, a film of biomass grows on their surface, comes into contact with the wastewater and treats biodegradable organic matter. Atmospheric oxygen is supplied to the bacteria in the biofilm when the discs are out of the wastewater (MoUD, 2008).
- **Fluidised Aerated Bed (FAB) Reactor:** An aerobic process in which wastewater flows vertically upwards through a filter bed of lightweight inert media at a sufficient velocity to 'fluidise' the bed. A bacterial biofilm develops on the media particles and treats the wastewater as it passes through. This process is ideal for treatment of small to medium flows in congested locations (MoUD, 2008).
- **Aerobic Lagoon:** An aerated pond is a large, outdoor, mixed aerobic reactor. Mechanical aerators provide oxygen and keep the aerobic organisms suspended and mixed with the water to achieve a high rate of organic degradation and nutrient removal (Tilley et al., 2008).
- **Sequencing Batch Reactors (SBR):** This variant of ASP (activated sludge processes) technology is essentially a batch treatment by combining, primary settling, aeration, secondary settling and decanting the treated sewage in a series of sequenced and or simultaneous reactions in the same basin on a time deferred cycle. Thus, multiple basins are used whereby when one basin is in one part of the cycle such as aeration, another tank will be settling and discharging the treated sewage in a cyclically repeated operation (MoUD, 2012). More information in factsheet F9.

- **Membrane Bio Reactors (MBR):** This technology combines the aeration and secondary clarifier in the same tank by sucking out the aerated mixed liquor through membranes instead of settling in a separate downstream tank and to that extent, it does yield a treated sewage with practically no BOD and Suspended Solids (SS). They sustain mixed liquor suspended solids (MLSS) of three to four times than what is possible in the conventional aeration tanks, minimising overall land area requirements (MoUD, 2012). More information in factsheet F10.
- **Moving Bed Bio Reactor (MBBR):** This technology is essentially the same as activated sludge except that the media suspended in the reactor offers additional surfaces for the microbes to grow and this in turn maximises the growth of microbes in a given volume of aeration tank compared to the conventional aeration without the media and to that extent, it does appear preferable. Diffused aeration is of course needed. The media is kept stationary and fluidised in the aeration tank (MoUD, 2012). More information in factsheet F11.
- **Constructed Wetlands:** They are classified as Free Water Surface (FWS) and Sub-Surface Flow (SSF). SSF CWs consist of beds that are usually dug into the ground, lined, filled with a granular medium, and planted with emergent macrophytes. Wastewater flows through the granular medium and comes into contact with biofilms and plant roots and rhizomes. Contaminants are removed by a wide range of processes (Garcia et al., 2010). More information on various CW types in factsheets F14, F15, F16 and F17.

Tertiary Treatment Options for Sewage Treatment

- **Membrane Filtration:** It is used to remove minute solids, colloidal material, dissolved organic matter, etc. from secondary effluents using several kinds of membranes. According to separating particles size, membranes are classified as follows:
  - **MF** - Microfiltration membranes are porous membranes with pore sizes between 0.1 and 1 micron (1 micron=1000 nanometre). They allow almost all dissolved solids to get through and retain only solids particles over the pore size.
  - **UF** - Ultra filtration membranes are asymmetric or composite membranes with pore sizes around between 0.005 and 0.05 micron. They allow almost mineral salts and organic molecules to get through and retain only macromolecules
  - **NF** - Nano filtration membranes are reverse osmosis with pore sizes around 0.001 micron. They retain multivalent ions and organic solutes that are larger than 0.001 micron.
  - **RO** - Reverse osmosis membranes are dense skin, asymmetric or composite membranes that let water get through and rejects almost all salts (CPHEEO, 2012).
- **Chlorination:** Chlorination is effective against a wide range of infectious organisms. An advantage of chlorination is that the equipment can be easily adjusted, so as to continue providing adequate disinfection if there is a change in effluent quality. Chlorine maybe added as a tablet, a liquid or a gas (Zipper, 2009).
- **Ozonation:** Treatment with ozone is another means of treating effluent. Like chlorination, ozonation kills pathogenic organisms by physical contact. The process operates via injection of ozone gas into the effluent. Unlike chlorination, the ozone is generated in the treatment unit, so there is no on-site storage of a hazardous substance. As a gas, the ozone (O_3) evaporates easily to the atmosphere where it degrades to harmless O_2, so it is not necessary to remove the ozone from treated effluent (Zipper, 2009).

Further Considerations

Economic consideration of a decentralised wastewater, one of the most important aspects, requires a detailed analysis of Cost-Benefit or Cost-Effectiveness. The major fiscal advantage of a decentralised system is the elimination of a great deal of the collection system, which costs about 80% of the sewage treatment system. The sewers in decentralised system like small bore sewer systems and settled sewer systems do not carry solids. Hence, the maintenance of such sewers is comparatively easy.

Public acceptance of Decentralised Wastewater Management (DWWM) Systems is vital to the overall future of wastewater reuse and the consequences of poor public perception could jeopardise future wastewater reuse projects. The selection of any decentralised wastewater treatment technology must be accompanied in advance by a detailed examination of the self-sufficiency and technological capacity of the community. The treatment alternatives must be manageable by the local community. Regular and uninterrupted O&M of DWWS is essential to attain satisfactory performance for which the community must have skilled personnel for O&M in order to tackle any type of problems under contingencies.

As per the Constitution of India (Item No. 5 & 6 of the 12th Schedule of Article 243 W), Water Supply and Sanitation is a State Subject. It is the responsibility of the State Government and Urban Local Bodies to implement operate and maintain water supply and sanitation systems and also arrange finances for the same. Further, the 74th Constitution Amendment Act 1992 provides a framework and devolves upon the Urban Local Bodies the responsibilities of providing water supply and sanitation facilities in urban areas in the country. It is mandatory on the part of the concerned agency responsible for approval of DWWS to incorporate adequate legal provisions in the Municipal Bye-Laws to accommodate and encourage implementation of decentralised systems in their jurisdiction. While formulating City Development Plans, adequate land shall be earmarked in different places in the city for implementation of decentralised sewerage system. It is also advisable to have a proper inspection procedure before providing operational consent to DWWMS. Moreover, provisions should be provided to renew or stop the consent, based on the operation, maintenance and performance of the DWWMs (Dhinadhayalan and Nema, 2012).

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Wastewater Recharge and Reuse

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Photos by Barreto Dillon 2013 and 2012

Introduction

Domestic water consumption makes up 8% of total global water use (UNWATER, 2012). Household water consumption has a large potential to be reduced in developing countries. Benefits of reducing domestic water consumption include lower water bills, reduced pressure on local water resources and increased availability of water available for appropriate purposes, such as drinking, cooking, and hygiene. One effective way of reducing water consumption is to reuse the wastewater produced at the household level. Wastewater reuse presents an opportunity to not only save water and financial resources by reducing water consumption, but to simultaneously increase food production or create livelihood. In developing countries, optimising wastewater reuse can therefore be a significant window for development. A critical aspect for wastewater reuse is that the quality of wastewater must be appropriate for its reuse (WHO, 2006). There are several different types of wastewater produced at the household level: rainwater, greywater (all household wastewater except toilet flushing water), urine, blackwater, and faeces. These wastewater streams have very different levels of contaminants (i.e. nutrients, pathogens) and reuse potential (i.e. car washing, flushing toilets, irrigation, and groundwater recharge).

Principles and Processes

The different wastewater streams produced and/or collected at the household level are: rainwater, greywater (all household wastewater except toilet flushing water), urine, blackwater, and faeces. They have different levels of contaminants (i.e. nutrients, pathogens) and reuse potential. Separating these streams reduces the amount of wastewater contaminated by pathogens (i.e. blackwater, faeces, urine). In this way, it is possible to retain high volumes of relatively safe water (i.e. greywater, rainwater) that can be directly reused, whilst reducing the volume of wastewater (i.e. blackwater) that must be treated before reuse. Depending on the contaminants present in wastewater and its future reuse, wastewater can either be directly reused, or treated and reused (recycled).

Section 1: Direct Reuse

Water that is of a relatively high quality with few contaminants, such as rainwater or greywater, can be directly reused. Numerous technologies exist for household rainwater harvesting, while greywater can be collected by refitting pipes to divert wastewater from appliances like showers, washing machines, and sinks. Even though water for direct reuse may be relatively free of contaminants, the future reuse of rainwater and greywater must be appropriate for the level of contaminants. Appropriate purposes for direct reuse can include:

- **Washing** (cars, etc.)
- **Flushing** for different types of toilets and flushing systems. For instance, flush toilets consist of a toilet bowl and a cistern. Excreta are flushed away with water stored in the cistern (up to 20 litres per flush). Dual flush toilets are available to reduce water. A siphon provides a water seal against odours from the effluent pipe.
- **Irrigation:** There are two kinds of irrigation technologies, which are appropriate for using treated wastewaters: 1) drip irrigation, where the water is dripped slowly on or near the root area; and 2) surface water irrigation, where water is routed overland in a series of dug channels or furrows.

- **Gardening** can be done for example with vertical gardens, greywater tower or vertical garden. A greywater tower is a circular bag, which is filled with soil, ash and/or compost mixture and a gravel column at the centre. A vertical garden is any kind of construction and support structure for growing plants in a vertical way.

Section 2: Wastewater Recycling

If wastewater is not suitable for direct reuse, household wastewater treatment options may be employed to reduce the level of contaminants to a level that is safe for reuse. Some possibilities for decentralised wastewater treatment systems include:

- **Constructed Wetlands:** More information in factsheets F14, F15, F16 and F17.
- **Biogas settlers:** They are airtight reactors used for the pre-settlement of wastewater and the conversion of the settled sludge into biogas via anaerobic digestion. Biogas is recovered and can be transformed into heat, light or any other energy.
- **Anaerobic Baffled Reactors:** They are improved septic tanks, which, after a primary settling chamber, use a series of baffles to force the grey, black or industrial wastewater to flow under and over the baffles as it passes from the inlet to the outlet. More information in factsheet F6.
- **Septic Tanks:** They are an underground watertight chamber made of brick work, concrete, fibreglass, PVC or plastic that receive both blackwater from cistern or pour-flush toilets and greywater through a pipe from inside a building.
- **Surface or Subsurface Groundwater Recharge:** It is the planned infiltration of effluents from wastewater treatment systems, stormwater or surface runoff into the aquifer in order to increase the natural replenishment of groundwater resources. More information in factsheet F22 and F23.

Once treated, wastewater can be used similar as rainwater or greywater, for purposes such as gardening and urban farming, toilet flushing, etc. (see "Direct reuse" above).

Section 3: Organic Waste Recycling

Organic waste can be reused as compost or soil amendments. However, because faeces and excreta contain pathogens that can transmit diseases, treatment must take place before reuse. Composting may be produced from kitchen waste as well as faeces and excreta. Sludge, kitchen waste and toilet waste can be recycled for energy production (biogas). There are numerous technologies that use anaerobic digestion processes to produce biogas, including:

- **Small-scale Anaerobic Digester:** Small-scale biogas digesters are reactors typically designed to produce biogas at the household or community level. The airtight reactors are filled with organic waste, such as sludge. Kitchen and garden wastes can also be added and toilets can directly be linked to the reactor for co-treatment of excreta.
- **Biogas Settlers:** See above.
- **Anaerobic Raffled Reactor:** See above.

Biogas may either be used directly for cooking, heating or lighting or to produce electricity.

Further Considerations

Measures can be taken for optimising (reducing, reusing) wastewater or organic waste in almost any household. It may be more difficult to reuse greywater if significant changes must be made to wastewater collection, such as in areas where greywater collection must be modified, or if reusing wastewater is illegal. However, if it is permitted, reusing wastewater can greatly reduce the amount of potable water that is needed for a household.

Different software tools can be implemented in order to optimise wastewater recharge and reuse. The most important is the intelligent irrigation system. It is a solution that aims to maximise the surface irrigated and flow with the lowest energy demand. However, this solution is used mainly in large-scale irrigation systems.

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Chapter 4

NaWaTech Technologies

NaWaTech Technologies

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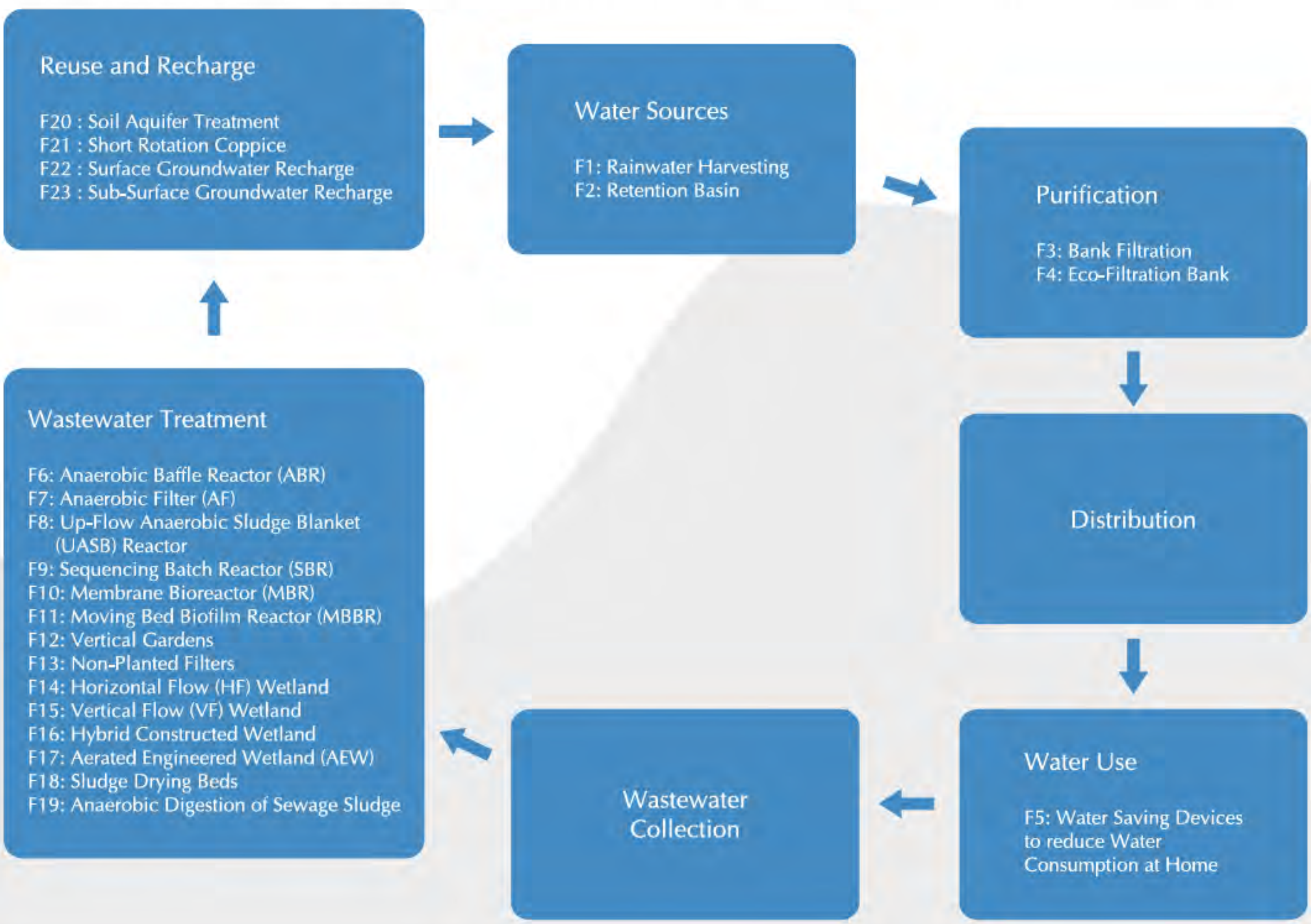
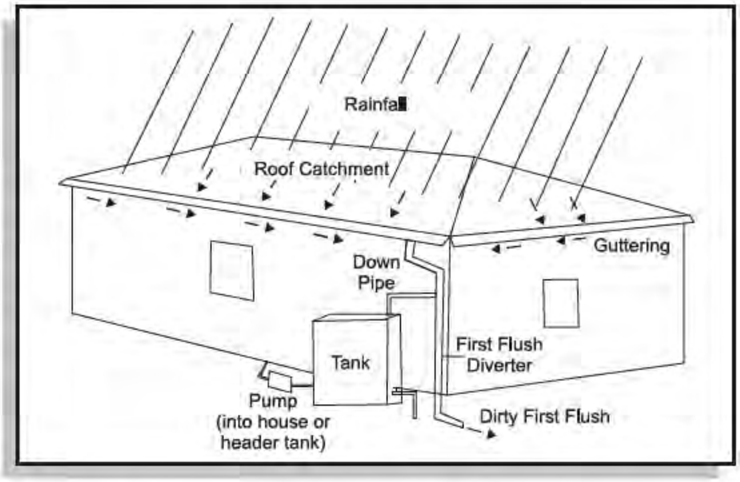
Photo by Barreto Dillon 2013

The following section presents a collection of technologies applicable at different steps of the urban water cycle, optimising its management to cope with water shortages in urban areas. The aim of this section is to deepen into selected key technologies that have been already mentioned in the previous chapter. Each selected NaWaTech technology is presented in detail, with a description of its processes, design, O&M and cost considerations, advantages and disadvantages. At the end of each factsheet the experiences on NaWaTech technologies in the world, and particularly in India are presented. During the process of planning an urban water strategy, technologies have to be viewed as part of a system composed of these 7 steps, and not as standing alone units. This holistic view will minimise consumption of water supply by recycling wastewater and storm water, reducing as well the wastewater treatment efforts.



Fact Sheets

Varad Shende
Ecosan Services Foundation (ESF)



Rainwater Harvesting (RWH) is a method of collecting and conserving surface runoff rain water for storage and use or for groundwater recharge. RWH has been in practice for centuries but gross misuse of existing water sources has led to global awareness and its increased importance off-late. Though simple in principle, numerous variables come into play while implementing an efficient RWH system (climate, humidity, temperature, rainfall pattern, finances etc.).

Design and Construction Principles

All designs of RWH systems basically include: (A) rain, (B) catchment area (roof, pavement area, storm drains etc.), (C) conveyance system (gutters, down pipes), (D) storage units or tanks (over ground / underground) and (E) distribution system (pipelines, pumps). In addition, there are some complementary units like filter/screens, first-flush diverters, disinfection methods (chlorination, boiling, UV) and overflow management pipes to complete the RWH system (CSE, 2013). The "Rational Method" states that Potential Rainwater Harvested = Rainfall (mm/year) x Catchment area (m^2) x Runoff Coefficient; run-off coefficient is defined as amount of water that runs-off the catchment area and can be collected relative to the amount of rainwater that it actually receives. It differs case-wise depending on surface of the catchment area (Thomas & Martinson, 2007). Keeping in mind the above, some construction guidelines are: (1) Catchment Area: use of paints, heavy metals, tiles for coating should be conscientious; (2) Gutters PVC or G.I: non-corrosive & sturdy, width of the gutters based on catchment area; (3) Filters /Screens: coarse mesh (5mm) or fine mesh (0.4mm); first-line defence to protect water quality; (4) Storage tanks (RCC, ferrocement, plastic, etc.): size depends on many factors like amount of rainfall, no. of end users, cost etc. (CEHI & UNEP, 2009).

Operation and Maintenance

Periodic inspection of the RWH system is imperative to preserve quality, reduce contamination and ensure full use of the system. It does not require skilled labour. Cleaning of catchment areas before the start of every rainy season is the normal practice. Also annual inspection and cleaning of the storage tank, gutters, down-pipes and filters (3 to 6 months) is sufficient (Khoury-Nolde, n.y). Repair of broken/ cracked storage tanks tops the priority list. Disinfection of the stored water should be carried out periodically, if it is used for potable purposes.

Cost Considerations

RWH is site specific and it is difficult to give an overall cost for it. Rain and catchment area are free of cost, especially if RWH is integrated ab initio, but varying capital and O & M costs are incurred for the conveyance system (downpipes, gutters, filters/screens), which can be brought down by diligent work plans. Majorly, the storage tank occupies 30-70% of the total costs. A study in Andhra Pradesh (India) put the cost of constructing RWH at Rs 1.30 / litre / household (Babu, 2005). Elsewhere, the U.S. Environmental Protection Agency report construction cost at approx. $4 - $6 / gallon / person (EPA, 2013) (1 gallon= 3.78 L).

Advantages (adapted from Khoury-Nolde, n.y.)

- Excellent alternative source of water for all purposes
- Flexible designs and capacities to suit diverse needs
- Simple technology, owner-managed.
- Avoids loss of good quality water; restricts floods.

Disadvantages (adapted from CEHI & UNEP, 2009)

- Limitations: rainfall, size of catchment area & tank
- Chance contamination: air pollutants, dirt, etc.
- Storage tank construction adds to the cost
- O&M: very essential specially for potable purpose

Experiences in Europe and other Cities of the World (adapted from Global Water Partnership–Mediterranean, 2013)

The Mediterranean islands, among the most arid regions in the world with limited freshwater resources depend heavily on desalination and water transfer and have recently adapted to the RWH technology for tackling their water issues. The region is more prone to issues such as water scarcity and extreme weather events with a heavy impact on freshwater availability in terms of quantity and quality. To demonstrate and educate people towards a "new water culture" necessary for addressing the current and future water scarcity challenges, a Non-Conventional Water Resources (NCWR) Programme was implemented in 2008 by the Global Water Partnership – Mediterranean (GWP-Med) and partner institutions (including the Ministries of Greece & Mozo) with companies like Coca Cola as a key collaborators primarily targeting the Grecian and Maltese islands.

It aims at advancing the use of NCWR and in revitalising and reintroducing traditional RWH combined and improved with innovative techniques and methods in those islands to secure water availability and facilitate sustainable development. Also included are software activities like awareness generation, capacity building and trainings. The soaring success of the programme has resulted in successful implementation of new RWH systems and rehabilitation of old systems numbering 50 RWH demonstration projects in toto for public buildings in 19 Mediterranean islands till the start of 2013. This has culminated in a combined annual yield of approx. 8 million litres of water along with training of thousands of student's teachers and technicians on RWH.

Experiences in India

Rainwater harvesting in South Asia differs from that in many parts of the world in that it has a history of continuous practice for at least the last 8000 years. However, it matters more today than ever before (Pandey, 2003). Many reasons typical to a developing economy like diminishing fresh water sources, decline in the groundwater tables, low productivity of wells, climate changes and exponential human population growth have been responsible for an attempt to search sustainable and renewable water sources in India. In June 2001, the Ministry of Urban Affairs and Poverty Alleviation made RWH mandatory in all new buildings with a roof area of more than 100 m^2 and in all plots with an area of more than 1000 m^2 that were being developed (Legislation on RWH CSE, 2013). Further, under the Jawaharlal Nehru National Urban Renewal Mission targeting formation of environmentally sustainable cities, a directive was issued to all the Urban Local Bodies for amending their building by-laws and making RWH mandatory (MoUD, India). Accordingly in 2007, the BMC Mumbai made it compulsory for buildings with plot areas of 300 m^2 to have RWH system. Similarly other cities like Chennai, Bangalore, Thrissur, Hyderabad, Pune and Nagpur have also made RWH mandatory for new constructions. Very recently, East Delhi has decided to join the bandwagon by making prerequisite for all households of 27m^2 or above (as against 84 m^2 previously) to have water conservation facility (Deccan Herrald, 2013). The obvious advantages conferred by the technology are seen to be percolating positively among people. Many success stories are seen arising from the village backdrop since there is no municipal water supply as a backup option upon depletion of ground water reserves and therefore villagers have started being proactive towards conservation of rainwater to tackle times of crisis. Unlike the village scenario, the urban population faces a crunching need, i.e. space constraints. However some successful urban projects of RWH are described below:

Panchsheel Park Colony, Delhi: In a benchmark achievement, the society invested Rs. 0.8 million (USD 20,000) to secure RWH for all the plots in the colony. From the total roof and surface area of 357,150 m^2 receiving rainfall (611 mm/year), 174,575 m^3 rainwater was harvested in 2002 resulting in a total rise of 0.7 m of groundwater level in the area (Mathur et al., 2009).

Aizawl, Mizoram: At present, Aizawl has more than 10,000 RWH tanks in individual houses, which have been constructed by the residents at their own expense or with state government assistance. Rainfall in Mizoram (average 2,500 mm/year) is distributed throughout the year. Most of the buildings are constructed with sloping roofs that use Corrugated Galvanised Iron (CGI) sheets, which are conducive to RWH. Rain gutters (PVC pipes / bamboo) are used to drain water into the cylindrical storage tanks with GI semi-circular rain gutters to catch rainwater. Gradually, reinforced cement concrete (RCC), ferrocement and plastic tanks are being introduced (roughly averaging 10,000 litres capacity). In a pollution-free state like Mizoram where major industries are yet to come, rainwater is free from undesirable chemicals and is of potable quality (Mathur et al., 2009).

In spite of these advances, the situation continues to be critical. Maharashtra is currently facing the worst drought conditions in 40 years with 11,801 villages in 15 districts declared as drought-affected and millions of people migrating towards the cities in a huge exodus (IBTL, 2013). Also a recent study by Observer Research Foundation claimed that RWH in Mumbai was a 'joke' with many new buildings not following the above guidelines and with many existing RWH systems being non-functional (ToI, 2013). By adhering to state guidelines, conscientious implementation of RWH systems and diligent O & M one can definitely overcome obstacles and help the country move towards a more sustainable model of water management.

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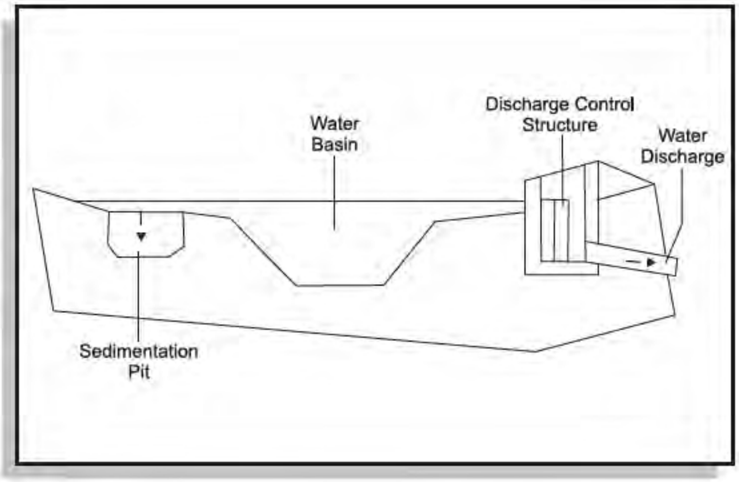
Pranav Nagarnaik, Girish R. Pophali and Pawan Labhasetwar
CSIR-NEERI



Retention basins are predominantly used for storm water control and treatment. Rainwater is stored in a pond, which further filters through the sediments and soil column and in the process recharges the aquifer. The retention basin prevents successional flooding by storing the water in a confined area. Due to the flow of water through the soil, water gets treated naturally before reaching the aquifer. Water from the retention basin can be used in irrigation, industry or at household level after an appropriate secondary treatment. Nutrients are removed effectively because of the photosynthetic activities and bacteria attached to the plants.

Design and Construction Principles

The design of a retention basin is unique to the individual site, as integration to the surrounding environment is required. The criteria for site selection is based on the availability of land and its cost, as well as the water holding capacity of the soil and ability to support pond environment. Site-specific constraints for construction of retention basins may include impact on the environment, relocation of utilities lines like pipelines and electric supply lines and type of bed rock. The construction of a retention basin is effective in an area where storm water can naturally flow and be collected in the basin. Modifications to retention basins could be done by planting native aquatic vegetation to improve its functioning. The hydraulic conductivity is another important technical design parameter for constructing the retention basin. A low hydraulic conductivity restricts percolation of water to the aquifer, while high hydraulic conductivity does not allow for retention of water in the basin. The hydraulic loading rate in a retention basin is a function of the hydraulic conductivity and infiltration rate. The under laying soils and bed rock should have a permeability between 10^{-5} and 10^{-6} cm/s to retain water in the retention basin (US-EPA, 1999). In case of a soil with high hydraulic conductivity, a clay blanket may be overlaid (US-EPA, 1999). Retention ponds need to hold back a constant level of water. Retention basins filter pollutants such as metals, nutrients, sediments, or organics by sedimentation. Further removal of pollutants is achieved through algal and wetland plant uptake as well as bacterial decomposition (US-EPA, 1999).

Operation and Maintenance

Retention basins require limited maintenance. Permanent access must be provided to the embankment areas for preventive maintenance, which includes control of erosion and suspension of sediments. This should be done to reduce unwanted sediment export. The routine maintenance includes quarterly inspections of inlet and outlet, sediments, trash dredging, repairs to the embankment, control of algal growth, insects and odour (SERPC, 1991). The retention basin should be inspected after every storm.

Cost Considerations

The capital cost for construction of retention basins includes the land and excavation cost. High investment is required for the construction of retention predominantly due to the land cost. The cost varies depending on the location and the area required. Retention basin has minimum maintenance cost and usually lasts for over 20 years. Once in operation, only minimal maintenance cost arises. Retrofitting retention basin in a developed area is usually expensive owing to the high land costs. Retention basin is built at a community level by the local authority or large area land developer.

Advantages

- Design is simple
- Collection and improvement of water quality at the same time.
- Natural process with no energy and no advanced requirements.
- Improved storm water management and flood control.
- New habitat can be created.

Disadvantages

- High land requirements
- Has a drowning danger for children
- If not designed correctly, negative impacts on water instruments quality can occur
- Not applicable in areas with low precipitation and highly permeable soil

Experiences in Europe and other Cities of the World

A retention basin is used to manage storm water to prevent flooding, soil erosion and control transport of pollutants carried by rainfall runoff. It is an artificial lake designed to carry a permanent pool of water. Retention basins have been extensively studied in the US, Canada, South-East Asia and parts of Europe (SERPC, 1991; Borden, 1996; Sounders, 1997; Wakelin, 2003). Along the Czech Republic – Germany border the implementation of retention basin reduced storm water runoff peak flows by up to 48% (Reinhardt, 2012). In recent years, there has been increased focus on optimising the design of retention basins for the purpose of maximising cost savings. Studies have also been carried out in Germany to assess the ecological impact of retention basins (Reinhardt, 2012). Along with the improvements in the water quality and habitat, the adverse impact of change in the hydrological conditions resulted in the modification of the vegetation in the region (Scholz, 2007).

Experiences in India

Retention basins offer a viable solution to the problem of urban storm water runoff in developing countries. Due to financial constraints and lack of infrastructure, wastewater management systems are not well equipped to treat sudden increase in hydraulic load due to rain or floods. Retention basins offer an inexpensive and sustainable drainage solution to this problem. Studies show that incorporating retention basins to conventional drainage networks can prevent flooding in receiving bodies and transport of oil, organics and toxic metals through stormwater runoff (CIDCO, 2013). Retention basins or holding ponds have been constructed in coastal Navi Mumbai to avoid water logging of low lying areas and prevent pollutants to flow into the creek (CIDCO, 2013). In Mumbai, retention basin was effective in storm water flooding and reducing the total suspended solids (Zope, 2008)

In rural India, retention basins have been used for centuries for holding rainfall to augment drinking water and irrigation supply. Case studies have been reported from various parts of India including Hyderabad, Suratand Karnataka (Chakrabarti, 2009). These local initiatives have been successful in preventing flooding in areas with heavy rainfall and preventing water scarcity in desert areas.

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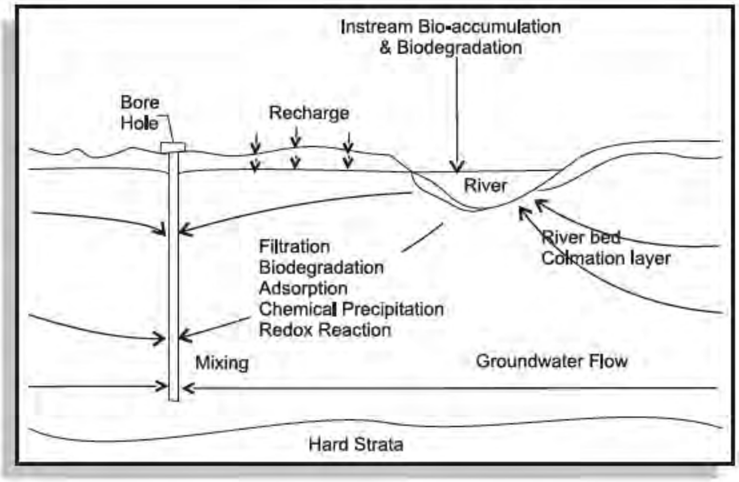
Bank filtration (BF) is a drinking water pre-treatment step, where river water is induced to percolate in subsurface passage through a riverbed and mix with ambient (or natural) groundwater, before being extracted through a pumping well adjacent to the river bed. It can be applied as first step within a multi-barrier approach in an overall treatment chain where groundwater quantity is insufficient or of poor quality (e.g. geogenic pollution).



Design and Construction Principles

During subsurface passage in biologically active soil layers (with aerobic, anaerobic and anoxic milieus), water quality of surface water can be improved before being mixed with groundwater and extracted for use. BF systems involve several physical, chemical and biochemical processes and are particularly known for the efficient reduction/removal (or even elimination) of suspended solids, organic pollutants, microorganisms, heavy metals, nitrogen, toxic algae as well as organic trace compounds (e.g.: pharmaceutical products), salinity or taste- and odour causing compounds (Rakesh et al., 2010; Sprenger et al., 2006; Huelshoff et al., 2009b). Relying on natural processes, design and treatment capacity (and efficiency) of BF systems strongly depends on local circumstances such as quality and quantity of available river- and ground water, hydraulic residence times of the water in the soil, the porosity of the soil, the hydraulic potential of the aquifer, temperature, pH values and oxygen concentrations as well as underlying redox processes (Schmidt et al., 2003; Ziegler, 2001). Depending on the bank filtrate quality, disinfection or even supplementary treatment steps are necessary to achieve drinking water quality. Besides its polishing function, BF also provides huge fresh water storage capacity for buffering extreme climatic conditions and shock loads (Huelshoff et al., 2009a&b; Sharma and Amy, 2009; Schmidt et al., 2003), but also represents an artificial groundwater recharge technique preventing the overuse of aquifers, saltwater intrusion and land subsidence (NRMMC, 2009) (see Recharge chapter).

Operation and Maintenance

Basic requirements for the operation of a BF system are the availability of surface water as primary water source and a detailed consideration of the groundwater level in the surroundings of the abstraction well. Water abstraction should not result in adverse effects on the aquifer or the river downstream of the site. Depending on the BF site's characteristics and purpose of the output water, operation of a BF system is easy and only little maintenance is needed (Huelshoff et al., 2009a; Hiscock and Grischek, 2002). Compared to high-end technologies, requirements for skilled labour and energy & chemical use are very low (Ray et al., 2002; Ziegler 2001). However, more requirements may arise in relation to design, operation and maintenance of the water abstraction well. One challenge in relation to well operation is the prevention/handling of colmation of the infiltration path.

Cost Considerations

Costs for establishing riverbank filtration systems depend on many factors, including aquifer characteristics, type of well-screen installation, facility design, and distance to the population served. However, costs can be classified as moderate. Using natural treatment processes, BF system can be considered as cost-effective system, which ideally can reduce costs for subsequent treatment steps (Schmidt et al., 2003). Additional costs can arise in dependency of raw-water quality and continuative treatment steps for diverging intended purpose (e.g. drinking water use). Investment costs are costs for the abstraction well (construction, pump, main, control system etc.) as a minimum, as well as costs for groundwater monitoring of BF processes and water quality. Operational costs are primarily costs for pumping electricity for abstraction well operation. For abstraction (and treatment) facilities skilled personal is required (see "Abstraction with drilled and dug wells" in Water Sources Chapter).

Advantages

- Can dampen pollution peaks and buffer extreme climatic conditions (quality and quantity)
- Huge freshwater storage capacity
- Can reduce costs of supplementary treatment steps
- Low requirements for skilled labour, chemicals and energy use (depending on purpose of output water)

Disadvantages

- Prone to clogging/colmation at high levels of suspended solids
- Permeability can be influenced by high (seasonal) temperature amplitude
- High organic pollution and high mean temperatures can lead to lowered treatment efficiency

Experiences in Europe and other Cities of the World

For many decades Bank Filtration has been used in Europe and the United States for drinking water supply in communities located on river banks, applying both large-scale schemes involving high-tech extraction methods (providing water for central water supply entities) as well as low-tech household-based schemes. In Germany, more than 300 water works use BF producing about 16% of the German drinking water. Along the Danube River large-scale BF-systems exist in all major cities like Vienna (Austria), Bratislava und Gabicikova (Slovakia), Budapest (Hungary) and Belgrad (Serbia). About 50% of the public drinking water supplies in Slovakia and about 45% in Hungary are provided through BF (Hiscock and Grischek, 2002). Production capacities are varying significantly not only depending on the productivity of the aquifer, but also on the type and number of extraction wells used. In Vienna, for example, up to 2.000 L/s are extracted with BF from the Danube using a total of 13 radial collector wells and 11 vertical filter wells. In Central Europe, increasing chemical pollution, high concentrations of ammonia, organic compounds and micro-pollutants in the river water called for the introduction of supplementary pre- and post-treatment steps to build up a multi-barrier system (e.g. granular activated carbon filters, often combined with isolation and filtration) (Schmidt et al., 2003). Sandhu et al. (2010) emphasised on the necessity to be aware of the severe differences in the geological, hydrogeochemical, hydrological and river morphological characteristics of river systems, when transferring experiences from Europe to India. Thus, design and operation of BF systems should not only use adapted well designs, but also take into account prevalent cultural and operational constraints.

Experiences in India

Sandhu et al. (2010) investigated the potential of riverbank filtration for drinking water supply in India based on experiences with operating large-scale riverbed filtration schemes in the cities of Ahmedabad, Delhi, Haridwar, Mathura, Medinipur and Kharagpur, Nainital, Patna and Srinagar. Large diameter caisson wells, vertical filter wells, radial collector wells and small-scale radial collector wells are used for water abstraction with production capacities ranging from $29m^3$/day to up to $110.000m^3$/day. Reported travel times of the bank filtrate range from min. 2 to max. 100 days. BF proved to be advantageous as pre-treatment in situations with high concentrations of organic compounds. Also the removal of pathogenic microorganisms, colour and dissolved organic carbon, UV absorbance, turbidity, total and faecal coliform counts during monsoon season could be observed. All investigated examples proved to sustain their treatment efficiency. They conclude that BF has a great potential for improving both quality and quantity of many water supplies throughout the country. In cities where BF is already applied, the BF process is accepted as purification treatment step in combination with – compared to other supply systems – much more limited post-treatment chlorination or ozonation (Sandhu et al., 2010; Singh et al., 2008). Sandhu et al. (2010) identified a number of feasibility issues such as sufficient flow in rivers, protection of landside groundwater from contamination, high arsenic concentrations at shallow depths, insufficient scouring of riverbed and removal of the clogging layer due to heavily regulated surface flows and discontinuous well operation due to lack of continuous electricity supply or electricity saving measures. Facing increasing quantities of insufficiently treated wastewater being discharged into rivers, the authors propose to preferably locate BF systems upstream of big cities to minimise the risk of landside groundwater contamination. Moreover, attention should be paid to private production wells and unmonitored pumping resulting in decline of the groundwater level (e.g. as been observed in Delhi). Lorenzen et al. (2010) propose to accompany planning and operation of BF sites by ?eld studies on a local scale to optimise the systems in accordance with local conditions (e.g.: observing content of undesired substances, obtain the desired shares from each source and attenuate contaminant concentrations). Hydrogeological investigations are pointed out to be essential, not only to assess hydraulic parameters but also to evaluate the risk of contamination by different substances and to understand the contributing processes. Water levels and quality in surface water should be monitored throughout the first year at least, to identify temporal and spatial variations in the interaction zone of surface water and groundwater. Temperature logging is proposed as relatively easy and cheap method that may reveal valuable information on the ?ow regime.

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NaWaTech

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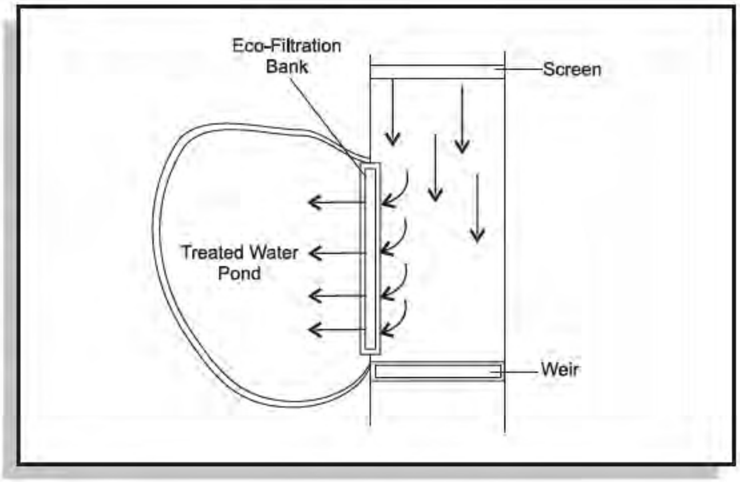
Eco-filtration Bank (EFB) is a variant of Green Bridge Technology – in-stream horizontal eco-filtration process. Contaminated water in the small stream or tributary is filtered through an enclosure in the bank of the stream made up of locally available stones and sand for protection of biofilms, which degrade pollutants. They are absorbed in the micro-ecosystem. Thus the desired quantity of water in the stream can be purified for desired application.



Design and Construction Principles

Contaminated water in the stream is diverted by constructing a porous weir of desired height to ensure the designed flow enters into the EFB. The screen box (coarse and fine) should be installed upstream of the EFB to trap the non-biodegradables from the water. The size, shape and porosity will be dependent on the concentration of non-biodegradable, inert floating materials. In the weir created small impounding, some natural flocculation and settling takes place which helps in removal of pollutants. EFB acts as an ecological filtration involving adsorption, absorption and biodegradation of pollutants taking place in the biofilms developed on the filtration media of locally available stones and gravels. This process can be accelerated by adding specialised bacterial cultures. Treated water is collected in the adjacent pond lined with stones. Water retention due to weir is about 11 minutes. Filtration is instantaneous; time required is not more than 1 minute. Treated water pond has retention time of 24 hours. Filtration area of EFB is 0.14 m^2/PE (1 PE = 135 L/d) suitable for dense areas also. EFB is constructed using locally available stones, gravels and coarse sand with some specially enriched natural non-pathogenic microbes. Screen-box can be made of mild steel coated with anti-corrosive paints. Weir is made of rubbles and stones. EFB improves the dissolved oxygen concentration and facilitates the ecological elimination of pathogens in the range of 90 -99%. Reduction in BOD is expected to be in the range of 50 – 70%.

Operation and Maintenance

EFB is zero electricity technique and does not require any chemical inputs for the removal of contaminants. It is based on the ecological principles of self-purification of running water bodies. It needs routine removal of non-biodegradable materials from the screen box. These materials shall be transported to common solid waste processing site. Settled solids from the impounded area before weir shall be removed once in six months. These solids being bio-stabilised can be effectively used as organic manure for the gardens. Treated water pump shall be operated every day for watering of the community gardens and green belts in the vicinity. Routine operations are very simple and can be managed by the local community.

Cost Considerations

Estimated construction cost of the EFB are inclusive of screen box, weir, EFB unit, treated water pond and simple barbed wire fencing with labour, supervision, and plantation per PE is about 30% that of conventional or advanced treatment units. Electro-mechanical costs involving the pump and treated water distribution pipeline are hardly 20% of conventional treatment system. Therefore, project cost is sum total of construction, mechanical with additional costs of landscaping and beautification of treatment area converting it into river-side landscape. Being demonstrative project, community expects external financing support. Operational costs inclusive of screen cleaning, biosolids removal and pumping are 5% that of conventional system.

Advantages

- No electricity, no chemicals
- Less land requirement – minimum space footprint
- Eco-friendly, no carbon footprint, no odour, no mosquitoes
- User friendly, can be operated by unskilled personnel

Disadvantages

- Vandalism is a major threat
- Non-biodegradables during the floods may damage the EBF

Experiences in Europe and other Cities of the World

Eco-Filtration Bank is a combination of chemical and ecological principles of bank filtration and green bridge – horizontal eco-filtration. There is no any example of eco-filtration bank in Europe since it is recent innovation in India. First of its kind was developed for a farmer to use water for irrigation from the ecological restoration project on Ahar river in Udaipur, Rajasthan state. Eco-filtration bank is designed to purify the polluted water flowing through the stream by passing through the porous green banks by facilitating combined action of green vegetation and microorganisms. This process may produce potable water directly, or may act as a simple pre-treatment for further purification. There are three filtration mechanisms involved, namely, physical filtration (straining through interstitial spaces of alluvial soil/sand), biological filtration (soil microorganisms remove dissolved or suspended organic material and chemical constituents), and ion exchange (aquifer soils react with soluble chemicals in the water). Eco-filtration Bank has designated efficiency to remove suspended solids, COD, BOD and faecal coliforms because of aerobic processes. Reduction in micro-pollutants, removal of the pathogen and suspended solids are also noted in European riverbank ?ltration systems (de Vet, 2009; Schmidt et al., 2003).

Experiences in India

Ecotechnology for water purification is fundamentally the discipline of sustainable water resources management, which promises the restoration and preservation of ecological health of water body for human use through the integration of engineering and ecological principles. It operates within the borders of ecosystem. Therefore, it has got non-conventional design considerations, parameters and scale ups. These considerations are dependent on the self-designing and controlling abilities of ecosystems. When changes occur in the river and lake systems due to external inputs, nutrient discharges, releases of pollutants are reorganised and balanced. This is the scientific basis of green bridge (horizontal eco-filtration) technique, which can be harnessed for the eco-filtration bank method of purification to facilitate the treatment of desired quantity of stream or lakewater.

Farmers are using the eco-filtration bank system along the Ahar River Udaipur India. It was polluted till December 2009 due to city drains and industrial discharges about 150 MLD (Kodarkar and Joshi, 2010). The river lost its ecological health, biodiversity and usefulness for routine human activities in the urban and rural areas downstream of Udaipur to organic and toxic pollutants. But the quality of water changed due to ecological restoration design having in-situ green bridge system and eco-filtration banks. Farmers are now getting enough clean water for cultivation of vegetables.

Buddha NEER project is a federal government initiative involving Ministry of Environment and Forests, Central Government, National River Conservation Directorate (NRCD), Central Pollution Control Board (CPCB), Punjab Government, Punjab Pollution Control Board (PPCB) and Ludhiana Municipal Corporation (LMC) to restore the ecological health of highly polluted stream of dry weather flow of 600 MLD to make the water available for agriculture. In-stream green bridges with eco-filtration banks are being developed to reduce the pollution and toxicity levels of Buddha stream water.

The major challenges in treated the running water bodies in India are ingress of liquid waste discharges and disposal of solid wastes. All the initial field scale applications were supported by local communities and funded by industrial organisations as corporate social responsibility. Out of them, 50% systems are still running successfully. There is need of sustainable, uninterrupted finance for their long-term operations. Government of India has come forward with technology assessment programme for adaptation of such technologies. So there are hopes in future, the treatment systems will be run efficiently with sustainable funding.

Eco-filtration bank system is found to be suitable for integration with green belts or city garden plans or any other treatment systems because–

- No requirement of extra space. So, space footprint as compared to conventional systems is negligible.
- Zero electricity ecological correction system as there is no requirement of pumping or machinery to introduce oxygen for aerobic degradation or there is no sludge handling.
- Capital expenditure and operational costs are considerably less as compared to conventional engineered treatment systems.
- Ecological treatment systems are easily adaptable in cultural fabric of Indian urban and rural set ups as the local resident communities owned the systems by participating in the installation of the systems and routine operations and monitoring of improvements in waterbody.

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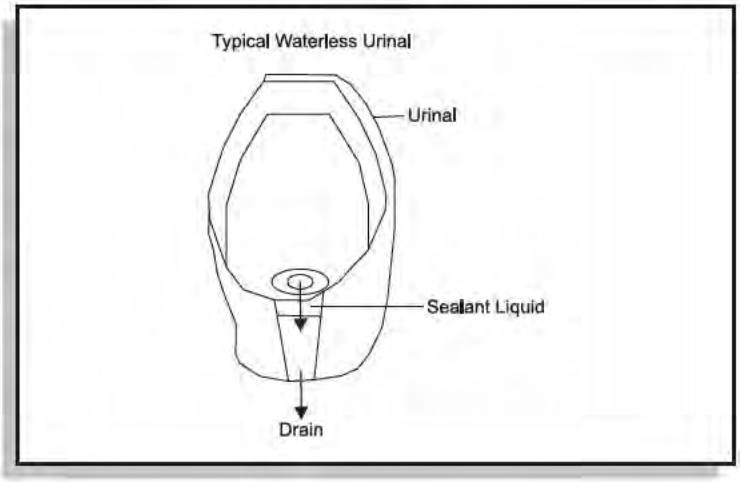
Reducing water consumption and improving water efficiency in buildings is a major step towards sustainable water management. Everyone can contribute towards saving water at home with actions that are simple yet efficient. Installing water efficient fixtures in toilets and kitchens could be the first step. Traditionally, plumbing fixtures in a building would include toilets (cisterns and commodes), faucets, showerheads, urinals etc. apart from the other appliances like washing machines and dishwashers. Over the years, significant technological improvements have taken place aiming at improvement in water efficiency with minimum compromise on performance.



Low Flow Toilets

Toilet flushing constitute up to 27% of the sewage. Different categories of low flow toilets are available based on fixture technologies viz. Dual-flush toilets, Interruptible Flush Cistern, High Efficiency Toilets, Pressure Assist Toiletsand Power Assist Toilets, which give flushing volumes ranging from 3.8 L – 6 L / flush. Sometimes the design or working principle itself differs viz. composting/urine diversion dehydration toilets (sometimes called Ecosan toilets), which make minimum use of water. The capital investment may relative be higher but the huge savings of flush water and the smaller volume of generated wastewater reduces operation costs significantly. In the O&M aspects regular cleaning, avoiding other objects than faeces or urine being flushed away (Stauffer, 2011). Low flow toilets have low water requirement but they also have disadvantages such as pipe clogging or sometimes may require two or more flushes to adequately clean the bowl.

Vacuum Toilets

This type of toilet makes use of air to drive waste through the toilet and vacuum piping to the treatment tank or intermediate collection tank. Two basic designs are available viz. Constant Vacuum System (CVS) and the Vacuum on Demand (VOD) system. The location parameters are important factors in choosing type of toilet system. The capital invest for these toilets are high but in comparison with common flush-toilet system, it could be slightly cheaper, due to less piping costs and on-site treatment system can be more easily installed (Stauffer, 2012).The in-house installations require little maintenance and are easy to clean. The suction effect increases hygiene and reduces odour (Heeb et al., 2007). Periodical cleaning of composting tank will avoid an overflow. The O&M of the technical components such as valves or pipes should be carried out with the help of external technical support. Advantages include its simplicity to install, low water consumption, odour free and the fact that they are very hygienic. The disadvantages are higher capital investment, higher energy consumption, clogging due to bulky materials and space requirements for connections (Stauffer, 2011).

Waterless Urinals

These urinals make use of a trap or a barrier, which restricts urine from poolingand gathering. It requires less water to clean and is odour free in some cases. Most of the designs are based on the sealant liquid traps, valves,membrane traps and biological blocks. Other types of odour traps viz. hydrostatic float barriers andair enclosing trapsare also available. These urinals save anything between 56 m^3 to 170 m^3 of water/urinal/year. In India,the cost of urinals with sealant liquid trap ranges from Rs 6,000 to Rs 15,000. Membrane traps would cost between Rs 100 to Rs 150 and the biological blocks are priced around Rs.20/block. The O&M of waterless urinals include avoiding spitting and throwing of cigarette butts and chewing gum in the urinal pans, appropriate cleaning mechanism based on the type of waterless urinal. These urinals save freshwater, enhance efficiencies of sewer lines, conserve electricity used for pumping water and treating wastewater and reduce pollution of water bodies, but also have disadvantages such as the difficulty of retrofitting and the expensive costsof sealant liquids. Replacement of cartridges, biological blocks and refilling of sealant liquid increases the maintenance costs. Biological blocks need to be replaced approx. 2-3 days based on the usage and clogging (Chariar&Sakthivel, n.y).

Water Tap and Showers with Aerators

The devices such as taps or showers with flow fixtures or aerators help in minimising the use of fresh water and reduce load on wastewater systems. These fixtures provide same effect as conventional flow fixtures, whilst reducing the volume of water flowing through the system. These fixtures are designed at a particular supply pressure for effective water supply. The advancements such as sensors or timers also help in reducing the water wastage. Fixtures such as flow restrictors or aerators are relatively cheap and do not require high maintenance,whilst the sensor or timer based taps or showers would require more investment, but their maintenance is relatively cheaper (Autotaps, 2013).

In case there is a breakdown of a sensor or a timer, these need to be repaired with appropriate technical support. These accessories have advantages such as higher water savings, but also have disadvantages including higher energy requirement for sensor, timer based taps, showers and the possibility of clogging.

Water Efficient Dishwashing Machines and Washing Machines

Washing machines are available in different capacities and models viz. top loading, front loading, automatic, etc. The water efficiency differs based on the model and capacity of the machine. Generally, an average washing machine uses 10 L water/kg of cottons at 40°C. Tests have shown that water usage varies between models, ranging from 5.5 L of water/kg of cottons to 13.6 L water/kg of cottons (WHICH, 2013a). The dishwasher models differ greatly. Studies show that water usage ranges between 21 L for a normal program to just 10 L during its equivalent wash cycle. The studies have shown that full-sized dishwasher set on eco or energy-saving program can save up to 30% of water(WHICH, 2013b). The maintenance of cloth washing/dishwashing machines should be undertaken with the help of appropriate technical support. These machines save water, but consume more energy, have space requirements and require higher investments, as compared to traditional washing methods.

Experiences in Europe and other Cities of the World

The city of Hong Kong started a project in 2009, where all major government buildings were to be retrofitted with devices such as low flow sensor type water taps, low-flow showerheads, dual-flush cisterns, sensor type urinals saving 2 Mm^3 of fresh water and 0.8 $Mm^3$of seawater annually (CLG,2011). During 2009 and 2011, in the cities of Cardiff, London and Edinburgh, under the EU Life+ RENEW project, about 25,000 people were given advices about the water saving devices including water taps, low-flow showers, dual-flush cisterns, washing machines and dishwashing machines. It was observed that after implementation of above strategies about 176,000 m^3 of fresh water was saved from homes annually (EST, 2013). In the city of Goleta, California the city authorities introduced a water efficiency program that emphasised plumbing retrofits, including high-efficiency toilets and high-efficiency showers, which resulted in a 30% drop in district water use (US-EPA, 2002).

Experiences in India

Until now, most of the Indian families have been traditional in terms of using water resources for various activities. Water saving devices such as low flow toilets, waterless urinals, vacuum toilets, taps and showers with aerators, flow fixtures and water efficient washing machines or dishwashing machines are relatively new concepts for the Indian market. With the rise of various policies and voluntary schemes including IGBC Green Homes, TERI GRIHA (ADaRSH, 2012), Ecohousing, among other, the use of these water saving devices is increasing. Various statistics in India show that more than 800 buildings (IGBC, n.y. andADaRSH, 2012) have undergone various green building certifications, which include all or some of the water saving devices are incorporated in their designs and have been implemented.

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NaWaTech

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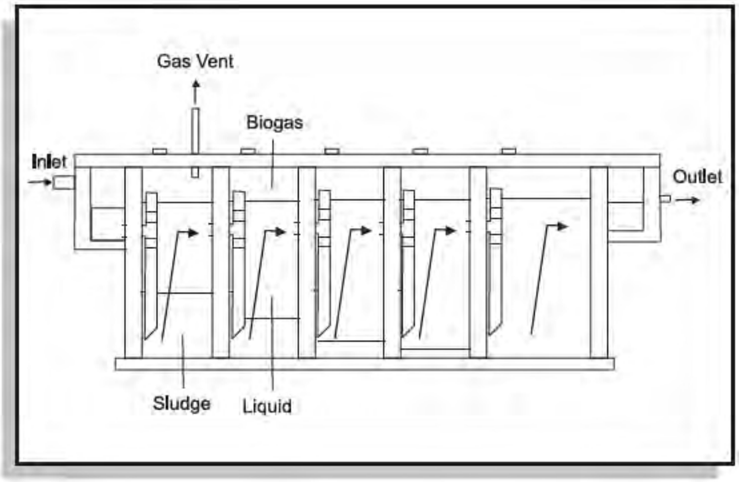
"The Anaerobic Baffle Reactor (ABR) is an improved septic tank, built with alternating baffles, which directs the wastewater to flow under and over it as the water moves from inlet to outlet" (Spuhler, 2010). Its design ensures increased contact time of the wastewater with the sludge and hence increases the efficiency. ABR was developed in the early 1980s at Stanford University. Due to its compact structure and possibility of integration into any construction designs, ABR is now considered as a key component in decentralised wastewater treatment systems.



Design and Construction Principles

The design concept of ABR is similar to the septic tank, as an anaerobic environment is created without any mechanical mixing. The factors, which govern the design of the ABR are – (1) Inflow parameters – quantity and quality, (2) HRT, which is dependent on the climatic characteristics and the inflow quality (CSE, n.y.)."The majority of solids are removed in the sedimentation chamber at the beginning of the ABR, which typically represents 50 % of the total volume. The up flow chambers provide additional removal and digestion of organic matter: BOD may be reduced by up to 90 %, which is far superior to that of a conventional septic tank. As sludge is accumulating, desludging is required every 2 to 3 years. Critical design parameters include a hydraulic retention time (HRT) between 48 to 72 hours, up-flow velocity of the wastewater less than 0.6 m/h and the number of up-flow chambers (2 to 3)"(Tilley et al., 2008). An ABR can easily be constructed underground as an RCC structure or brick masonry and will consume one square meter of area per cum of wastewater flow (CSE, n.y.).

Operation and Maintenance

The tanks must be checked and ensured that they are watertight in order to avoid any infiltration. Also the scum and sludge levels have to be checked regularly for smooth and efficient functioning (adapted from Tilley et al., 2008). Desludging has to be carried out (annually or once in two years) depending on the rate sludge formation, by using vacuum pumps. The tanks should not be emptied while desludging, as residual biomass is required for further treatment cycles. The flow to the system has to be maintained as per the design considerations to ensure the required level of treatments (adapted from Spuhler, 2010).

Cost Considerations

When ABR is installed as a part of a DEWATS (decentralised wastewater treatment system), it consumes about 40% of the system cost (CSE. n.y.). The variability in the construction cost is dependent on the properties and composition of the soil, which is to be excavated. The costs of desludging will account to about Rs. 5000 for a 10 m^3 tank, which is the only a yearly recurring expense. Areactor of 12 m^3 volume (comprising 6 compartments of 2.0 m^3 each) built at Adarsh College Badlapur in the year 2008 as a part of a DEWATS system had a cost of Rs.1,20,000 (about 2300 USD at that time) (Zimmermann, 2010).

Advantages

- Resistant to organic and hydraulic shock loa
- No electrical energy required
- Can be built and repaired with locally available materials
- High reduction of organics

Source: Tilley et al., 2008

Disadvantages

- Requires constant source of water
- Need of secondary treatment due to low reduction pathogens
- Requires expert design and construction
- Pre-treatment is required to prevent clogging

Experiences in Europe and other Cities of the World

ABR is a suitable technology across the world, wherever the climatic conditions are suitable for anaerobic digestion. The temperature of tropics is generally suitable for anaerobic digestion processes, which has enabled the installation of ABR in many parts of the world. The wastewater treatment system installed at Khac Niem Commune, in Bac Ninh City, Vietnam includes an ABR along with a settling unit, anaerobic filter and polishing pond. The project implemented during the year 2009 treats a volume of 400 m^3/day. The complete project cost was about 370,000 USD and the plant is successfully discharging the effluents as per the national quality regulations – COD < 80 mg/L and BOD <50 mg/L (BORDA, 2010).

The DEWATS system at Manjuyod Public Market, in the Philippines has also integrated an ABR as one of the unit systems. The plant, constructed for a total volume of 40 m^3/day at a cost of 120 million PhP (approx 108 million rupees), accepts wastewater from a vegetable market and a group of restaurants and the municipal health office. The influent water has a BOD of 600 mg/L, which is being reduced to the discharge standards of <30 mg/L (BORDA, 2008).

Experiences in India

Anaerobic Baffle Reactors enjoy growing popularity as an anaerobic digestion process unit in decentralised treatment systems in many parts of the country. It has been installed a standalone treatment system, when there is no intended reuse and appropriate disposal options are available. Furthermore, it has also been implemented as part of DEWATS systems, where there are reuse opportunities. Being an underground installation that requires virtually zero open space, ABR is a perfect option for decentralised treatment in the urban scenario of India.

The wastewater treatment system implemented at Kamalini Kuteer resort by Ecosan Services Foundation (ESF) in 2009 has a combination of ABR and Anaerobic Filter. The resort is located around 60km south-west of Pune and is lying next to Kanindi River. The system receives approximately 5m^3 wastewater per day withBOD of 240mg/L. The system has been giving stable performance (BOD>30mg/L) since its implementation.

During the construction of a bridge over Brahmaputra River at Bogibeel near Dibrugrah in Assam, ESF designed a decentralised wastewater treatment system for Hindustan Construction Company for the wastewater generated from the labour colony .The system was designed for 800 people equivalent and the anaerobic system has a capacity of 10 m^3/day. The system has been running for the past 6 months and has shown stable treatment efficiency.

The decentralised water management system implemented at Adarsh Vidyaprasarak Sanstha's College of Arts & Commerce, Badlapur, Maharashtra is working example of ABR. The institution hosts 2600 students and also acts a community centre for many programmes. With a daily wastewater production of 8m^3, the ABR was constructed for 12m^3 considering an HRT of 1.5 days. The total project cost came up to Rs.4.5 lakhs (approx.. 8000 € at 2008 exchange rate) out of which 1.2 lakhs (approx. 2200 € at 2008 exchange rate) was for the ABR. The wastewater is treated as it flows through a biogas settler, anaerobic baffle reactor, upflow filter and a constructed wetland. Further, the water enters in the polishing pond from where it is being taken to reuse in irrigation purposes. The project was an EU funded AsiaProEco II and was executed by Badlapur Municipal Council with the support from Ecosan Serviced Foundation, seecon international gmbh and Paradigm Environmental Strategies Ltd. (Zimmermann, 2010).

An innovative concept of prefabricated DEWATS has been implemented for rehabilitation projects by CDD_BORDA in many parts of the world. These systems were installed in different parts of Tamil Nadu as a part of Tsunami rehabilitation project. These are systems made of FRP tanks and can easily be transferred by shipping containers, which has reduced the cost and time for construction considerably (BORDA, 2009).

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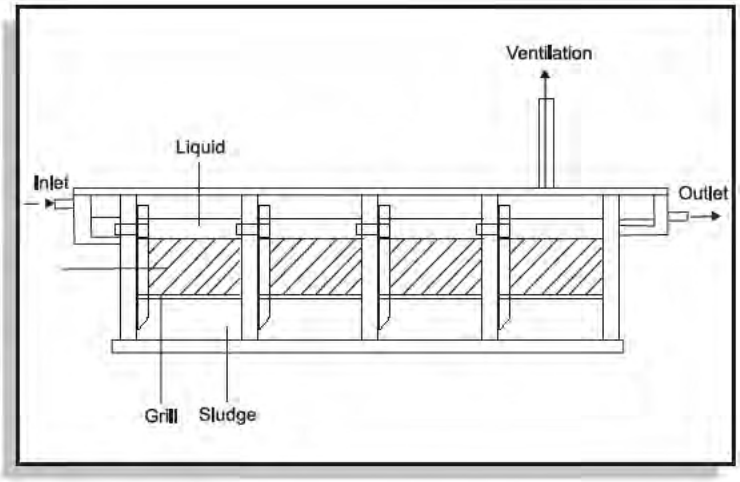

An Anaerobic Filter (AF) is a fixed-bed biological reactor used for treating wastewater having non-settable and dissolved solids. As wastewater flows through the filter, particles are trapped and organic matter is degraded by the biomass that is attached to the filter material. There are two main types of AF viz. up-flow and down-flow filters. AFs are considered as one of the most useful system at high organic loading rates for treatment of low and high strength wastewaters (Tay and Show, 1998). AFs are widely used as secondary treatment in DEWATS.

Design and Construction Principle

AF may consist of cylindrical or rectangular tanks having an enclosed fixed or floating media within the reactor. AF operates as a flow-through contact process and most of the times it is operated in up-flow mode (Young and Yang, 1989). Whilst designing the AFs, parameters including characteristics of wastewater, volumetric organic loading, flow velocity, physical features, gas collection and the solid separation need to be addressed. The design should also consider Solid Retention Time (SRT), Hydraulic Retention Time (HRT), allowable head-loss, and backwash requirements (if any) along with the media to be used in the system (Tchobanoglous et al., 2003). "Typical filter material size ranges from 12 to 55 mm in diameter. Ideally, the material will provide between 90 to 300 m^2 of surface area per 1m^3 of reactor volume. The water level should cover the filter media by at least 0.3 m to guarantee an even flow regime. A HRT of 0.5 to 1.5 days is typical and recommended. A maximum surface-loading (i.e. flow per area) rate of 2.8 m/d has proven to be suitable" (Tilley et al., 2008). At lower temperatures, bacterial activity decreases and it results in lower treatment performance. Hence in cold climate countries, only a small separated portion of the sewage, namely the primary and secondary sludge are treated anaerobically, however requiring heavy insulation and heating system, while the bulk of the volume, the wastewater, is treated aerobically (Van Haandel and Lettinga, 1994).

Operation and Maintenance

Process parameters need to be monitored closely viz. temperature, pH, effluent concentration, gas production (Tchobanoglous et al., 2003). AFs are less energy intensive. The seeding is required in order to grow the anaerobic bio culture on the filter media. In case of fixed film filter, the hydraulic load must correspond to the upstream velocity and must correspond to the organic load. Desludging is periodical. Backwash is required in case of clogging of the filter media. Appropriate management of flammable gases like methane is necessary either by collection, venting or burning in the air. O & M of anaerobic filters require skilled staff.

Cost Considerations

Construction costs are low in case filter materials are locally available. Neither moving parts nor technical energy needed for operation of AF. Manual or vacuum desludging required annually and back-washing of filter materials may be required every five to ten years (Sanimas, 2005).

Advantages

- A high degree of waste stabilisation
- Low production of by-products i.e. waste biological sludge
- Low nutrient requirements
- Useful end product i.e. Methane

Source: McCarty, 1964, Bodik, I., 1999 & Sanimas, 2005

Disadvantages

- Relatively high temperatures required for optimum operation
- Dilute wastes may not produce sufficient methane
- Clogging of matrix
- Master mason required for high-quality plastering work

Experiences in Europe and other Cities of the World

The first models of fixed film AF were designed during 1968 whilst the down-flow anaerobic filters were scaled fully in 1983 (Irwin, n.y.). Since then these systems are being used in the world. The AF is being used for beverage, food-processing, pharmaceutical and chemical industries due to its high capability of bio-solids retention (Ersahin et al., n.y.). Anaerobic Filters are being used in countries including Brazil, Colombia, Mexico (Cakir, 2004) and they are rarely employed in U.S. onsite applications (Corea, 1998).

Bodik et al. (2000) undertook a research for finding economically and technologically suitable technology for treating municipal wastewater. Based on the experiments and observations, it was found that the use of Upflow Anaerobic Filter reactor is potential technology for treating of wastewater produced by small communities in comparison with UASB. He further states that this technology is relatively cheap and could be a technological solution for the post-communist countries (Central & Eastern European countries), where there is a high demand for a larger number of smaller WWTPs.

Experiences in India

Anaerobic Filters are widely used in hot climates, where domestic wastewaters have high organic content (Corea et al., 1998). A pilot study was carried out for a community of 300 people near city of Auroville in Tamil Nadu, where the AF has been used in combination of Reed Bed Technology to treat domestic wastewater from the community (CPCB, 2008).

Banu et al. (2007) studied a hybrid system of Anaerobic Filter and Upflow Anaerobic Sludge Blanket (UASB) to treat domestic wastewater. They termed this hybrid system as Hybrid Upflow Anaerobic Sludge Blanket (HUASB). The team collected the domestic wastewater from Nessapakkam Sewage Treatment Plant, Chennai, India. This sewage was treated with HUSAB and they found that COD removal varies from 75-86% and the BOD removal efficiency was in the range of 70-91%. They concluded their study by stating that "HUSAB appears to be a promising alternative for the treatment of domestic wastewater in developing countries like India". Ecosan Services Foundation (ESF) and seecon gmbh in 2008, constructed a Decentralised Wastewater Treatment System (DEWATS) at Adarsh College, Badlapur, India; where AF was used in combination with Anaerobic Baffle Reactor (ABR) as a secondary treatment system. This DEWATS caters 8 m^3/day of wastewater generated by the college students (Zimmermann et al., 2008). In 2010, two DEWATS systems involving AFs were installed and made operational for boy's hotels block and admin office at Tata Dhan Academy at Madurai. Both the systems cater wastewater generated by 300 people (Götzenberger, 2010). CDD - BORDA has implemented 3 DEWATS systems in the City of Nagpur, India catering population of 4,420 which generates over 344 m^3 of wastewater. Anaerobic Filters are the crucial part of secondary treatment in these DEWAT systems (Bhandarkar, 2013).

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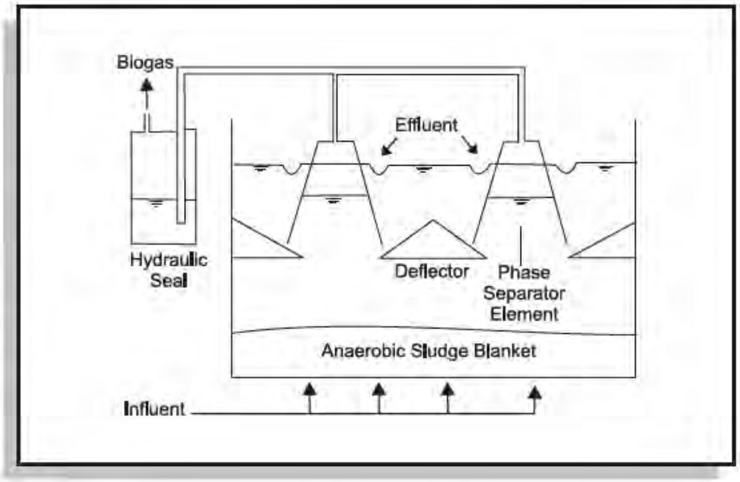
NaWaTech

Rajesh Shenoy, Girish Pophali, Pawan Labhasetwar and Pranav Nagarnaik, CSIR-NEERI

UASB maintains a high concentration of biomass through formation of highly settable microbial aggregates. Wastewater flows upwards through a blanket of flocculated biomass in a vertical reactor containing anaerobic bacteria, which break down carbonaceous organic matter. At the top of the reactor phase separation between gas-solid-liquid takes place. The process is suitable for both soluble wastes and those containing particulate matter. This technology is used as a primary treatment option and the effluent cannot be discharged directly without adequate post treatment.



Design and Construction Principles

Wastewater flows upwards through a blanket of flocculated biomass in a reactor containing anaerobic bacteria, which break down carbonaceous organic matter. The dimension of UASBs is calculated on the volume of sewage to be treated and the flow rate maintained in the reactor. For dilute wastes, the minimum HRT at average flow may be 6 to 12 h for wastes containing suspended organic matter. The average hydraulic over flow rate should not exceed 1 m/h for flocculent sludge and 3 m/h for granular sludge. The SRT in UASB varies between 15-30 days (CPHEEO, 2012).The space requirement is 0.2-0.3 ha/MLD of installed capacity. Commonly used construction material is Reinforced Cement Concrete (Khalil et al., 2008).The most preferred post treatment option for installed UASBs is Waste Stabilisation Ponds (WSP). For an organic loading of 1-2 kg COD/m^3, the COD reduction efficiency would be in range of 50-70% (CPHEEO, 2012). In the case of treatment of municipal sewage, the BOD oftreated effluent could be expected to be 50 mg/l assuming the influent to be 200 mg/l.

Operation and Maintenance

The energy requirement is 10-15 KW/ML of sewage treated (NRCD, 2009). Regular painting/coating of corrosion susceptible material/exposed surfaces is required. Furthermore, careful monitoring and control of the reactor sludge levels and sludge withdrawal is needed, as well asfrequent cleaning or desludging of distribution or division boxes and influent pipes (Tare and Bose, 2009).The sludge production in UASB is well stabilised and dries directly on a sand bed. Removal of scum and floating materials from the settling zone needed. Prevent mixing of industrial effluents with toxic elements and sulphates or sulphites (MoUD, 2008).

Cost Considerations

It is estimated that about Rs. 2.5-3.6 million/MLD is required as capital cost. Approximately 65% of the total capital cost is of civil works and remaining 35% is for electrical and mechanical works (MoUD, 2008).About Rs. 0.08-0.17 million/MLD/y are required as operation and maintenance costs, constituting 1% of the capital costs. Installation of UASB would require external finances. The financing of the UASB based Sewage Treatment Plants installed in India was by made by the Central Government of India.

Advantages

- Power supply interruptions have minimal effect
- Sludge handling is minimised
- Can absorb hydraulic and organic shock loading
- Resource recovery option via sludge and biogas

Disadvantages

- Can not meet standards without post treatment
- Faecal and Total Coliform removal is poor
- Poor acceptability due to aesthetics (dark effluent)
- Exploitation of biogas unsustainable for sewage

Experiences in Europe and Other Cities of the World

UASBs to treat domestic sewage have been in operation under low temperature conditions in the Netherlands since 1976 (van Velsen, 1988). A joint project financed by the Dutch Government was carried out in Cali (Colombia) to test the financial and technical feasibility of the UASB process for sewage treatment at pilot scale (Schellinkhout, 1985). In 1987, a demonstration UASB plant of 336 m^3 was built in Senigallia (Italy) (Urbini, 1988).

In 1990, a sewage treatment plant based on UASB was started up in Bacuramanga, Colombia with a capacity to treat 31,000m^3/d. In Odemira, southern Portugal, a 20 m^3 demonstration plant was constructed under Portuguese-Dutch cooperation. Two stage UASB reactors were also applied to domestic sewage in Spain, which experienced COD reduction up to 62% at 14 h HRT. A pilot scale UASB reactor was operated in University of Tanzania, which attained 64% COD removal efficiency. Average removal efficiency of 70%, 80% and 87% was obtained for COD, BOD and TSS respectively in a pilot UASB (for a community of 235 people) operating in Brazil. Three 1.2 m^3 UASB was tested in Bandung, Indonesia. The treatment efficiencies were high due to high sludge stabilisation and high sludge hold up achieved (Seghezzo et al., 1998).

Experiences in India

UASB technology was introduced in India in the late eighties during Ganga Action Plan (GAP). A set of pilot plants was installed at Kanpur for treatment of mixture of sewage and tannery effluents and later exclusively for sewage. Based on the limited experience of the two pilots at Kanpur, UASB was the most preferred technology option under Yamuna Action Plan (YAP), which was implemented during 1993-2002. Under this plan UASBs were installed across Delhi and the states of Uttar Pradesh and Haryana.At present, 23 full scale UASBs are in operation across India with a total installed capacity of 985 MLD (Khalil et al., 2008). The largest UASB plant is in Agra, Uttar Pradesh (78 MLD). When the UASBs based Sewage Treatment Plants (STPs) were evaluated, none of them were complying with the discharge standards in terms of BOD, SS and FC removal.

UASB technology has been found to be very effective for treatment of high strength industrial effluents. However, when applied for sewage, the cumulative experience has shown that their "unique" features are not convincing for variety of reasons. UASB reactor requires second stage aerobic treatment to enable compliance with discharge standards. Under YAP-1, all UASBs were followed by FPUs of one-day retention for secondary treatment. This limited retention time minimised land requirement, but from treatment point of view it at best offered only removal of solids washed out of the reactor (Sato et al., 2006). Washout of sludge has been observed to be an operational problem as biogas resulting in instability of the reactor leading to deteriorations in the performance and very high BOD and suspended solids in the effluent (WSP, 2008). Anaerobic bacterial culture is affected by a fluctuation of 3-5^{0}C. Therefore biogas production has shown to go down in winters of North India. Performance of UASB based plants has been adversely affected by mixing industrial effluents that contain some toxic materials. There is a risk of corrosion of the engine parts as the biogas typically contains hydrogen sulphide. The dual fuel engines, which are installed due to their low cost, invariably require large quantity of diesel fuel as supplementary fuel. It makes no business sense to operate the dual fuel generators on externally purchased fuel. There have been cases of gas engines being taken off due to severe corrosion and desulphurisation plant being abandoned due to lack of required chemicals and resources. Another resource recovery option through the sale of sludge has found no takers (Tare and Nema, 2006).

The Central Public Health and Environmental Engineering Research Organisation (CPHEEO) manual on Sewage and Sewerage Management released in 2012 explicitly states that the use of UASBs shall be discontinued gradually over a period of time.

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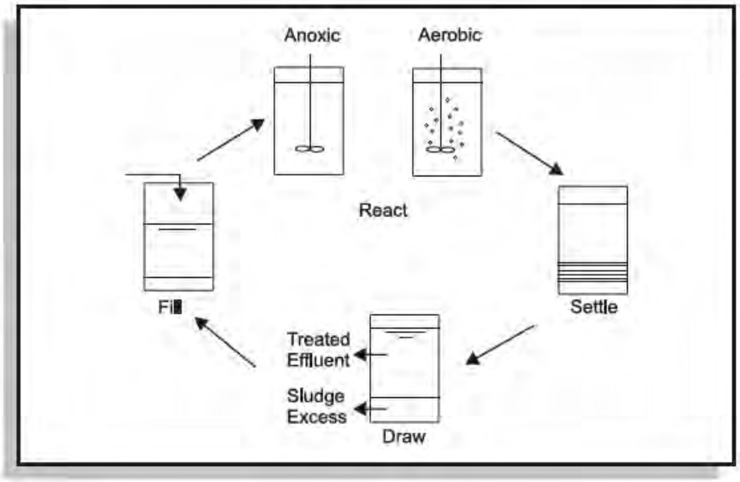
(Adapted from: Dorothee Spuhler
seecon international gmbh)

Activated sludge reactors are aerobic suspended-growth type processes. Large amounts of injected oxygen allow maintaining aerobic conditions and optimally mixing the active biomass with the wastewater to be treated. Activated sludge systems are highly efficient for organic matter and nutrient removal, though pathogen removal is low. In the view of reuse of the effluent in agriculture, it is not beneficial to remove all nutrients while standards for pathogen removal are barely met.



Design and Construction Principles

The Sequencing Batch Reactor (SBR) is a different configuration of the conventional activated sludge systems, in which the process can be operated in batches, where the different conditions are all achieved in the same reactor but at different times. The treatment consists of a cycle of five stages: fill, react, settle, draw and idle. During the reaction type, oxygen is added by an aeration system. During this phase, bacteria oxidise the organic matter just as in activated sludge systems. Thereafter, aeration is stopped to allow the sludge to settle. In the next step, the water and the sludge are separated by decantation and the clear layer (supernatant) is discharged from the reaction chamber (Asano et al., 2007). Depending on the rate of sludge production, some sludge may also be purged. After a phase of idle, the tank is filled with a new batch of wastewater (UNEP & Murdoch University, 2004). At least two tanks are needed for the batch mode of operation as continuous influent needs to be stored during the operation phase. Small systems may apply only one tank. In this case, the influent must either be retained in a pond or continuously discharged to the bottom of the tank in order not to disturb the settling, draw and idle phases. SBRs are suited to lower flows, because the size of each tank is determined by the volume of wastewater produced during the treatment period in the other tank (UNEP & Murdoch University, 2004). Pollutants removal efficiency: BOD_5: 95%, COD: 90%, TSS: 95%, Pathogen: N/A.

Operation and Maintenance

Mechanical equipment, such as pumps, aerates and mixers, require continuous maintenance and control, and supply of oxygen and sludge is essential (WSP, 2008). Control of concentrations of sludge and oxygen levels in the aeration tanks is required and technical appliances (e.g. pH-meter, temperature, oxygen content, etc.) need to be maintained carefully. To make sure that optimal living conditions for the required bacteria are guaranteed and a satisfying effluent quality is met, the influent as well as the effluent should be supervised and controlled constantly (e.g. by a centralised computerised monitoring system).

Cost Considerations

Construction and maintenance costs are high as activated sludge treatment units are highly mechanised. Operation costs have been usually expensive due to the requirement of permanent professional operation, high electricity consumption (pumping and aeration) and costly mechanical parts (Sanimas, 2005), but in the last years the development of cheaper and more energy efficient equipment has reduced significantly the operational cost.

Advantages

- Little land required
- High effluent quality
- Fully automatized
- Resistant against shock-loads and applicable for a large range of organic and hydraulic loading rates

Disadvantages

- Requires continuous supply of energy
- Highly mechanised equipment (control panel)
- Effluent and sludge might require further treatment

Experiences in Europe and other Cities of the World

Fill-and-draw batch processes similar to the SBR are not a recent development as commonly thought. Between 1914 and 1920, several full-scale fill-and draw systems were in operation. Interest in SBRs was revived in the late 1950s and early 1960s, with the development of new equipment and technology. Improvements in aeration devices and controls have allowed SBRs to successfully compete with conventional activated sludge systems (EPA, 1999).

The Sequencing Batch Reactor (SBR) process has been successfully applied to more than 1,300 plants in the U.S., Canada, and Europe within the last 25 years. In particular, the number of SBR plants in North America is growing rapidly. Many of these facilities have been constructed for small communities, producing less than 4,500 m^3/d of wastewater, although larger plants (up to 870,000 in Dublin, Ireland) have used SBR technology with similar effluent quality results (Toprak, 2005).

Further examples of the compact design of the SBR process can be found in Bangkok, Thailand (average daily flow of 200,000 m^3/d and peak flow of 500,000 m^3/d) utilise tanks stacked on 4 levels to achieve a treatment plant footprint of 6,000 m^2.

Experiences in India

SBR technology is being successfully applied worldwide for treatment of landfill leachate, phenolic effluent, oilfield wastewater, slaughterhouse effluent, milking parlour effluent, dyeing wastewater and various other industrial wastewaters. However, the feasibility of SBR application has neither been explored nor very much tried in India (Science & ENGG., 2006). Currently some SBRs have been installed in urban areas like:

- Mundhwa Sewage Treatment Plant, Pune, India. The results are yet to be available as a published source, but it is stated that the raw BOD, SS and TKN of 205, 262 and 45 mg/l are reduced to less than 10 mg/l with phosphorous being 2.3 in the inlet and 0.7 in the outlet. The raw sewage MPN Faecal coliform of 230,000/100 ml was reduced to 7,500/100 ml but was still much higher than the NRCD limitations of 1000/100 ml.
- Sewage Treatment Plant (SBR) Kalpataru Construction Overseas, Mumbai. Capacity 65 m^3/day. For the Commercial and residential building at the Camlin compound in Andheri, Mumbai. Sequential Batch Reactor (SBR) was chosen because of its compact footprint and ability to achieve enhanced nutrient removal. Also the output water needed to be used for a multiple of uses – right from toilet flushing, landscaping and cooling towers.
- Magarpatta City: SBR treating 3,000 m^3/d of wastewater produced by the city. The treated water is used for lake recharge and secondary uses.
- Noida City: SBR built in Noida City to treat 35,000 m^3/d of wastewater corresponding to the current and the expected wastewater to be produced by some areas of the city in the next years.

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(Adapted from: Dorothee Spuhler
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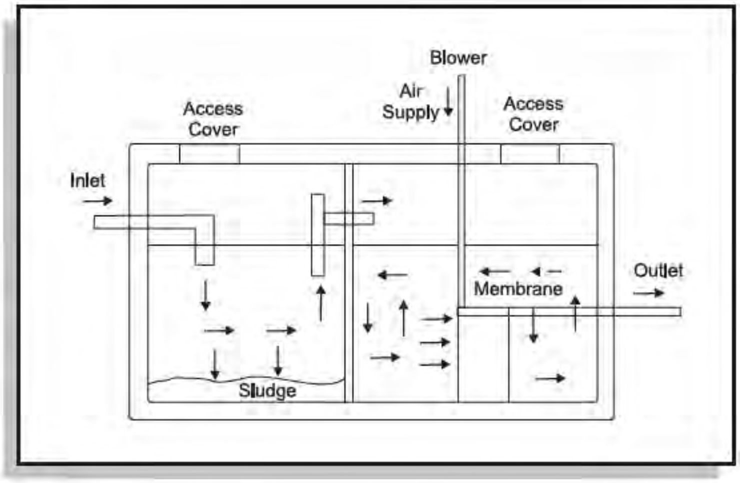
MBRs combine conventional biological treatment processes with membrane filtration to provide an advanced level of organic and suspended solids removal. The development of new polymeric membranes, cheaper and more resistant, together with less pressure requirements and higher permeate flow, has made the submerged membrane configuration in MBRs the most common, although it is also possible to use external membranes.



Design and Construction Principles

The Membrane Bioreactor (MBR) process (membrane activated sludge process) is an advanced wastewater treatment technology and constitutes a suspended growth activated sludge system, which instead of secondary clarifiers utilises low-pressure membranes for solid/liquid separation. As opposed to secondary clarification, the quality of solids separation is not dependent upon the mixed liquor suspended solids concentration, or the settling characteristic. Hence, the fact that MBRs can operate with much higher mixed liquor suspended solid concentrations, which provides an intensified biological process. Accordingly, the two major benefits of the MBR process are substantially reduced land and space requirements, and the reclamation of water (permeate) of excellent quality, which is a valuable source for higher demand reuse applications (Lahnsteiner et al., 2007). There are five types of membrane configuration, which are currently in operation: Hollow fibre (HF), Spiral-wound, Plate-and-frame (i.e. flat sheet - FS), Pleated filter cartridge and Tubular. To provide optimal aeration and scour around the membranes, the mixed liquor is typically kept in the 1.0-1.2% solids range, which is 4 times that of a conventional plant. Pollutants removal efficiency: BOD_5: 99%, COD: 95%, TSS: 99%, Pathogen: 99.99% (Fitzgerald, 2008)

Operation and Maintenance

Most MBRs employ chemical maintenance cleaning on a weekly basis and recovery cleaning when filtration is no longer durable (once or twice per year). A deposit that cannot be removed by available methods of cleaning is called "irrecoverable fouling". This fouling builds up over the years of operation and eventually determines the membrane lifetime (Radjenovic et al., 2008). All O&M tasks have to be done by skilled workers. Modern systems are maintained with chemicals, i.e. it is not necessary to remove the membranes from the membrane tank (Kubota, 2010).

Cost Considerations

Although MBR capital and operational costs (membranes, oxygen utilisation, expert design, etc.) exceed the costs of conventional process, it seems that the upgrade of conventional process occurs even in cases when conventional treatment works well. This can be related to increase of water prices and the need for water reuse as well as with more stringent regulations on the effluent quality.

Advantages

- Low plant footprint.
- Less sludge production than the conventional activated sludge systems.
- High effluent quality
- High loading rate capability

Disadvantages

- Operation and capital costs (membranes) higher than in non-conventional systems.
- Membrane complexity and fouling
- Medium-Skilled personnel required
- Energy demanding system

Experiences in Europe and other Cities of the World

At present, approximately 800 MBRs with a total capacity of nearly 1.2 million m^3/day are treating municipal wastewater worldwide. Indeed, since 2000, the number of plants has tripled and total capacity has increased by a factor of 20 (Pinnekamp, 2007). Most of the plants have been built in Asia (303 MBRs) followed by North America (295 MBRs), while in Europe only 169 MBRs have been realised. However, if the total capacities are considered, the picture is quite different, i.e. North America: 492,000m^3/day, Europe: 423,000 m^3/day, Asia: 268,000 m^3/day (Lahnsteiner et al., 2007).

In Europe, the first full-scale MBR plant for treatment of municipal wastewater was constructed in Porlock (UK, commissioned in 1998, 3,800 PE), soon followed by Büchel and Rödingen WWTPs (Germany, 1999, resp. 1,000 and 3,000 PE), and Perthes-en-Gâtinais WWTP (France, 1999, 4,500 PE). Only a few years later, in 2004, the largest MBR plant worldwide so far was commissioned to serve a population of 80,000 PE in Kaarst, Germany. The installations have thus grown from "small-size WWTPs" to "very large-size WWTPs" within only a few years (Lesjean and Huisjes, 2007).

Experiences in India

The Manual on Sewerage and Sewage Treatment published by the Indian Ministry of Urban Development in 1993 (last update on 2012) emphasised conventional sewage treatment technologies such as Activated Sludge Process (ASP), Waste Stabilisation Pond (WSP), Upflow Anaerobic Sludge Blanket (UASB) Reactor, etc. Over the last two decades, many new technologies for sewerage and sewage treatment have emerged like membrane bioreactors. This technology, which is being used in other parts of the world, has not been deployed in India on a large scale until recently. Because of the advantages of the technology, the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) has recently adopted the MBR technology as a suitable technology for the Indian conditions.

Some examples of MBR plants in India are:

- Delhi Games Village - Water treatment plant. Capacity: 4,545 m^3/d.
- India's first wastewater recycling plant for IOCL Panipat. Capacity: 21,600 m^3/d.
- India's largest lamella wastewater treatment plant for the Brihan Mumbai Municipal Corp. (BMC).
- India's first wastewater treatment plant based on a (Build-Own-Operate-Transfer) BOOT model for Alandur. Capacity: 24,000 m^3/d.

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NaWaTech

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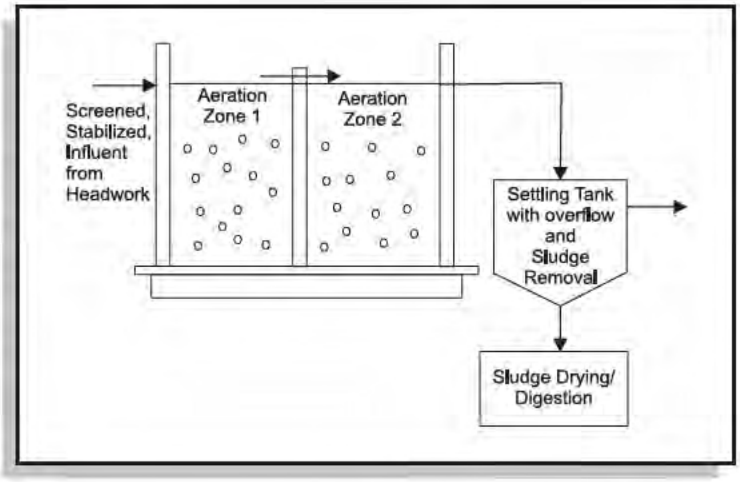
It's a combination of activated sludge process (suspended growth) and biofilter processes (attached growth). Moving Bed Biofilm Bioreactor (MBBR) process uses the whole tank volume for biomass growth. It uses simple floating media, which are carriers for attached growth of biofilms. Biofilm carrier movement is caused by the agitation of air bubbles. This compact treatment system is effective in removal of BOD as well as nitrogen and phosphorus while facilitating effective solids separation.



Design and Construction Principles

This reactor can have any shape and different loads in a reactor volume depending on carrier filling. Design of the reactor is based on the actual wastewater characteristics and local conditions. MBBR units are placed in series based on the load entering each reactor. Neutralised and settled wastewater passes through MBBR for reduction in BOD/COD. Most of the MBBR plants are provided with vertically or horizontally mounted rectangular mesh sieves or cylindrical bar sieves. Biofilm carriers are made up of high density (0.95 g/cm^3) polyethelene. These are normally shaped as small cylinders with a cross inside and fins outside. The standard filling of carrier is below 70% with a maximum specific area not more than 465 m^2/m^3. Generally, design load for COD-BOD removal is 20 g COD / m^2d. Smaller carriers need smaller reactor volume at a given loading rate (as g/m^2d) when the carrier filling is same. HRT of the reactor is about 3 – 4 hours for effective BOD and nitrogen removal. It is advisable to use MBBR in combination with a septic tank or a pre-coagulation step as a pre-treatment unit, depending on the local conditions and input characteristics. It is a very robust and compact alternative for secondary treatment of municipal wastewater, having removal efficiency for BOD 90 – 95 % (low rate) and that of 75 – 80 % for high rate. Average nitrogen removal is about 85 %. There is no need for sludge recirculation. Phosphorus and faecal coliform reduction is feasible with additional passive (non-mechanical) or active (mechanical) system components.

Operation and Maintenance

A constantly operating MBBR does not require backwashing or return sludge flows. It has minimal head-loss. Coarse-bubble aeration in the aeration zone in the wastewater treatment tank provides ease of operation at low-cost. Agitation continuously moves the carrier elements over the surface of the screen thus preventing clogging. Maintenance of MBBR system includes screening, influent equalisation, clarifier system, sludge handling and integrated control system. There is no need to maintain f/M ratio as there is self-maintenance of an optimum level of productive biofilm. Skilled labour is required for routine monitoring and operations of pumps and blowers.

Cost Considerations

Construction cost of the MBBR is moderate (80%) as compared to other hi-tech wastewater treatment systems, including the screen box, MBBR, clarifier, foundations for units, sludge collection and drying with simple barbed wire fencing for treatment area. The electro-mechanical cost involves machines and monitoring equipment, like pumps for wastewater transfer, blower for air, distribution pipelines for water and air with internal support systems and on-line pressure gauges. Operational costs are inclusive of screen cleaning, biosolids removal, pumping, aeration, and skilled man-power.

Advantages

- Low power consumption
- Up-gradation and mobility
- Flexibility to adapt fluctuating hydraulic & organic loads
- Aesthetics

Disadvantages

- Change of media after some time
- Odour
- Higher running cost

Experiences in Europe and other Cities of the World

There are more than 10 variants of MBBR in the various parts of the world such as Kaldnes, Pegasus, Captor, Linpor, etc. These variants are the result different materials used for developing biofilm carriers. MBBR treatment system is being used worldwide to treat different flows high-strength industrial and domestic wastes. Since 1970-80s after inception of Linpor and Kaldnes processes, many existing activated sludge processes were retrofitted with MBBR systems by adding biofilm carriers (Odegaard, 1994 and CPHEEO, 2012).

It is experienced that sewage treatment units using MBBR processes have treatment efficiency >95% in case of BOD removal and >99% for removal of ammoniacal nitrogen. Most of the European plants (Odegaard, 2006) are using MBBR for P-removal in addition to COD-BOD reduction. Some Norwegian MBBR systems have potential of nitrification rates as high as 1.2 g NH4-N/m^2 d to complete nitrification at low temperatures (11^{0}C), while denitrification rates are found as high as 3.5 g NO_3-Nequiv./m^2d. This implies that MBBR process improves the performance of biodegration of pollutants even at lower temperatures. In Asian countries like Japan, BOD removal is about 93% and total nitrogen removal is about 75% by upgrading ASP to MBBR. Depending on the extent of pre-treatment, the total HRT of the MBBR for N-removal can be provided in the range of 3 to 5 h.

Experiences in India

MBBR process under various commercial names is being used for sewage treatment in India for the flows ranging from 10 m^3/d to 8 MLD, especially for newly developing townships in the urban, semi-urban or rural-urban areas. It's mandatory for them to treat sewage as per statutory standards before releasing into the environment. There are about 300 – 400 installations in India. These systems are found useful in reducing the space footprint of conventional ASP based STPs. Adaptation of MBBR is reported to reduce solids load in secondary sedimentation tank.

There are some limitations of MBBR installations in India. Performance is affected by higher concentration of oil and grease and total suspended solids. The design criteria of MBBR adapted to the Indian conditions are not established, however the technology was introduced in the country a decade ago. Complex process parameters such as biofilm area, biodegration activity and treatment efficiency are based on empirical data of pilot studies or partial full-scale results. The adoption of MBBRs for existing STPs has not been smooth, giving rise to problems, such as clogging because of non-availability of primary sedimentation or large pores of screens. Dissolved oxygen is very essential for the effectiveness of biofilms. One of the major shortcomings of the technology in Indian conditions is that there is less nutrient removal than that of claimed (MoEF, 2010 and MoUD, 2012).

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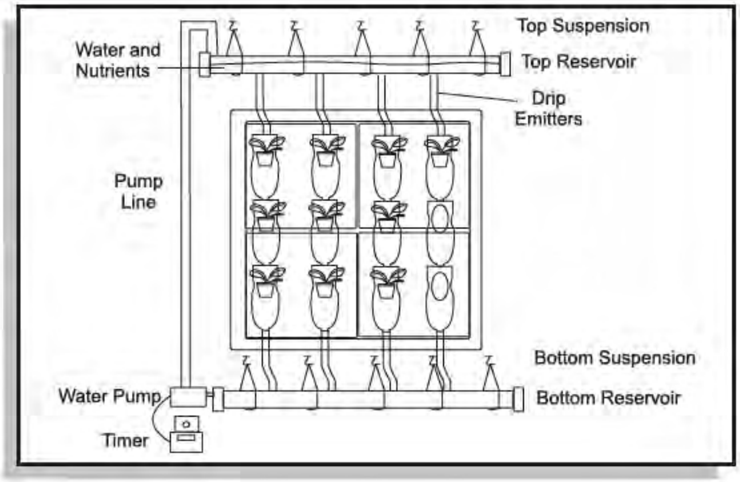

The Vertical Garden is a stackable planter made for indoor and outdoor use. Also called plant wall, green wall and bio wall, this is a light framed, mostly self –supporting plant community where the necessary water, light and plant food are provided by a highly automatized system. The system is based on the principles of hydroponics where the plants are rooted in a porous material soaked in fertilizer instead of soil. When adapting its construction to improve the filtration capacity, this can be used also as greywater treatment, permitting to reuse the treated water.

Design and Construction Principles

The design of vertical garden depends on the available material, space and local preferences as well as on the creativity and imagination of the users. There are very simple designs like tray models similar to nursery flats, where rectangular, plastic trays are divided into planting cells — all slanted at a 30-degree angle, with bottom holes that promote drainage and aeration. Each tray comes with a bracket for mounting. Complicated structures like green wall can be also there where the structure itself is a 10 mm-thick humidity-proof plastic panel fitted on a stainless metal frame, which is covered in a special, rot-free, absorbent synthetic felt in layers. This felt serves as pockets for planting. The entire width of the structure is 4-20 cm, with the larger for greywater treatments. The supporting frame includes a water-tank and an automatized drip irrigation system. A properly adapted green wall can receive greywater instead of normal water, ensuring a good level of treatment; greywater have to be pre-treated (degreaser and a pre-filter are suggested to avoid obstruction of the drip irrigation system and of the vertical filters). There are very few applications in the world with treatment purpose; even these experiences are successful and interesting, currently it is difficult to list precise construction principles: generally, they use different panel types and various filling material (LECA and other lightweight granular material seem the most adaptable). The selection of the plants is a technical criterion of utmost importance because determines the texture, colour-combination, shape variety and life span of the wall and in case of treatment also the removal efficiency The loading often happens on two panels in series. A pilot system recently developed in Germany (Rousseau and Baumer, 2013), with a hydraulic loading rate of 35 L/ m^2 of vertical wall (2 m^2/PE), the unit shows removal of 96% for COD, 91% for N, 67% of P, 97% of foam, whereas the disinfection is limited to 2 log.

Operation and Maintenance

Vertical gardens require more maintenance than gardens in traditional horizontal plane. Fertilisation and watering (usually using nutrients enriched water) should be automated to ensure that the needed ingredients are evenly -and regularly- distributed. In this sense the use of the vertical wall as greywater treatment could be attractive, considering that the greywater are normally produced every day and they could substitute the irrigation needs.

Cost Considerations

Cost depends on design chosen. A simple tray model will cost up to a maximum of 100 €, which includes the costs of tray, wire mesh and fertiliser. However, big scale vertical gardening projects can be really expensive; the species and the demands of the plants as well as the automated systems used are greatly affecting the cost of the project. Rousseau & Baumer (2013) have estimated the cost of a 4 PE greywater treatment by green wall in 2,600 € (650 €/PE) including disinfection (excluding labour).

Advantages

- Local reuse of wastewater from household wastes
- Low energy cost and minimal area required
- Temperature insulation by growing plants on the walls of houses
- Simple and easy to understand

Disadvantages

- Unpleasant odours may appear during the irrigation with grey water if not well designed
- A certain amount of labour required

Experiences in Europe and other Cities of the World

Several vertical gardens are growing in many cities around the world, but the examples of green walls used for greywater treatment at large scale are very limited. Promoters of the green wall mention in publications that greywater or recycled greywater is a possible irrigation source for the vegetation system (Weinmaster, 2009). There are some examples of green wall installations, which use recycled greywater, such as "The Gauge" in Melbourne, Australia built by The Greenwall Company (Hopkins and Goodwin 2011).

A relevant case is constituted by the 2,500 m^2 vertical garden at the Tabacalera Space in Tarragona (Spain): completed in December 2011, the green wall is made by Babylon type modular pieces 50 x 100 cm and 14 cm thick substrate and it constitutes in this case the tertiary treatment after an horizontal flow system. The process is developed and patented by Vivers Ter-Asepma as proven greywater treatment by biofiltration using the architectural element of the vegetable walls, and permits the regeneration of greywater from shower and sink for different uses such as irrigation of green areas or supply the toilets.

A pilot vertical filter wall (175 cm depth) was constructed in Ås, Norway and dosed with domestic greywater for a period of three months. Despite a daily dosing rate of nearly 1000 l/m^2 the system achieved average reduction rates of over 95%, 80%, 90%, 30%, and 69% for BOD5, COD, TSS, total nitrogen, and total phosphorus, respectively, as well as approximately two log unit reduction of *E. coli*. (Svete, 2012)

Another demonstrative system is built at Gammelgarn on the Island Gotland, eastern Sweden; the green wall shows good removal of pollutants (95% P, 75% COD, 50% N, 99.5% E.coli) and respects the reuse limits. The dimensions of the wall are 2.40 x 1.55 height x 0.2 m thick and the filter material is gravel (average diameter 1 cm), placed on the backside where greywater is put in, whereas on the front side there are 18 compartments where plants are growing (Bussy, 2009)

Experiences in India

No experiences of green wall for greywater treatment are documented in India; the following examples are successful experiences of vertical garden in the country.

Antilia, Mumbai is designed as the largest and tallest living wall in the world - a seamless, vertical garden that encompasses all walls of the building climbing to the 40th floor. Chicago-based Perkins+Will designed the 24-story tower for business tycoon Mukesh Ambani. Antilia features a band of vertical and horizontal gardens that demarcates the tower's different programme elements. In addition to signalling different space uses and providing privacy, these "vertical gardens" help to shade the building and reduce the urban heat island effect. The cost of the building is reported to be 1 billion dollars (Mathews, 2007).

One of the other examples in India is the Qualcomm Green Wall, which is the 1st indoor green wall project in Bangalore. It is a model indoor green wall project done by ZTC international Landscaping solutions Pvt Ltd. The Qualcomm Green Wall, as conceived by the Architect of the building, is located facing the cafeteria. The wall is aimed at providing aesthetically pleasing appearance to the plain wall and also to improve the indoor air quality. It was installed in 2010 with a wall size of 51.6 m^2.

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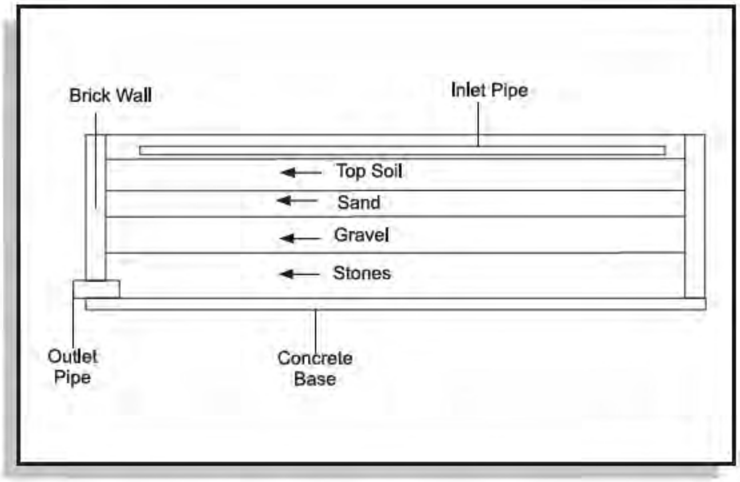

Non-planted sand or gravel filters are frequently applied for domestic greywater treatment throughout the world. It consists in a container filled with sand and/or gravel, through which wastewater flows and is filtered. There are several types of non-planted filters. The most successful is a vertical-flow filter in combination with a pre-treatment facility (e.g. septic tank).

Design and Construction Principles

In a non-planted filter, solids are removed by filtration and sedimentation, and organic matter degradation occurs by microorganisms that colonise the filter bed. Chemical adsorption of pollutants onto the media surface also plays a role in removal of some chemical constituents (e.g. phosphorus). The basic structure consists of a watertight box filled with granular material. The most usual depth of vertical filters is 1 to 1.20 m. However, if there is enough natural slope and good ventilation of the influent, vertical filters can also be built up to a depth of 3 metres (Sasse, 1998). Hydraulic loading ranges between 40-60 L/m^2.d, while space needed ranges from 5 to 10 m^2/PE depending on the design and the goals of the treatment (Crites and Tchobanaglous, 1998). Although different materials, such as pea gravel, peat or crushed glass, can be applied as filter media in non-planted filters, sand is the most widespread material used. Before the pre-treated wastewater or greywater enters the filter body, a pre-treatment is very important to remove oil, grease and solid materials. Septic tanks or anaerobic reactors are a common solution for primary treatment. A properly operated non-planted filter can produce high-quality effluent with less than 10 mg/L BOD (90–95% removal) and less than 10 mg/L TSS (90–95%). Nitrogen removal is rather limited (30–40%) (Morel and Diener, 2006). Bacteria, virus and phosphorus removal is enhanced when using sand rich in iron oxides (Heeb et al., 2007).

Operation and Maintenance

Regular maintenance works at the treatment facility comprises removal of unwanted vegetation from filter bed and cleaning of the inlet/outlet systems. The sludge from the pre-treatment system is removed regularly (depends on system) and managed correctly. The filter bed maintenance becomes more complicated when it is covered (UN-HABITAT, 2008). As for constructed wetlands, the most important concern is clogging. With time, the gravel will become clogged with accumulated solids and bacterial film. The material may have to be replaced every 8 to 15 or more years. The pre-treatment facility must be maintained and emptied regularly.

Cost Considerations

Capital costs are moderate compared to intensive treatment options. They are mainly related to land requirements and purchase. Costs for materials are limited if they are locally available (Sanimas,2005). Furthermore, use of feeder pumps increases operational costs (Sanimas, 2005) as well as maintenance and periodically emptying of the pre-treatment facility (e.g. septic tank). Considering capital and operation and maintenance costs, non-planted filters are still less expensive than intensive treatment options (i.e. activated sludge).

Advantages

- High removal efficiency and good quality of effluent
- Low operation and maintenance
- Local materials required
- Electricity generally only required for pumps

Disadvantages

- Pre-treatment is required to prevent clogging
- Not very tolerant to cold climates

Experiences in Europe and other Cities of the World

Since the 1950s, sand and gravel filters have enjoyed a resurgence of interest and today they are among the most successful methods for onsite wastewater treatment over the world. Their capability for nutrient and pathogen removal, their low maintenance and power requirements, and their tolerance for periodic surges in loading rates make them practical and economic. Non-planted filters are very common in the United States of America. Crites and Tchobanoglous (1998) reported several successful experiences of non-planted filters implementation to treat wastewater in small communities since 1940s. Sand was the mostly used medium while septic tanks or settling tanks and solid separation were the most used pre-treatment.

Drip irrigation was the most common method for effluent reuse. Removal efficiency of these systems was about 90-99% for BOD_5, 50-80% for ammonia and 15-50 % for total nitrogen.

Experiences in India

Non-planted filter are frequently and successfully implemented in India, especially for greywater treatment. UNICEF and NEERI along with Government and Non-government partners have constructed six greywater treatment plants in Dhar and Jhabua, two districts of Madhya Pradesh in Central Province of India (NEERI, 2007).

In these systems the greywater is treated using primary, secondary and tertiary treatment technologies (Godfrey et al., 2009):

- Primary treatment consists of absorption of soap suds using a synthetic sponge, sedimentation baffled/graded settlement tank;
- Secondary treatment involves filtration of water using gravel (10–60mm size) and non-planted sand filter;
- In tertiary treatment the effluent is treated using aeration and chlorination before being pumped to an overhead tank for reusing.

These plants treat between 1,000 and 4,500 L/d. The treated greywater is reused in flushing toilets and irrigation. The operation and maintenance of these greywater treatment plants are looked after by students and Parent Teachers Association (PTA) (NEERI, 2007).

The performance evaluation of these plants carried out by NEERI, showed that the turbidity removal was about 50% (<200 NTU) and that the filtration treatments removed up to 80% of microbial pollution (NEERI, 2007).

The financial feasibility of greywater reuse system was undertaken based on a case study of one Girls boarding school in Ganganagar, District Dhar of Madhya Pradesh (Godfrey et al., 2009). The construction costs (material and labour costs) and operation and maintenance costs were considered, as well as the internal benefits generated by the reduction in water consumption. Results showed that the cost of the system might be recovered in two years furthermore (Godfrey et al., 2009).

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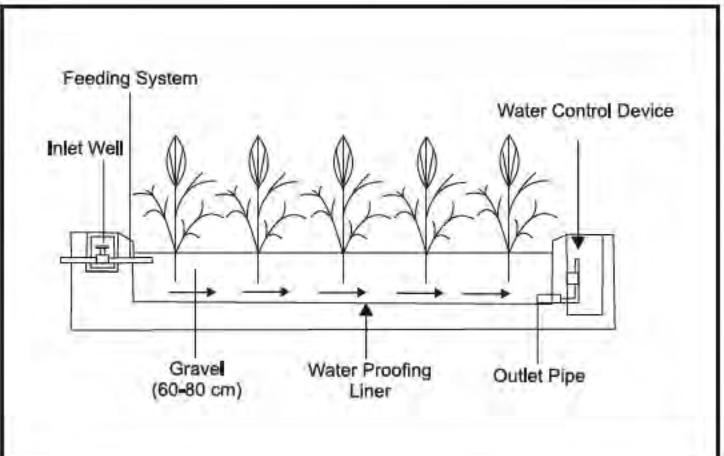
HF CWs are secondary treatment facilities for household, municipal and industrial wastewater, and they can also be used as a tertiary treatment system for polishing. Pre-treated wastewater flows horizontally through a planted filter bed. Plants provide suitable environments for microbiological attachment, aerobic biofilm growth and transfer of oxygen to the root zone. Organic matter and suspended solids are mainly removed by filtration and degradation



Design and Construction Principles

The water in CWs is treated by a combination of biological and physical processes such as adsorption, precipitation, filtration, nitrification, denitrification, decomposition, etc.(Hoffmann et al., 2011). HF CWs, being water saturated filtering beds, are particularly efficient in suspended solids, carbon and pathogens removal, as well as for denitrification, whereas nitrification is limited (Vymazal and Kröpfelová, 2008). In HF systems the wastewater is fed at the inlet zone, usually by gravity, and flows horizontally through the porous filter medium (that is normally small, round, evenly sized gravel of 5-20 mm in Ø, while sand is more prone to clogging and should be avoided), remaining under the surface of the bed and without any contact with the atmosphere, until it reaches the outlet zone. To avoid clogging of the wetland, pre-treatment is necessary to separate solid materials, grease or oils from the liquid. The basins are waterproofed by a plastic liner to avoid soil contamination and planted with aquatic plants (Phragmites is the most common). The depth of filter beds is normally 60-80 cm. The bottom slope should be 0.5-1% from inlet to outlet to achieve good drainage (Morel and Diener, 2006) and the filter length no longer than 25-30 m. The hydraulic retention time and the specific surface area depend on the results to achieve, normally 2-5 days and about 2-5 m^2/PE are enough for discharge in fresh water (the lowest values are applied in warm climates). The hydraulic loading should be 60-80 mm/d for greywater (Ridderstolpe, 2004; Morel and Diener, 2006), 30-40 mm/d for mixed wastewater. The reduction of BOD is about 80-90 %, TSS is from 80 to 95 %, TN until 60 % and for Faecal Coliform is about 2 to 4 log.

Operation and Maintenance

O&M requirements for HF CWs are relatively simple and conducted by unskilled labour (no high-tech appliances or chemical additives), which may allow a community organisation or a private to manage the system. The maintenance includes a periodical sludge and scum control and emptying in primary treatment, plant harvesting, ensuring clogging does not occur in the bed (with time the gravel will become clogged, and may have to be replaced or regenerated every 10-20 or more years), sampling of the discharged water.

Cost Considerations

HF CWs construction costs are in the range of 40-100 €/m^2 depending by the design, the extension, the country, the availability of suitable material in the region and the labour cost. To this cost, the price of pre-treatment installation and pipe connection has to be added. Filling media constitutes the 30-50% of the total investment cost. WSP (2008) reports cost of 1,300 Rs/m^2 (30 USD/m^2) for horizontal flow beds.In developed country the maintenance cost is in the range of 10-15 €/PE, in developing countries this cost is in the range of 2-8 €/PE. The average O&M cost in Nepal is about 0.5-2 USD/m^2 (UN-HABITAT, 2008).

Advantages

- Efficient removal of organic matter, nutrients and pathogens
- Low operation and maintenance – process stability
- No high-tech appliances or chemical additives
- Utilisation of natural processes

Disadvantages

- Permanent space required, high footprint
- Requires expert design and supervision
- Pre-treatment is required to prevent clogging
- Low nitrification especially in cold climates

Experiences in Europe and other Cities of the World

This type of CW was developed in the 1950s in Germany by Käthe Seidel, who designed the HF CWs making use of coarse materials as rooting medium. In the '60s, Reinhold Kickuth experimented soil media with high clay content and called the system the "Root Zone Method". In the early '80s, the HF CWs technology was introduced to Denmark and by 1987 nearly 100 soil-based systems were put in operation. During the late '80s, the HF CWs were also introduced to other countries, such as Austria and UK and then in the 1990s, this system spread into most European countries and also to North America, Australia, Asia and Africa.

In this period, soil or sand was replaced by coarser material (Vymazal, 2012). Nowadays several thousands of HF CW systems are in operation, mainly applied to domestic/municipal wastewater as also for industrial effluents with high organic loads (wineries, dairy farms, landfill leachates, oil firms, etc.) and urban or agricultural runoffs. HF CWs are considered in most cases the most appropriate CW technology for greywater treatment (Masi et al., 2010). When compared to VF CWs, the main advantage appears to be the chance of feeding the system by gravity, with no needs of alternate dosing of the wastewater.

Experiences in India

Despite CWs have a strong potential for application in developing countries, particularly by small rural communities, due to their low cost and easy maintenance, these systems have not found widespread use in India, due to lack of awareness and local expertise in developing the technology on a local basis. India's first constructed wetland (HF of 2,700 m^2) was installed at Sainik School, Bhubaneshwar in the State of Orissa; planted with two types of macrophytes, viz. Typha latifolia and Phragmites karka. At present 180-200 m^3 wastewater are being treated by the wetland. BOD and nitrogen removal were 67-90% and 58-63% respectively (Juwarkar et al, 1995). An HF demonstration unit was constructed by EPCO at Ekant Park in Bhopal to treat 70 m^3/day: a septic tank of 35 m^3 was installed before the HF system of 700 m^2 filled with gravel and planted with Phragmites karka. The monitoring results (April 2002-Sept 2003) show good removal for COD (77%), TSS (79%), Coliform bacteria (99%) (Vipat et al., 2008). Another field scale HF case study was realised at the Ujjain Charitable Trust Hospital and Research Centre (Madhya Pradesh): the system, filled with gravel 10-25 mm and planted with Typha latifolia, treats 8 m^3/day with a surface of 80 m^2 and showed during the monitoring good removal for BOD (75%), TSS (78%), NH4 (68%) (Diwan et al., 2008), with a hydraulic retention time less than 2 days. In similar climatic conditions, at the Ravindra Nagar Township Ujjain (Madhya Pradesh), another HF system, filled with zeolite 3-9 mm, was monitored from 2006 to 2008 (Billore et al., 2008), showing ammonia removal of about 70%. Few studies on pilot scale were carried on during the last 10-15 year: i.e. in Mahendragiri (Tamil Nadu) for domestic wastewater; and at Mother Dairy, Delhi, for dairy wastewater by CPCB and GTZ. Another interesting pilot study was carried on for a small community of residential areas in Ujjain, Central India, where the functioning of a horizontal flow system of 42 m^2 and planted with Phragmites karka was investigated: average treatment performance after five months from this HF system recorded removal efficiencies of 78% for NH4-N, TSS; 58-65% for P, BOD and TKN (Billore et al., 1999). In 2000 in Ujjain, on the abandoned playground of the Education College, an HF system that receives the outfall of sewage from the Ravindra Nagar residential colony was built. The wastewater is pre-treated in sedimentation tank, and then it goes to the HF system, consisting on a rectangular bed with an effective surface area of 300 m^2 and hydraulic loading of 40 m^3/d. The surface area of gravel bed was planted with Phragmites karka. The removal efficiency of organic nitrogen and of ammonium nitrogen were 86% and 40%, respectively (Billore et al., 2006). The CDD Society is a non-governmental and non-profit organisation located in India, that promotes the use of DEWATS, and has so far implemented more than 350 projects in South Asia, including India (CDD, 2013). The adopted treatment is a modular system with a simple design, non-dependent on energy, consisting in 4 treatment phases: a septic tank or UASB, an anaerobic filter or baffled reactor, a planted gravel filter (HF) and in some cases a polishing ponds (free water system). About thirty DEWATS system have been realised in India, most of these near Bangalore and in Karnataka regions, but also in Maharashtra, Kerala and Tamil Nadu. The volume of wastewater treated in these plants ranges from 1.5 to 615 m^3/d and the size of the HF CWs range from 1.4 to 14.6 m^2/m^3 of wastewater, with an average of 5.7 m^2/m^3. The system allows in most cases a reduction of BOD and COD of 97/99%.

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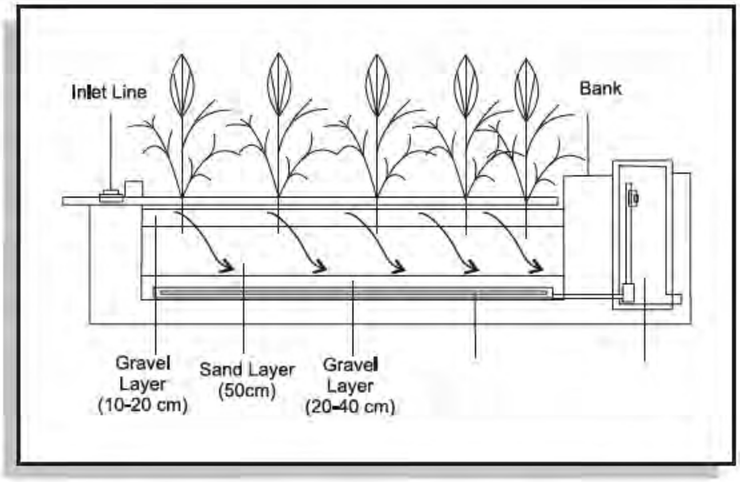

VF CWs are secondary and/or tertiary treatment facilities for household, municipal and industrial wastewater. Pre-treated wastewater is intermittently distributed over the whole surface and flows vertically through the filtering media. The plants' role is less important than in HF CWs, but it still improves the performances especially in the long term. Organic matter, ammonium and suspended solids are removed by filtration and microbial degradation in mainly aerobic conditions.

Design and Construction Principles

The water in CWs is treated by a combination of biological and physical processes such as adsorption, precipitation, filtration, etc. (Hoffmann et al., 2010). VF CWs are particularly efficient in suspended solids and carbon removal, as well as for nitrification, while denitrification is limited. Pre-treated wastewater is distributed above the entire surface of the bed by a system of pipes, fed by a pump or energy-free siphon devices, with an intermittent short-term loading intervals (4 to 12 doses/day), and long resting periods (2-6 h); the wastewater flows through the porous medium in a vertical path until it reaches the drainage system on the bottom connected to an outlet manhole. Normally the filling media consists of a sand layer of at least 50 cm, with an additional 15-20 cm of drainage layer with coarse gravel on the bottom, a transitional layer between sand and coarse gravel of 10-15 cm, and 10-20 cm of fine gravel on the top of the bed for ensuring a proper even distribution over the sand layer. The total height is generally around 0.8-1.2 m. To avoid clogging of the wetland, pre-treatment is necessary, except in "French System" VF beds (FRB) that are used for treating raw wastewater without any primary treatment and any production of primary sludge. French systems are composed by two stages for a total of 2-2.5 m^2/PE (Molle et al., 2004). Here the sludge is accumulated on the top of the 1st stage and the filling material has a different layers and granulometries distribution. In VF CWs as well as FRB the basins are waterproofed by a plastic liner and planted with suitable plants. In Austria is in development a two-stage VF system that reduces the footprint to 2 m^2/PE (Langergraber et al., 2010). The hydraulic loading rate in cold climates should not exceed 100-120 mm/d (DWA, 2006). The reduction of BOD_5 is about 90-99 %, for TSS is from 90 to 99 %, for TN about 30 % (Ridderstolpe, 2004) and for FC is about 1-2 logs (Morel and Diener, 2006).

Operation and Maintenance

O&M requirements for VF CWs are relatively simple and can be conducted by unskilled labour (there are not high-tech components or chemicals to be added). The maintenance includes a periodical sludge and scum control and emptying in the primary treatment unit (not for FRBs), plant harvesting (usable as biomass for energy production, or as building material for thermal and acoustic insulation), ensuring clogging does not occur in the bed (a VF bed can recover well after a resting period of two-three weeks in sunny and dry season) and sampling of the discharged water. For FRBs, the organic layer which is developing and increasing in thickness on the surface of the 1st stage has to be removed with a frequency of about 10 years (this organic matter is not similar to a primary sludge, but instead to a composted and dehydrated sludge that can be used as soil conditioner if not polluted by heavy metals or persistent organics).

Cost Considerations

VF CWs realisation costs are in the range of 50-110 €/m^2 depending by the design, the country, the availability of suitable material (i.e. filling media and waterproofing liner) in the region and the labour cost. The price of pre-treatment units and pipe connections has to be added to the above mentioned costs. Filling media constitutes 30-50% of the total investment cost. WSP (2008) reports cost of 2,100 Rs/m^2 (50 USD/m^2) for vertical flow beds. In developed countries the maintenance cost is in the range of 10-15 €/PE, in developing countries this cost is in the range of 2-8 €/PE. The average O&M cost in Nepal is about 0.5-2 USD/m^2 (UN-HABITAT, 2008).

Advantages

- Efficient removal of organic matter, nutrients and pathogens
- Low O&M costs and process stability
- No high-tech components or chemical additives
- Utilisation of natural processes and energy

Disadvantages

- Permanent space required – high footprint
- Requires expert design and supervision
- Pre-treatment required to prevent (except FRB)
- Low denitrification and disinfection performances

Experiences in Europe and other Cities of the World

VF CWs are less affected by the low temperatures compared to the other CWs and also require less land, so they are mostly used in the northern European countries (Austria, Denmark, France, Germany, and UK) (Kadlec and Wallace, 2009). Moreover, the VF systems are better suited to manage fluctuations in the hydraulic and the organic load. In Orhei, Moldova, the largest CW in the world for secondary treatment is under realisation: construction began in early 2012, founded by World Bank. The urban wastewater will be pre-treated, and then treated by a "French CW system" formed by four parallel lines, each one composed by two stages in series, the first being a RBF and the second a normal VF bed;at the end the water will have the option of an emergency disinfection treatment, and then it will be discharged to the Raut river. The plant has been designed for an average flow of 4,600 m^3/d estimated for 2020 (in 2010 the measured flow was 2,100 m^3/d) and occupies an area of 4 ha (1.8 ha for VFB and 1.7 ha for VF bed). The French System has been used since over 20 years, and approximately 1,000 CWs of this type are in operation in France (Molle, 2005). Several thousand of conventional VF plants are nowadays in use in Germany (more than 100,000 units, mainly for households), Portugal, Spain (Hoffmann et al., 2010) and more than 3,000 in Austria (Langergraber and Haberl, 2012).

Experiences in India

Despite CWs have a strong potential for application in developing countries, particularly by small rural communities, due to their low cost and easy maintenance, these systems have not found widespread use in India, due to lack of awareness, and local expertise in developing the technology on a local basis.

Borkar and Mahatme (2011) studied a VF CW with raw wastewater collected from Amba Nala. The experiment was conducted with a constructed wetland pilot model made of plastic, and consisting in a cylinder with diameter 23 cm and height 45 cm filled from the top with 15 cm of soil media (black cotton soil and sandy soil), 5 cm of sand layer, a geotextile layer and two layers of gravel, 10 cm deep (16 mm Ø) and 15 cm deep (31.5 mm Ø). The experiment compared a system without plants and a system with Typha orientalis: the planted system with a black cotton soil showed the better results in terms of BOD and COD reduction (respectively 59 % and 53 % for unplanted CW and 86% and 63% for the planted one).

A pilot scale CW unit was realised in the at Anna University, Chennai, to study the capacity of a VF bed to remove heavy metal (nickel); the cells were filled with gravel and sand and planted with Arundo donax, showing removal of 70-75% of nickel from an initial concentration of 7-8 mg/l (Sivaraman et al., 2011).

In Nepal, thanks to the efforts of various NGOs and UN cooperation services, several CWs were realised for various type of wastewater (as reported in UN-HABITAT, 2008). Examples of VF CWs reported are:

- Combined laboratory and domestic wastewater treatment (ENPHO), a little VF bed of 15 m^2 for 7 PE running since 2002;
- Grey water treatment (Private residence), a little 6 m^2 VF bed for 8 PE planted with Phragmites Karka and Canna latifolia that permits the reuse for gardening.

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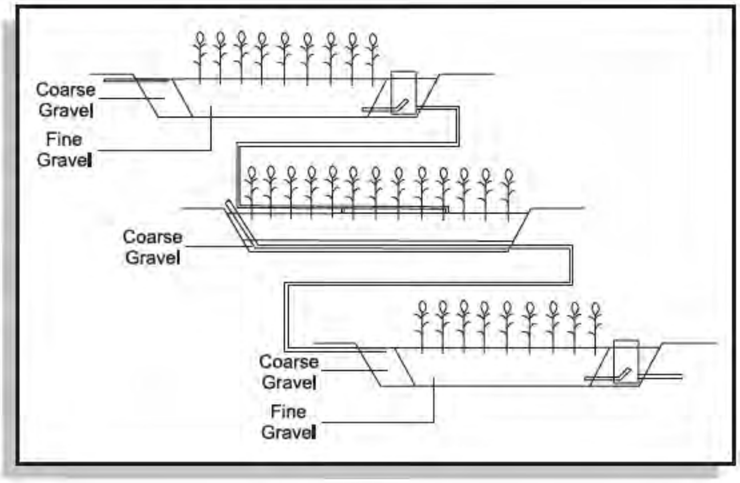

Constructed wetlands (CWs) are natural wastewater treatment systems, which have been set up all over the world as an alternative to conventional intensive systems especially for the sanitation of small communities. There are three different types of CWs: horizontal, vertical and free surface flow CWs. These types of CWs may be combined with each other in hybrid CWs in order to exploit the specific advantages of the different systems.

Design and Construction Principles

Various CW configurations may be combined so as to fit different types of wastewater and to increase their treatment efficiency, especially for nitrogen. These hybrid systems are normally comprised of vertical flow (VF) followed by horizontal flow (HF) CWs. HF systems cannot provide nitrification because of their limited oxygen transfer capacity. VF systems, on the other hand, do provide good conditions for nitrification but denitrification does not really occur in these systems. Thenceforward, the strengths and weaknesses of each type of system balance each other out and in consequence it is possible to obtain an effluent low in BOD, ammonia-N and total-N concentrations (Vymazal, 2005). In general, the design consists of two stages of several parallel VF beds (usually planted with Phragmites australis), followed by one or three horizontal beds (planted e.g. Typha or Carex). In these systems, the VF beds are loaded with pre-treated wastewater for 1–2 days, and then allowed to dry out for 4–8 days (Vymazal, 2005). HRT can range between 1 and 5 days, while space required can be very variable depending on the design and the goals of the treatment (1-10 m^2/PE). The efficiency achieved in terms of BOD, TSS, and total-N removal range between 60 and 95% depending on climate conditions. Free surface flow CWs as final treatment may contribute to water disinfection. Construction materials (such as gravel, sand, plastics) are generally low cost and available on site (García and Corzo, 2008).

Operation and Maintenance

Basically, operation and maintenance is similar to HF or VF CWs. Operation and maintenance activities should focus on ensuring that primary treatment effectively reduces organics and solids concentrations before entering the wetland (Tilley et al., 2008). The difficulty in hybrid constructed wetlands is also to ensure that the system is adjusted and the beds loaded correctly (Hoffmann et al., 2010). That means it needs expert knowledge and trained operators. The most important concern in CWs is clogging. With time, the gravel will become clogged with accumulated solids and bacterial biofilm. The material may have to be replaced every 8 to 15 or more years.

Cost Considerations

Hybrid CWs are more expensive than non-hybrid CWs. A larger area is required and they are more complicated and complex to operate, especially for adjustment and monitoring of the loads (Hoffmann et al., 2010). However, compared to other intensive high-rate treatment options (e.g. activated sludge), hybrids CWs are still less expensive.

Advantages

- Higher treatment efficiency than non-hybrid systems
- Low operation and maintenance in comparison to intensive systems
- Local materials required
- Electricity generally only required for pumping

Disadvantages

- Large area requirements in comparison to intensive systems
- Pre-treatment is required to prevent clogging
- Not very tolerant to cold climates

Experiences in Europe and other Cities of the World

Many of these systems are derived from original hybrid systems developed by Seidel at the Max Planck Institute in Krefeld, Germany. The Seidel design consists of two stages of several parallel VF beds followed by two or three HF beds in series (Vymazal, 2005). In the early 1980s, several hybrid systems of Seidel's type were built in France and in UK. In the 1990s and early 2000s, VF–HF systems were built in many European countries, e.g. in Slovenia, Norway, Austria, France and Ireland and now this type is getting more attention in most European countries (Vymazal, 2005).

In mid-1990s, Johansen and Brix (1996) introduced a HF–VF hybrid system. This system was implemented firstly in Darzlubie in Poland (Obarska-Pempkowiak, 1999). Recently, hybrid CW often includes a FWS stage. This design was implemented in different locations. In Italy, it was successfully used to treat concentrated winery wastewaters (Masi et al., 2002). In Montreal (Canada) it was implemented for domestic wastewater treatment (Laouali et al., 1996). At Yantian industry area in Shenzen City in southeast China, it is used to process industrial wastewater (Wang et al., 1994).

Experiences in India

Hybrid CWs are effective to remove organic matter, suspended solid and nutrients from landfill leachate, river polluted water, domestic, industrial, hospital, runoff and agricultural wastewaters in lab-scale, pilot-scale and full-scale with various configurations (Sayadi et al., 2012). Despite their versatility and their strong potential for application in small communities of developing countries, hybrid systems have not found widespread use in India, due to lack of awareness and local expertise in developing the technology on a local basis.

Nevertheless, different experiences took place in South Asia.

In South Korea 3-stage hybrid constructed wetlands (VF+HF+HF) for treating domestic sewage from individual housing units surrounding agricultural villages were implemented and evaluated. Removal efficiencies of BOD, COD, TSS, total nitrogen, and total phosphorous were 99, 98, 99, 83, and 75%, respectively (Seo et al., 2008).

During the last decade, different hybrid CW systems were implemented in Nepal (UN-HABITAT, 2008):

- Hospital wastewater treatment (Dhulikhel Hospital): hybrid system HF+VF, 240 m^2; operating since 1997, the system treat until 35-75 m^3/day (386 PE at 2006) reaching COD removal of 80% or more;
- Institutional wastewater treatment (Kathmandu University), 628 m^2 of hybrid CW system (HF+VF) able to treat 193 PE, running since 2001 with removal of organic matter and nitrogen up to 80%.
- Municipal wastewater treatment (Sunga, Thimi), 300 m^2 of hybrid system (HF+VF) able to treat 285 PE, running since 2005 with removal of organic matter and suspended solids up to more than 80%.
- Septage and landfill leachate treatment (Pokhara), both in operation since 2003: the sludge drying reed bed is composed of 7 beds with an overall surface of 1,645 m^2 and it is able to treat about 35 m^3/day of septage; the CW for the leachate is an hybrid system HF+VF of 2,680 m^2 and treats 40 m^3/day.

In Taiwan, hybrid CW systems have received tremendous interests for water quality enhancement during the last years due to insufficient sewage treatment and groundwater deterioration (Yeh and Wu, 2009). The performance of a field-scale hybrid CW system implemented at National University of Kaohsiung was assessed. The system included an oxidation pond, two serial surface flow wetlands with a cascade in between, and a subsurface flow wetland receiving secondary treated dormitory sewage. The results of the study showed an average TSS, BOD and COD removal efficiency of 86.7, 86.5 and 57.8%, respectively, while Total Kjeldahl Nitrogen and Ammonium decreased from 4.08 to 1.43 and 3.74 to 1.21mg/L, respectively (Yeh and Wu, 2009).

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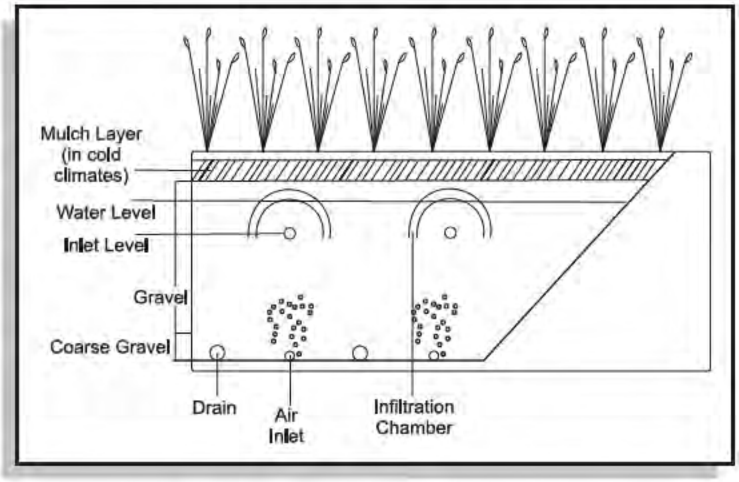

AEWs are an advanced type of CWs, which allow more efficient removals of contaminants from wastewaters, due to the higher availability of oxygen. The wastewater being treated flows subsurface beneath an aggregate substrate, which is aerated mechanically from below, with an appropriate distribution system of air. This system is ideal for treating wastewater with high loads of BOD and COD and for minimising the footprint.

Design and Construction Principles

After preliminary and primary treatment (generally a manual or automatic screen followed by a sedimentation phase in septic tanks or lagoons), the secondary treatment is provided in aerobic bioreactors, the AEW beds. The flow in these beds may be horizontal or vertical. The aerated EW is an advanced type of wetland where a coarse bubble aeration network is placed under the gravel substrate of a sub-surface flow wetland basin, and air is supplied to it by a blower. This eco-technology allows the removal rates of biologically-oxidable contaminants (e.g., ammonia, BOD) to increase to almost complete elimination levels (Higgins et al., 2010a). While any kind of wetland cell can be operated in the AEW mode, sub-surface flow (SSF) cells are mainly used (Higgins, 1997). Aerated SSF EWs generally have much smaller surface area, even 5-10 times less size of the equivalent passive sub-surface CWs. Aeration was found to profoundly affect treatment performances. When aerated at 0.85 m^3 of air per hour per m^3 of wetland bed, the volumetric (2TIS) BOD_5 removal rate constant averaged 5.4 day^{-1} with a temperature coefficient (θ) of 1.03, based on experiments conducted at 22°C and 4°C. In contrast, the non-aerated wetland had a rate coefficient of 0.55 day^{-1} (Wallace and Liner, 2009). So AEWs are capable of achieving >95% removals of most pollutants, during summer and winter, in facilities which are only a fraction of the size of traditional CWs (Higgins et al., 2010b). In special conditions, such as water contaminated with glycolic compounds in airport runoff treatment (where the AEWs were successfully used), the operation of the treatment system can be influenced by the limitations of nutrients if the main effluent does not contain nitrogen, phosphorus and other nutrients; so the nutrient demands for bacterial growth should always be estimated in order to provide the appropriate fertilisation in case of lack of nutrients. As regards to the consumption of energy, it depends of the type of wastewater and the oxygen demand: i.e. to treat the urban wastewater of a municipality in Eastern Ontario, an external energy input of only 0.16 kWh/m^3 is required and this energy input is considerably less than activated sludge processes (2.39 – 0.51 kWh/m^3) (Wallace et al., 2006).

Operation and Maintenance

O&M requirements for AEW are relatively simple and conducted for the great part by unskilled labour as the other type of CWs treatment schemes, which may allow a community organisation or a private to manage the system. Nevertheless the system is more complex from a technological point of view, and a skilled labour could be required to conduct and to maintain the blowers and the forced aeration system. The maintenance includes a periodical sludge and scum control and emptying in primary treatment, plant harvesting, checking the functioning of the distribution system and of the aeration system, regulating the air flow according to inlet wastewater characteristics, ensuring clogging does not occur in the bed and sampling of the discharged water.

Cost Considerations

The costs per surface unit are higher than VFs and HFs because of the presence of the air compression system and the air distribution pipes, but the required surface per PE is sensitively lower. Considering the investment for the treatment system at Buffalo Niagara International Airport, the costs are around 300 €/m^2, that means about 60-120 €/PE for large scale systems, going up to 150 €/PE for medium size and 200C/PE for small size plants. In developed countries the maintenance cost is in the range of 15-22 €/PE

Advantages

- Very high reduction of organic matter, nutrients and pathogens, even in cold climates
- Less use of land than the standard CW, less clogging
- More flexible design, depending on the blower capacity the system is easier to upgrade to a higher load.

Disadvantages

- Requires expert design and supervision
- Use of delicate technological components, which are not needed in regular passive CW systems
- Higher energy consumption due to aeration compared to other passive types of CWs

Experiences in Europe and other Cities of the World

This new technology has been developed in America, and responds to the needs to process large loads of COD, but can be applied in any context to reduce the CWs footprint. A very interesting case study is the Buffalo Niagara International Airport. Here the problem was the wastewater with excessive quantities of COD, due to the use of glycol de-icing compounds. So, after several years of permit limit exceeded, in the 2009 the AEW system was completed with an area of approximately 19,000 m^2, divided in 4 large aerated VF AEW cells (51 m by 91 m each, located in an open area near the airport's main runway). The filtering beds were filled by washed gravel (10-15 mm of diameter) with 1.5 m thickness. Influent is distributed uniformly over the cells surface via inlet distributor chambers buried near the substrate surface, and flows vertically down through the gravel to a drainage system. Air is supplied from four air blowers (186.5 kW) located in a nearby Utility Building, and is pumped to the cells through a network of perforated aeration pipes located on the bottom of the beds. When HF EW cells were aerated at 0.85m^3air per hour (per m^3 of wetland bed) the carbonaceous BOD_5 removal rate constant averaged 5.4/d with an Arrhenius temperature coefficient (θ) of 1.03. While the design was based on a BOD_5 loading rate of 4,500 kg/d (corresponding about 50,000 PE), actual loadings exceeded 20,000 kg/d (corresponding about 220,000 PE). BOD_5 removals remained in the range of 90 to 100% (with an average removal rate of 98.3%), and reductions in treatment efficiency were only observed at the heaviest organic loadings (Wallace and Liner, 2009). The realisation cost was 10,000,000 USD, and the operation cost was in the 1st year of 100,000 USD, while now is less than 50,000 USD/year (Clark, 2012).

At London's Heathrow Airport the existing standard HF facility was upgraded in 2010 with a forced bed aeration system, to provide a significant increase in treatment capacity, from 350 kg of BOD to a minimum of 3,500 kg of BOD per day (Wallace and Liner, 2009).In Casper, Wyoming, an AEW was implemented in a former BP refinery plant. Today, it is the largest remediation wetland in the United States, and the realisation cost was 3,400,000 USD (Wallace 2004). This treatment system needed to handle up to 11,000 m^3/day of gasoline-contaminated groundwater. The plant consists in a cascade aeration system (for iron oxidation), a surface-flow wetland (for iron precipitation) of 0.6 ha (divided in 2 basin), and 1.3 ha of aerated HF system, divided in 2 circular basin (with 90 cm deep gravel beds).The design flow rate for the system is 6,000 m^3/d, although actual flows are approximately 2,700 m^3/d (45% of design), with a 100% of benzene removal percentage (Wallace, 2011).

In Wellsville, New York, in a closed oil refinery of the Sinclair a treatment facility was implemented consisting in four major units that are designed to reduce metals, organic compounds, and buffer the pH of the recovered groundwater. A cascade aeration system, a sedimentation pond, a series of surface flow wetlands (3 in parallel) of 0.7 ha, and a series of vertical flow wetlands (5 in parallel) of 0.07 ha were constructed. The system is designed to operate at 840 m^3/day, but actual flow rates have exceeded this by 20%, with a removal percentage of 87% for the benzene and 98% for iron.

In Canada, the project for the North Glengarry (Eastern Ontario) domestic water treatment with AEW is currently under construction. The pilot facility demonstrates that the nitrification of domestic wastewater with AEW requires significantly less surface, approximately 30.4 ha by a standard subsurface flow CW, whereas only 1.4 ha by AEW (Wallace, 2006).

Experiences in India

No experiences in India are referred on this quite new technology.

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NaWaTech

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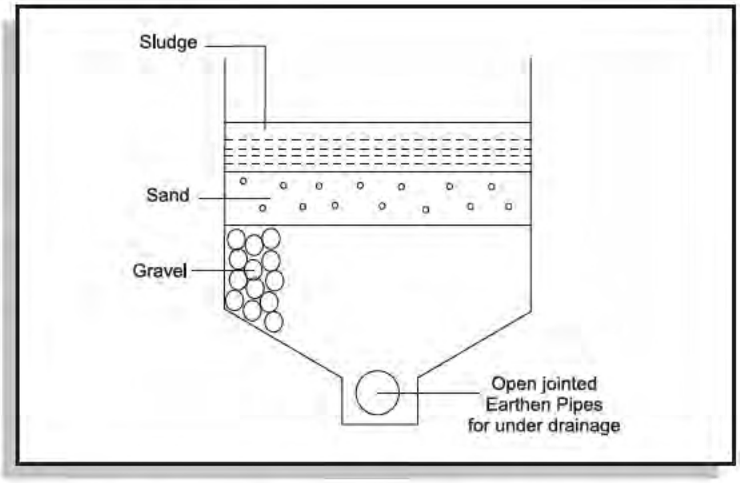

Sludge drying bed (SDB) is the most widely used method for sludge dewatering. Sludge drying involves natural ways of drying to mechanical ways of removing water content. SDB is generally used for small and medium sized communities (Tchobanoglous et al., 2003). The selection of the technology will depend upon land availability, climatic factors, the quantity and composition of the sludge. The construction of this is usually undertaken with civil structure.

Design and Construction Principle

The prediction of the drying rate is an empirical part of the designing the system. Drying of the sludge can be divided in to two different stages, namely drainage and evaporation (Chai, 2006). The design of SDB is based mainly on site specifications, as well as environmental and climatic factors. The sizing of the sludge drying beds should be done considering the worst case scenario (Ceronio, 1999). The loading is based on per capita basis or on a unit loading of pounds of dry solids per square foot per year (Tchobanoglous et al., 2003). There are mainly five types of sludge drying methods viz. conventional sand beds, paved drying beds, artificial media beds, vacuum assisted and solar. The typical conventional SDB has dimensions of 6 m width, 6 - 30 m length, with sand layer ranging from 230 – 300 mm depth. The sand should have a uniformity coefficient of not over 4.0 and effective size of 0.3 to 0.75 mm. The piping to the sludge drying beds should be designed for velocity of at-least 0.75 m/s (Tchobanoglous et al., 2003). The sludge is placed on the bed in 20–30 cm layers and allowed to dry. Sludge cake removal is manual by shovelling into wheel-barrows, trucks, scraper, or front-end loader. The drying period is 10–15 days, and the moisture content of the cake is 60 – 70%. Sludge loading rate is 100–300 kg dry solids/ m^2 /year for uncovered beds (Al-Malack et al., 2002).

Operation and Maintenance

The application of sludge treatment methods differs from country to country due to differences in operating conditions and energy prices (Ghazy et al., 2011). Conventional sludge drying is very simple, but trained staff for operation and maintenance is required to ensure proper functioning. This method doesn't require electrical energy (Tilley et al., 2008). The O & M also includes application of sludge, desludging, control of drainage system and the control of the secondary treatments for percolate or dried sludge.

Cost Considerations

This conventional sludge treatment technology is more land intensive rather than energy intensive. Based on the quantity of wastewater to be treated the sizing of the sludge drying bed changes. The capital investment for this treatment unit is the highest in terms of the land requirement followed by the construction costs. The O & M requirements include the labour hours, fuel energy, back washing as well as the annual materials and maintenance parts.

Advantages

- Easy to operate
- No electrical energy required
- Organic content can be used as fertiliser

Disadvantages

- Requires stabilised sludge to prevent nuisance and odours
- Technology is land intensive
- Climatic fluctuation may cause disturbance
- Clogging of sand bed
- Only applicable during dry seasons

Sources: Tchobanoglous et al., 2003; Sanimas, 2005; Tilley et al. 2008 and Ghazy et al. 2009.

Experiences in Europe and other Cities of the World

SDBs are being used throughout the world especially in United States since the beginning of the 20^{th} century, but over the years its applicability is limited due to the environmental and climatic factors (Carpenter, 1938). In the United States, the majority of Waste Water Treatment Plants (WWTPs) with capacities less than 5 MGD (equal to 18.93 m^3/day) use SDBs. Similarly, Russia and other Eastern European countries use SDBs in more than 80% of the WWTPs (Turovskiy and Mathai, 2006). By 2009, Egypt had approx. 303 WWTPs handling 11.85 $x10^6$ m^3 /day of sewage. Most of these WWTPs use natural sludge drying beds (Ghazy et al., 2009).

In Africa, a STP at Cambérène (Dakar, Senegal) uses SDB for sludge treatment since 2006. The initial design underestimated the sludge volumes to be treated and overestimated the sludge concentrations by 40%. This caused serious problems in operations. After detailed study this issue was resolved and the capacities of the SDBs were increased from 200 kg TS/m^2/year to 400 kg TS/m^2/year. Currently, the plant is running at 300 kg TS/m^2/year, thus allowing for an additional bed-scrubbing period of about ten days (EAWAG,2009).

Experiences in India

Many of the cities in India including Chennai, Thane, Pune, Patna, Chandigardh, and Bhopal use the conventional sludge drying beds as a part of sludge treatment process. The quantum of sludge to be treated is generally very high due to the amount of wastewater that is generated in these cities. The climatic conditions in India are also favourable for the use of SDBs as the solar energy is available in ample in Indian subcontinent. In the city of Patna, many municipal wastewater treatment plants are using the SDBs as part of sludge treatment technology. Plants at Beur, Saidpur have installed SDB having total capacity of 405 m^3 each. Furthermore, cities including Raipur, Khurd (Chandigarh), Ahemdabad, Vasna, Rajkot, Vadodara, Surat (located in the state of Gujarat) also have multiple sewage treatment plants, which include sludge drying beds as the treatment units (CPCB, 2005). Further to that The Central Public Health & Environmental Engineering Organisation under Ministry of Urban Development has published the design guidelines for Sludge Drying Beds in India (CPHEEO, 2012).

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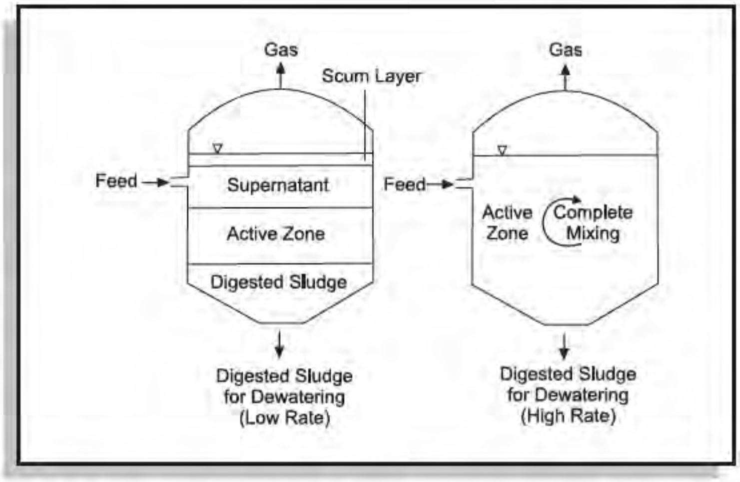

Anaerobic digestion is one of the most widely used processes for the stabilisation of wastewater treatment plant sludge. Due to its capacity to reduce the amount of organic matter up to 50%, anaerobic digestion represents a necessary step of sludge treatment prior to drying and incineration, optimising the post-treatment process and saving costs. Furthermore, the generated biogas with a high proportion of methane can be used as an energy source.

Design and Construction Principles

Anaerobic digestion is the biological degradation of organic matter in the absence of free oxygen. During this process, much of the organic matter is converted to biogas (methane, carbon dioxide and water) (CPHEEO, 2012). Also known as methane fermentation or anaerobic sludge stabilisation, this process can reduce the organic matter content of sludge by 40 and 50 % (Petitpain, 2013).Two different types in anaerobic sludge digestion process are in practice: (1) Low rate digestion: a large storage tank, occasionally, with some heating facility, and (2) High rate digestion: with pre-thickening of raw sludge, complete mixing, heating and uniform feeding of raw sludge (CPHEEO, 2012). Sludge feeding or organic loading rate (OLR) is expressed in terms of volatile solids (VS). Typically, it is 0.5– 0.6 kg VS/m^3/day for low rate digestion and 3.2–7.2 kg VS/m^3/day for high load digestion (Suryawanshi et al., 2013). The retention time is usually about one month (TBW, 2001). The HRT and the extent of each of the three reactions occurring during anaerobic digestion (hydrolysis, acidogenesis and methanogenesis) are directly related(De la Rubia et al., 2002). The process can either be thermophilic digestion, in which sludge is fermented in tanks at a temperature of 55^{0}C or mesophilic, at a temperature of around 36^{0}C. It can be designed with a batch or continuous configuration, in either one or two stages. The biodigester is an air and watertight structure that provides anaerobic conditions.

Operation and Maintenance

The O&M of an anaerobic digester requires a strict organisation and the continuous involvement of experts (Spuhler, 2013). There are many problems associated with its operation that should be given special attention (Surayawanshi et al., 2013): over-pumping of raw sludge, excessive withdrawal of the digested sludge,foaming, maintenance of an optimum/uniform temperature and inadequate mixing. In order to maintain optimal conditions for the microbial population to growth, nutrients (N and P) should be added in the form of ammonium chloride, aqueous ammonia, urea phosphate salts and phosphoric acid.

Cost Considerations

The capital requirements to install a digester vary depending on the design chosen, size and choice of equipment for utilisation of the biogas. The cost per unit volume installed increases for smaller treatment plants. Costs based on the price level in 2006 ranged from 250 USD/m^3 (for a plant of capacity 200,000 PE)up to 1,000 USD/m^3 (for 25,000 PE) (Van Haandel and van der Lubbe, 2011).The annual O&M requirements include labour hours (skilled and unskilled), electrical energy, fuel energy as well as the annual materials and maintenance. Thermophilic processes require heating systems, increasing the O&M costs.

Advantages

- Generation of Ch_4 as an additional source of energy
- Reduction of organic matter, optimising further treatments
- The remaining sludge can be used as soil conditioner
- Reduces production of landfill methane, a greenhouse gas

Disadvantages

- Accumulation of heavy metals and contaminants in sludge
- High capital costs
- Skilled manpower for design, construction and O&M
- High complexity to maintain optimal reaction conditions.

Experiences in Europe and other Cities of the World

Anaerobic digesters to treat excess sludge were first implemented in Exeter, UK in 1885, and since then the technology and its benefits have been well known for more than 100 years (Petitpain,2013). Because of the incertitude linked to the use of the remaining sludge in agriculture, this treatment solution remained weak in the past decades meanwhile other technologies, such as sludge drying, incineration and gasification were preferred. Today, due to the increasing energy costs and the introduction of green electricity certification in countries such as Germany and Belgium, this technology is gaining terrain in Europe. In North America, anaerobic digestion is the dominant municipal sludge stabilisation technology (Schafer et al., n.y.).

The anaerobic digestion process has been generally used for WWTPs having wastewater flow less than 4,000 m^3/day to more than 757,000 m^3/day (Ghazy et al., 2011). Despite the fact that the production of electricity from the digested gas recovery becomes more cost effective for plants with daily flows greater than 38,000 m^3/d (WEF, 1992), it is the preferable choice for WWTPs capacities less than 10,000 inhabitants in Germany (ATV-DVWK, 2003).The company Degrémont constructed numerous digesters during the past years; its most famous and largest facility is La Farfana in Santiago, Chile, with eight digesters of 15,000 $m^3$of capacity (Petitpain,2013).

Experiences in India

In India, anaerobic digestion has been practiced for years using different substrates, including sewerage sludge. The "Manual on Sewerage and Sewage Treatment Part A: Engineering" published by the Central Public Health and Environmental Engineering Organisation (CPHEEO, 2012) provides details regarding the recommended designs and technical aspects for the construction of anaerobic digesters in the country. According to this manual, anaerobic digestion is considered to be the preferred option under Indian conditions because "the process will generate methane and in turn electrical energy by burning it in gas engines, whereas the aerobic treatment will need pumping oxygen by means of aeration where electrical energy is expended. Anaerobic digestion requires the temperature to be in the range of above 25°C, which is of course available as the temperature of sewage almost throughout India and throughout almost the whole year" (CPHEEO, 2012).In large wastewater treatment plants in India (>7,500 m^3/day) the sludge management system generally recommended is to have a thickener, and a digester followed by a sludge drying arrangement as indicated below (Arceivala and Asolekar,2007):Various Sludges → Thickener → Anaerobic Digester → Dewatering → Disposal

"Digestion, as practised in India, is generally high-rate digestion done in cylindrical tanks of RCC (with depth-to-diameter ratios of 0.5-0.7) and conical bottoms. It mainly entails mixing of the digester contents using screw-pumps (with typical power inputs of 5-8 W/m^3) for a short period after feeding of raw sludge and maintaining suitable temperatures in the mesophilic range (35°C). The heating of digester contents is not considered necessary in most parts of India. Generally, the volumetric capacity of digesters in India is of the order of 0.07-0.1 m^3 per capita for sludge received from primary settling tanks mixed with excess activated sludge" (Arceivala and Asolekar,2007).According to the Central Pollution Control Board, most of the sludge-handling facilities in India are out of order. A report published by this organisation indicates that sludge removal, treatment and handling are the most neglected areas in STPs operation (CPCB, 2007). An evaluation conducted in 2007 shows how sludge-handling facilities were non-operational in 43 STPs based on Activated Sludge Processes technology (or other high rate aeration systems).It was observed that in many cases there was no gas generation and utilisation, despite of having anaerobic digesters. In other cases, the gas was being flared and not utilised. Only in 12 STPs the gas generated was being utilised as domestic fuel (5 STPs) or as fuel for gas engine (4 STPs) or duel fuel generator DFG (3 STPs).The wastewater treatment plant in Okhka (Delhi) shows a successful case in sludge management in India (CPCB, 2007). This plant, based on conventional activated sludge processes, has a capacity of 636 MLD. Here, out of 28 of sludge digesters, only one is not in operation. Part of the biogas produced is recycled for mixing with the help of compressors and the remaining biogas is supplied to nearby areas through pipelines and used as domestic fuel gas. An average of 14,000 m^3 of biogas is produced per day at the STP, which is fully utilised as domestic fuel through 3,500 connections. The CPCB recommends the implementation of anaerobic digestion for the treatment of sludge, as these projects can be financed through CDM (Clean Development Mechanism) (CPCB, 2007). "Projects based on generation of electric power from biogas, which is being produced as a result of digestion of sludge in STPs, are eligible for CDM, as it will help in reducing and stabilising the emissions due to methane, which is a greenhouse gas. Based on the potential of biogas/power generation from STPs, expenditure on O&M can be offset by earning 'carbon credits' on recurring basis and it can be a perennial source of revenue generation" (CPCB, 2007).

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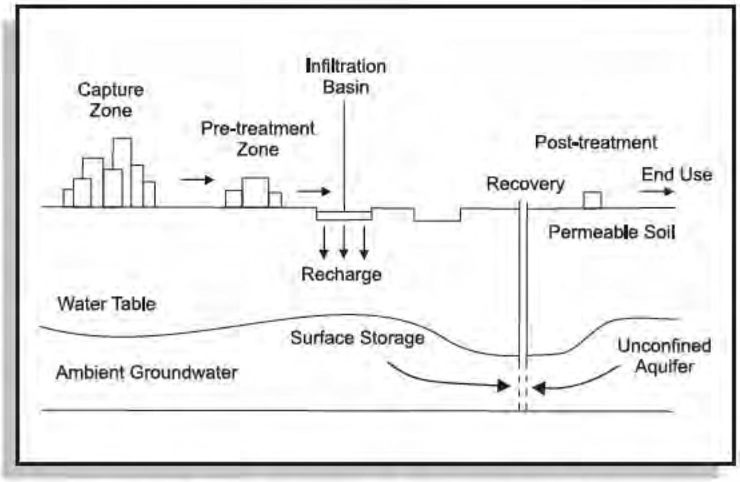

Soil Aquifer Treatment (SAT) facilitates to polish stormwater & treated wastewater and provides natural storage capacity prior to reuse or groundwater recharge. During subsurface passage of artificially infiltrated effluent, the effluent is subjected to physical, chemical and biological nutrient and pathogen removal. After underground storage, water can be extracted through recovery wells, (post-treated, if necessary) and re-used.

Design and Construction Principles

During wet cycles, infiltration basins (also "recharge basins") (for unconfined aquifers) or injection wells (for confined and unconfined aquifers) are loaded with treated effluent or stormwater (Melin, 2009; Sakthivadivel, 2007), followed by dry cycles for percolation. Involving both aerobic and anaerobic milieus, SAT facilitates to polish water for indirect potable or irrigation uses, but also offers natural storage and buffering capacity. Partial removal of organic and inorganic nitrogen, organic carbon as well as significant reduction effects in terms of phosphorus, some non-aromatic organics (including polysaccharides and proteins), trace metals or pathogens have been observed (Miotlinski et al., 2010; NRMMC, 2010; Jimenez, 2008). Relying on sub-surface transport and storage, this method is specifically valuable for areas with high evaporation rates (Miotlinski et al., 2010). Design and performance of SAT systems strongly depend on influent quality, geo-hydrological characteristics of soil and aquifer and operational schedule of infiltration components (hydraulic loading, drying intervals) as well as intended reuse purpose (NRMMC, 2010;NCSWS, 2001), whereas the following general set-up can be proposed: (1) Capture Zone (2) Pre-treatment (e.g. horizontal, vertical and free-surface CWs, waste stabilisation ponds, USAB reactors or advanced treatment such as ASP or membrane filtration systems) (3) Recharge unit (4) Subsurface storage (in the aquifer) (5) Recovery well or GW-recharge (6) Post-treatment (and Disinfection) (7) End use: drinking water supply, irrigation/industry, discharge to ecosystems. Conventional systems are designed for retention times in the aquifer of up to 12 months, "Short SAT" systems rely on retention times of 30-60 days. Land use requirements vary with the infiltration method used (Loftus, 2011; Cikurel, 2006).

Operation and Maintenance

O&M requirements strongly depend on design and complexity of the infiltration system, the aquifer, the characteristics of the treated effluent as well as on the extraction method. For simple systems, e.g. where roof run-off from single houses is infiltrated on a small-scale and extracted for non-potable uses, only limited expertise might be required (infiltration is management on behalf of the householder themselves). However, in these cases, a local authority should provide design requirements for the householders and also monitor regional effects on the aquifer. For more complex, large-scale systems, operation and regulation requires more expertise to guarantee for ecologically sustainable operation. This specifically refers to the issue of risk management, which requires a deep understanding of the system (NRMMC, 2010). A common maintenance issue is the development of a clogging layer on the infiltration basin's surface (or around the injection well) due to accumulation of biofilm, algae, suspended solids and chemical precipitates, resulting in the decline of the infiltration rate.

Cost Considerations

Following Pittock et al. (2009), the economically most favourable use of SAT output water is for substitution of potable water for uses such as irrigation, environmental restoration, cleaning, sanitation or industrial uses. Capital costs and running costs generally depend on the number of injection wells or recovery wells, or the area of infiltration ponds/galleries required to recharge/recover water at the required rate. In general, the higher the total costs per unit volume of recovered water, the lower the yields of the extraction well. Treatment processes required to avert clogging can cause a major part of the costs. Space can especially become very cost-relevant in urban settings where land prices are high (Moitlinski et al., 2010). Moreover, for large-scale systems, also investigation costs for understanding the soil profile and the aquifer dynamics can be substantial (NRMMC, 2010).

Advantages

- Reduction of evaporation rate & insect breeding
- Natural buffer of seasonal variations in availability and demand, temperature etc.
- Underground storage/natural buffer, which has advantages in terms of public perception
- Mitigation of saltwater or contaminant intrusion

Disadvantages

- Risk of nutrient discharge into GW aquifer, if not sufficiently pre-treated
- Space demand for infiltration basins limits urban applicability
- Vulnerability to clogging
- Dependency on pre-treatment steps

Experiences in Europe and other Cities of the World

In Basel (Switzerland) water from the river Rhine is used to provide around 60% of the total drinking water demand (25 Mm^3/y) applying SAT in the "Langen Erlen" – a former floodplain landscape in the city. Following rapid sand filtration, river water is applied on eleven forested recharge basins, whereas three sections (0.5ha each) are consecutively flooded for ten days, followed by a drying period of 20 days. The vegetation on the recharge basins consists of typical floodplain plants (such as ash tree, alders, willows, bird cherry, reed canary grass and sedges) building up a floodplain forest ecosystem whose plant roots and soil fauna keep the soil permeability continuously high. The shade offered by the plants prevents strong warming of the upper soil layers and hereby also algae growth. The infiltration capacity (1-2 $m^3/m^2/d$) of the recharge basins has been constant for decades. With a surface area demand of around 10 m^2/inh, the system is primarily suitable for areas with low land prices and/or large forests (Rüetschi, 2004). Another prominent example for large-scale SAT, is the Shafdan treatment in the Dan Region (Central Israel), where parts of the wastewater from seven cities is treated with SAT prior to re-use for irrigation in the South of the country. Infiltrating around 130-140 Mm^3/y on a total area of 80ha, this is one of the biggest reclamation sites applying SAT (Cikurel, 2006). The effluent percolates through a deep vadose zone (15-30m) and is horizontally spread through the saturated zone. 1-2 days surface spreading is followed by 2-6 days drying period and a retention time in the aquifer of 6-12 months resulting in "accidental drinking water quality". Facing increasing urbanisation pressure, a short SAT was introduced in combination with nano-filtration being superior to the conventional SAT technology in terms of land use, time parameters, and water quality (efficient removal of microorganisms and micro-pollutants) (Loftus, 2011;Cikurel, 2006).

Experiences in India

Investigations on potentials and challenges of (pilot-scale) SAT applications have been undertaken in e.g. Ahmedabad (Nema et al., 2001), Delhi (Jamwal and Mittal, 2010); Chennai City (Deepa and Krishnaveni, 2012). In Ahmedabad a pilot project was jointly conducted by Physical Research Laboratory, National Environmental Engineering Research Institute (NEERI) and Ahmedabad Municipal Corporation. SAT was applied for purifying the municipal secondary treated water and augmentation of groundwater. During an experiment period of 138 days in the post-monsoon period of 1996, an average of 1,650 m^3/d of primary settled sewage entered the pilot system, and a recovery rate of about 60% could be achieved. Analysis of the system performance proved a reduction in the cost of centralised recharge collection, treatment and disposal; rejuvenation and restoration of groundwater for agricultural use. Sakthivadivel (2007), who investigated potentials of various groundwater recharge approaches in India, proposes that aquifers best suited for artificial recharge are those, which can absorb and retain large quantities of water. For surface spreading schemes in the arid zone, recent river alluvium (where water table is subject to pronounced natural fluctuations) but also coastal dunes and deltas were identified as favourable sites. Another aspect that needs to be addressed is the public perception of SAT (or wastewater reuse in general). Nijhawan et al. (2013) investigated the public perception of wastewater reuse through artificial groundwater recharge in India based on public consultation through questionnaires. The idea of using wastewater for artificial groundwater recharge was supported by a large number of respondents. However, there was significant concern over the quality of treated municipal wastewater and the general feasibility of using this water for groundwater recharge. The authors emphasised on the need for extensive awareness raising and strict process monitoring to sufficiently protect groundwater bodies from pollution.

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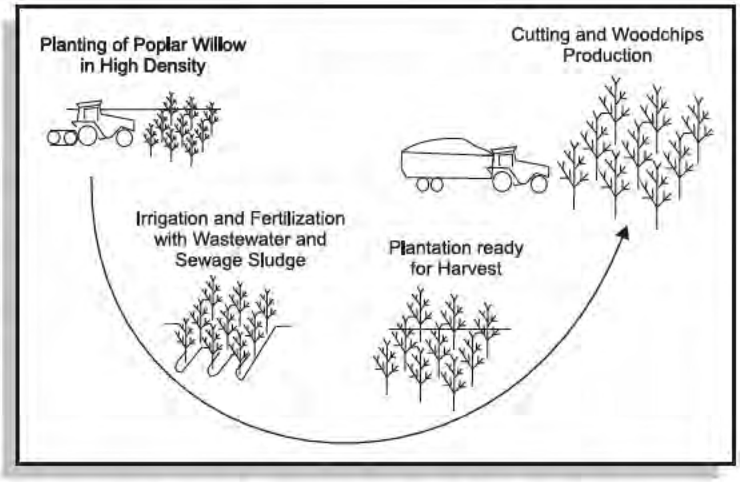

Short Rotation Coppice (SRC) is a farming method to cultivate fast growing trees. The main characteristic of SCR species is their ability to sprout again from their roots after harvesting. These plantations can be used to clean pre-treated domestic wastewater: the biologic activity in the soil purifies the wastewater and the plants can absorb nutrients. The wastewater can be spread on the fields using conventional irrigation systems. This can increase the yield of the trees up to 100%.

Design and Construction Principles

For these plantations species like willows, poplars, eucalyptus or bamboo are used, since they are fast growing in their youth and can sprout again from their roots after harvesting. The plantations are arranged in a single or double row system. An average yield of 10 tons absolute dry wood per year and hectare can be expected. This has the energy content equivalent to 5,000 L heating oil. The harvesting is usually conducted in intervals between 3 to 5 years depending on the formation and the tree species. Since water is their main growth limitation factor, on nutrient poor and dry soil yield can be increased significantly by adding nutrient-rich wastewater. The chipped harvested wood is an excellent fuel, which can be used in regional power plants, district heating systems or households. While constructed wetlands focus mainly on wastewater treatment and are sealed at their base for groundwater protection, the advantage of SRCs over constructed wetlands lies in the combined wastewater treatment and the production of wooden biomass, which means an additional income for farmers. A SRC represents an open-bottom fixed-bed reactor of a construction height of between 1.0 and 1.5 m resulting in an effective reduction of pathogens. To avoid a nutrient overload it is important to control and document the amount and quality of the applied wastewater and sewage sludge.

Operation and Maintenance

For this treatment system the main requirement is land. In Europe, cost-effectiveness using fully mechanical planting and harvesting systems is reached starting at 5 ha. The plantation of a SRC and its harvest can be also done manually. Cuttings from tree nurseries are required as seedlings. In one hectare up to 12,000 trees like willows, popular or eucalyptus can be grown. For the distribution of the wastewater a drip irrigation system and slurry pump are needed. Before the wastewater enters the system, a mechanical pre-treatment would be needed to filter and avoid clogging. To maintain SRC, typical farmer skills like knowledge about plants, fertilizer, irrigation, and familiarity with agricultural machinery are needed.

Cost Considerations

The running cost of a SRC are minimal, mainly the rent of the land. After establishment the main cost factor is incurred in the harvesting process, cost largely compensated by the sales profit on the wood chips. As a reference, the total cost for establishing a plantation are around 2,500 €/ha in Germany. The material cost for a simple and cheap drip irrigation system are approximately 300€. External financing is usually not needed and since the most of the work needed is unskilled labour, it can be done by the entrepreneur himself. To avoid losses, it is very important to take care of the sprouts during the first year.

Advantages

- Provides a second source of income to farmers
- It is a low technology system
- Supporting sustainable rural development
- Production of renewable biomass as a fuel

Disadvantages

- Bridge strong frost periods
- Large area required, implementation only in rural areas
- The particle size are limited
- Only for domestic wastewater

Experiences in Europe and other Cities of the World

The system SRC as water treatment system requires significant areas of land. The outskirts of urban areas are good locations due to the need of the produced fuel and availability of wastewater. Due to climatic conditions, in Europe the combination of SRC with wastewater treatment is only established in regions with less than 600 mm rainfall and nutrient poor soil. Different examples can be cited. For instance, a 5 ha SRC (willow, poplar, alder and robinia) was established in an old sewage sludge and wastewater dump nearby Berlin (Germany) (Hecker, 2012).

Other experiences can also be cited in the south of Europe (Granada-Spain, Ferrara-Italy)with poplars(EUBIA, 2008), where it was possible to double the biomass production. As for other regions, reference projects in Bangladesh and China (INAWAB, 2006; LADAS, 2006) can be cited as well. With a pre-treated wastewater, the environmental risk is low, and contributes to the reduction of conventional wastewater treatment. The hygienic risk from SRC biomass is also low due to the fact that the biomass is not for the food sector. The use of wastewater and sludge saved natural drinking water sources for irrigation and fertiliser because it contains valuable plant nutrients (especially Nitrogen and Phosphorus).

Experiences in India

The experiences and established tree species in SRC made in Europe are not transferable one to one to India due to different climate conditions. Different climatic regions inside India make it even more difficult to transfer successfully used tree species into other regions. The potential use of timber in India has a broad spectra beginning with fire wood, raw material for industry or as building material (I.e. bamboo). A summary about the experiences made with SRC trees in India is presented: In Jodhpur (North West India) trials with SRC species Acacia nilotica and Eucalyptus camaldulensis irrigated with municipal wastewater where conducted. In this study, Eucalyptus showed the advantage of the highest uptake rate of nutrients, which is an important parameter towards avoiding negative long term effects by accumulation of nutrients (Singh et al., 2010). In a study conducted in Palwal (70 km from New Delhi), different tree species were irrigated with secondary treated wastewater. The Tereticornis eucalyptus specie showed to have the highest biomass yield per tree. However, due to a higher survival rate the net biomass production per hectare was higher for Melia Azedarach (38 t/ha) followed by Ailanthus excels. The plants were grown for 2.5 years and showed a strong variation in survival rate. In this study different water/wastewater ratios where used with up to 100% wastewater. No effects were found concerning the ratio of wastewater used (Toky, 2011).The first species, which comes in mind for Indian climate, is probably bamboo. However studies on bamboo biomass production are scarce (Nath et al., 2009). A study conducted in subtropical warm and humid conditions in the Barak Valley Region found a biomass production of 37.7 t/ha /year. The productivity of acacia and bamboo was compared in a study in Kallipatty, India (Shanmughavel and Francis, 2001). The biomass production showed a strong increase with age and a high advantage of bamboo compared with acacia. The variation from 2.2 t/ha in year one to 298 t/ha in year 6 and back to 16 t/ha in year 10 after planting makes it clear that it is critical to consider rotation length when comparing studies. However, the biomass uptake was higher for bamboo during all periods.In a study carried out at the Haryana University of Agriculture, Leucaena leucocephala showed the highest net primary production of 33 t/ha /year closely followed by Eucalyptus teriticornis with 29 t/ha /year. Compared with these species, Acacia nilotica trees had just half the primary biomass production (Singh and Toky,1995). Altogether it has been seen that eucalyptus is the most experimented specie in India, not just as SRC plantation but also in combination with wastewater irrigation. Bamboo, which has a high potential due to its adaptation to Indian climate conditions as well as its broad spectrum for usage after harvesting, has been lest studied, and in particular not with irrigation of wastewater.

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Pranav M. Nagarnaik, Girish R. Pophali and Pawan Labhasetwar
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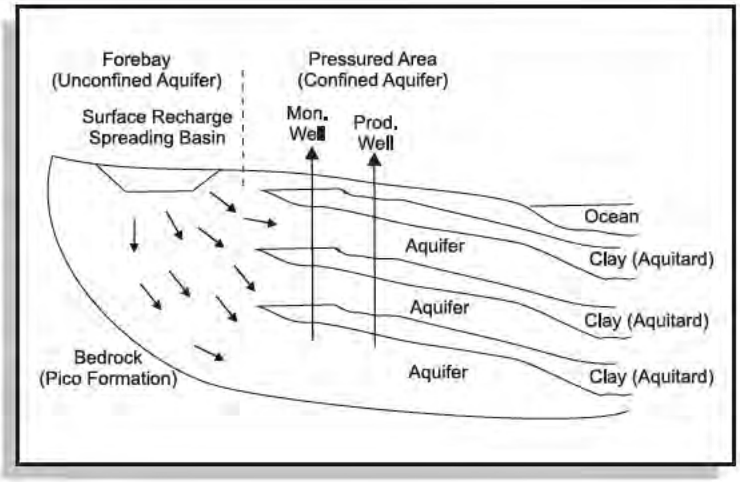
Groundwater recharge is an engineered process of replenishing the aquifer with water from the surface at an exceeding rate than the natural recharge rate. Over exploitation of groundwater has resulted in the depleting groundwater table in urban areas around the world. Groundwater recharge is the management of aquifer by reducing the water lost due to runoff and evaporation and redirecting to the excess water into the ground either by spreading on the surface or recharge basins or by altering natural conditions to increase infiltration to replenish an aquifer. All types of sources including fresh water, storm water and wastewater can be used for the ground water recharge.



Design and Construction Principles

The factors for consideration for surface groundwater recharge are quality and quantity of water available, clogging potential, underground aquifer space available and transmission characteristics of aquifer. The groundwater recharge is governed by geological and hydrological characteristics of the aquifer system. The design approach includes the distribution of the head and a stress prior to and during project operations, hydraulic properties and the fate of artificially recharged water. Important aspect in design is to identify basin compartmentalisation or impermeable layers within the aquifer that inhibit recharge to the aquifers. Another design consideration is the mixing of surface water and native groundwater, hydrological variability with the aquifers and nature of recharged water. Before implementing chemical and physical modelling of recharge options, detailed analysis of co-mingled water that have different initial chemical signatures, and measurement of recharge rates is required. The surface groundwater recharge techniques include: surface spreading techniques, flooding, ditches and furrows, recharge basins, runoff conservation structures, gully plugs, stream-channel modification and surface irrigation. The selection of type of technique depends on the local conditions and the land usage pattern.

Operation and Maintenance

Periodic maintenance is required for effective recharge, because the infiltration capacity is affected adversely due to silting, precipitation and accumulation of organic matter (Brown and Keys, 1985). There is limited monitoring and operations for the surface groundwater recharge.

Cost Considerations

The cost for construction and maintenance of the surface groundwater recharge scheme depends on the degree of treatment of the source water, the distance over which the source water needs to be transported and the stability of the recharge structure and resistance to silting and/or clogging. The capital cost for implementation of surface groundwater recharge scheme includes the land cost and the possible landscaping and modification of the area. In the urban areas this could be the limiting factor for implementation of surface groundwater recharge. The regular maintenance cost is minimal apart from some resources required for removal of deposited slit or organic matter, which is usually removed in 5-7 years.

Advantages

- The technology is well understood by engineers and well accepted by the population.
- The groundwater recharges stores the water in the wet season for it to be used during the droughts.
- Limited operation and maintenance.
- Within the river basin, groundwater recharge reduces sedimentation problems.
- Groundwater recharge with better quality water can improve the characteristics of the aquifer water facilitating its usage in different applications.

Disadvantages

- Limited economic feasibility
- Potential for contamination of groundwater from injects surface water runoffs
- Environmental impact on soil and vegetation cover may be caused during the construction of the plant.

Experiences in Europe and other Cities of the World

Surface groundwater recharge has been implemented around the globe. Surface groundwater recharge using treated wastewater has been implemented in the arid areas of Australia and in several states of the US including Arizona, California, Florida, New York and Texas (Beattie et al., 1978; Bouwer and Rice, 1984; Brown and Keys, 1985, Kimrey and Fayard, 1984; Nellor, 1984; OCWD, 1991; Seaburn and Aronson, 1984). Some countries, for example, the Hashemite Kingdom of Jordan and the Kingdom of Saudi Arabia, have a national policy to reuse all treated wastewater effluents and have made considerable progress toward this end. The Dan Reclamation Project in Israel utilises secondary effluent for aquifer recharge using surface spreading via recharge basins (Kanarek and Michail, 1996). Surface recharge techniques such as infiltration basins and the ditch and furrow method achieve high rates of removal of organics, BOD, COD, nitrogen, phosphorus and coliforms (Pescod, 1992).

Experiences in India

Surface recharge through percolation tanks or spreading basins is the most common method in India to recharge groundwater both in alluvial and hard rock formations. The efficiency of these structures is more in hard rock formation where the rocks are highly fractured and weathered. In the States of Maharashtra, Andhra Pradesh, Madhya Pradesh, Karnataka and Gujarat, percolation tanks have been constructed in basaltic lava flows and crystalline rocks. However, surface recharge cannot occur in clayey soils, which have low permeability (CGWB, 2009; NDWM, 1989).

Vertical recharge shafts can be provided in case of land constraints. In India, these have been constructed in Kurukshetra District, Haryana to obtain silt free water, Sangrur District, Punjab to treat surface runoff with heavy silt and New Delhi to recharge groundwater with rooftop and surface runoff (CGWB, 2009).

There is limited experience with groundwater recharge using treated wastewater in India. However, one pilot scale study was carried out in Ahmedabad to assess the potential of aquifer to treat primary treated wastewater. Primary treated domestic wastewater was used in order to address the cost and operative constraints of secondary wastewater treatment. It was suggested that the climate and characteristics of wastewater under Indian conditions, especially suspended solids, aid primary clarification and therefore increase the acceptability of primary effluent for recharge (Nema et al., 2001).

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NaWaTech

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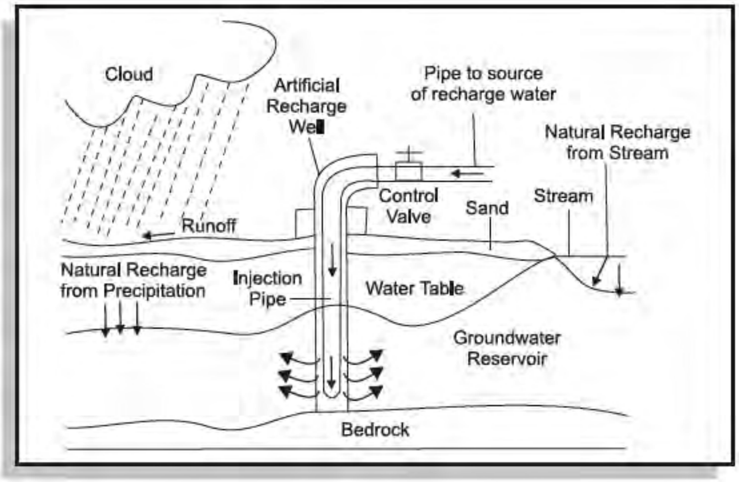

Artificial subsurface groundwater recharge is a process to capture lost water due to runoff and evaporation in the areas where groundwater supplies are depleted. Long-term withdrawal exceeds long term recharge, which has led to the depletion of the groundwater level. In such regions it is required to recharge the groundwater through engineered systems. The groundwater recharge methods are broadly classified into surface and subsurface methods. When the impervious layers overlie deeper aquifers, the infiltration from surface cannot recharge the subsurface aquifer under natural conditions. The techniques adopted to recharge the confined aquifers directly from surface water source are grouped under subsurface recharge techniques.

Design and Construction Principles

The different sub-surface groundwater recharge techniques include injection well, gravity head recharge wells, connector wells, recharge pits and recharge shafts. The design considerations for different types of subsurface recharge depend on the type of techniques to be implemented. Injection wells are structures similar to tube well but with the purpose of augmenting the groundwater storage of a confined aquifer by pumping in treated surface water under pressure. The design and construction of an injection well is similar to a tube well. Similar to tube wells, dug wells can also be used for subsurface recharge. The connector wells are special type of recharge wells, which connect two aquifers and the recharge takes place because of potentiometer head. The designing parameters depend on the quantity of water to be recharged and the rate of recharge to the ground water (CGWR, 1984).

Operation and Maintenance

Periodic maintenance of the system consists of pumping and / or flushing with a mildly acidic solution to remove encrusting chemical precipitates and bacterial growths on the well tube slots. By converting the injection or connector wells into dual purpose wells, the time interval between one cleansing and another can be extended, but in case of spreading structures annual desilting is necessary.

Cost Considerations

The initial cost of the artificial subsurface groundwater recharge is higher due for the construction of the wells. The cost depends on the depth of the aquifer and the integrity of rock structure. Large discharges and lower lift heads makes it an economic options even if the initial capital cost is higher. The maintenance cost depends on the treatment and the frequency of desilting and declogging of the wells.

Advantages

- Due to rock formation with high structural integrity, few additional materials may be required to construct the wells
- Sustainable and substantial increase in the aquifer yield
- Advantageous in arid regions

Disadvantages

- In adequate maintenance and repair may result in the contamination of aquifer
- Contamination of the groundwater due to water runoff from agricultural fields and road surfaces
- Treatment is required before subsurface recharge can be done to avoid contamination

Experiences in Europe and other Cities of the World

Subsurface recharge of groundwater is carried out through injection wells. A high degree of pre-treatment is needed in the case of injection wells as water is directly injected into the groundwater. Injection wells have been extensively studied in Israel, Australia and several states of the US including California, Florida, Oregon and Arizona (Bouwer, 2002). These studies provide significant data on the capability and reliability of advanced wastewater treatment processes to remove microbiological and chemical constituents, ground water quality, and monitoring techniques. Injection wells have been constructed in limestone, fractured rock and alluvial aquifers. Water used for injection is usually given tertiary treatment (sand filtration and chlorination). However, clogging still occurs when this water is used for groundwater recharge.

Therefore, geochemical factors (carbonate precipitation, iron hydroxide formation, mobilisation of mineral chemicals) must be considered. Membrane filtration of treatment of the water is effective in preventing well clogging. Alternatively, injection wells are pumped using a submersible pump, once or twice a day to prevent serious clogging, which has been shown to be more effective than using membrane filtration (Dillon et al., 1997).

Experiences in India

The use of injection wells for recharge of groundwater in India is largely experimental and is not used at a large scale anywhere. Studies have been carried out in alluvial or hard rock with confined aquifer to a depth of 40 m depth. Studies of artificial recharge have been carried out in Punjab and Gujarat, using canal water as the primary surface water source (NDWM, 1989). The natural, gravity-controlled recharge rate was 5.1 L/sec. Over time, the reproducible recharge rate obtained using the pressure injection system was found to be about 10 times greater than the rate obtained using gravity flow. Clogging of interstitial spaces within the aquifer also occurs.

Studies show that recharge rates increase with increase in recharge head. On the other hand, recharge rate is higher for wells constructed in the saturated zone as compared to the vadose zone. This is because of a higher proportion of coarse sand mixed with gravel in the former. pH values are found to decrease. However, there is no reduction in MPN and COD through subsurface recharge. Studies have also been carried out in the Saraswati River basin to study ambient flows in injection wells (Kumar et al., 2008; Kumar and Aiyagari, 1997).

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Chapter 5

Challenges in Implementing NaWaTech in India

Challenges in Implementing NaWaTech in India

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Photo by Nagarnaik 2011

Introduction

A scarce natural resource, water is fundamental to life, livelihood, food security and sustainable development. India has more than 18 % of the world's population, but has only 4 % of world's renewable water resources. Supply of safe and reliable drinking water to the entire population of India has several limitations, even when compared with other developing countries. With a growing population and rising needs of a fast developing nation, as well as the given indications of the impact of climate change, availability of utilisable water will be under further strain in the future, with the possibility of deepening water conflicts among different user groups (MoWR, 2012). A massive urban transformation is accompanying India's rapid economic growth, posing unprecedented challenges to India's growing cities and towns, particularly in the provision of infrastructure such as water, sanitation and sewerage, in order to meet the needs of a future urban population of 600 million people by 2031. According to the Central Pollution Control Board (2009), the total water supply for themore than 900 cities classified as Class-I (> 100,000 inh) andClass-II (between 50,000 and 99,999 inh) is approximately 48,090 MLD, with an average of water supply per capita of 179 and 120 L per day (in Class I and Class II cities respectively) (CPCB, 2009). The average of water supply hours in 28 Indian cities is 3.3 and no city has continuous 24 hours water supply. Other quality metrics, such as accessibility, affordability, cost recovery, extent of metering, and extent of non-revenue water, are all underperform vis-à-vis the set standards by a considerable degree. The reasons for such chronic underperformance are complex and deep-rooted.

Along with increasing water demand due to urbanisation there is decrease in the fresh water sources due to incessant discharge of untreated sewage in the water bodies. Traditionally, urbanisation and industrialisation has occurred near water bodies like rivers, reservoirs and lakes. Pollution of rivers has occurred in such urban conglomerates in India including Jhelam and Yamuna in North, Palar and Cauvery in South, Ganges in East, Tapi in West India and Wainganga and Mahanadi in Central India (Goldara and Banerjee, 2004, Sood et al., 2008; Ayyamperumal et al., 2006; Panda et al., 2006; Suthar et al., 2009; Rajaram et al., 2008; Shahul et al., 1997; Dekov et al., 1998). The major concern for local authorities is the fact that only 25-30 % of generated sewage is currently treated (CPCB, 2012).

Fig. 5.1: Goals, Challenges and Opportunities of Water Management in India

Given the limits on enhancing the availability of utilisable water resources and increased variability in supplies due to climate change, meeting the future needs in urban India will depend more on demand management. Hence, following recommendations in policy documents corroborating with main NaWaTech objectives are made:

- Bringing in maximum efficiency in use of water and avoiding wastages (MoWR, 2012).
- Recycle and reuse of water, including return flows, should be the general norm (MoWR, 2012).
- Urban water supply and sewage treatment schemes should be integrated and executed simultaneously (MoWR, 2012)
- Attention should be given to building, renewing and replenishing local water sources, including groundwater, to cut the costs of water supply through investments in sewerage (to stop pollution of waterways), and in increased reuse and recycling of waste waters (Report of the Working Group on Urban WSS for XII Five Year Plan)

The available data, as well as the ground reality are demanding the implementation of an integrated water management approach, counting with the technological know-how and knowledge base available. The technology has advanced; however, its effective implementation faces challenges in urban India. Social, administrative, financial and technical issues posing major challenges in the realm of 'water and sewage management cycle' and implementing and integrated NaWaTech approach in India are addressed in this chapter. Under these circumstances, now it is imperative to look at water and sewage management as an investment rather than expenditure. Figure 5.1 explains the proposed 'water management cycle' which also sets the objective for the manuscript.

Challenges of Water and Sewage Management

Social Challenges

Water is subject to particularly intense scrutiny due to its social, political and economic importance. The 'emotional' appeal of water as an essential commodity is not to be underestimated either. The 'Cultural and Religious' values associated with water especially in the Indian sub-continent also cannot be overlooked. The intermittent and not of standard quality water supply is observed all over India. The acceptance from the population of any need to change is a major implementation of NaWaTech in Indian society. The biggest social challenge for implementing any modification to the existing water management in India is the assertion of the local people of water being their right and they must not be asked to pay for it. Private vendors sometimes oppose legalisation of household connections for fear of losing out on their income. At times there is lack of communication between various stakeholders and ambiguity of control and authority. The influence of pressure groups, lobbyists and political groups hinders in the implementation of any social project.

The common practice of disposing domestic solid waste in the sewerage systems impacts the performance of the sewage treatment plants. The domestic solid waste contains nutrients, oil and grease and other non-degradable waste, which chock the sewer and changes the sewage characteristics. Many unaccounted industrial waste is discharged in the sewage network, which changes the sewage characteristics resulting in inefficient STP performance. Changing the mind-set of society to avoid disposing domestic solid waste to the sewage network is a challenge.

Urban water governance is highly skewed towards government control, without much involvement of all stakeholders, particularly the inhabitants. Most of the urban water supply and sewage management functions are the responsibility of the municipal water works, public health engineering and public works departments with ambiguity and little coordination among them. It is therefore geared towards serving the needs of public/departmental services rather than catering to the needs of the customers/citizens. Citizens must be made aware and encouraged to extend full cooperation to local government and regulatory bodies. Moreover, decentralised governance principles are yet to be followed i.e., citizen group empowerment, local level access and community/public involvement. It will therefore be a major challenge to mainstream NaWaTech technologies in urban water supply and sewage management cycle.

Institutional and Administrative Challenges

Water is constitutionally a subject governed by the State Governments, but with the provision for the Central Government to intervene in case of management of inter-state rivers. While water, in the constitution, originally referred to the management of rivers and irrigation, it is now more broadly understood to include all water bodies, aquifers, groundwater, urban and rural water supply schemes, sewerage, sanitation, etc. As such, currently in India, the Central Government is responsible for laying down the policy framework and for funding and monitoring schemes related to the provision and management of water resources. The implementation of the water policy through programs and schemes identified by the Central Government, such as the development of water infrastructure, operating, maintaining and regulating water supply system and setting and collecting water tariffs, is carried out by the State Governments and by parastatal agencies, such as the Urban Local Bodies (ULBs). Institutional challenges are one of the toughest challenges in water and sewage management in India. The organisational structures do not encourage efficiency and outputs, but reward positions based on the tenure and past experience. The current institutional arrangements for water resource managements at all levels, central, state and local, and both formal and informal structures, do not enable comprehensive water allocation, planning and management.

Other institutional limitations for improving urban water management include lack of coordination between the institutions, overlap of responsibilities, accountability gaps, inadequate fostering of grassroots institutions. Furthermore, lack of involvement of civil society, such as local communities, NGOs, private sector, academia and research institutions, restrict the improvement in urban water supply and sewage management.

The devolution of the responsibility for urban governance to Urban Local Bodies has not happened to the extent desired, which has led to the performance improvement being limited or absent. This in-turn traces itself to the lack of adequate capacity building and the non-accountability of Urban Local Bodies in implementing reforms successfully.

Lately, there is an increased interest in the effects of organisational culture within the agencies responsible for supplying water and managing sewage. However, the administrative hurdles in ensuring the effective monitoring of supply of safe water still exist. The ambiguity of control and authority poses challenges, resulting in delays in the implementation of projects. Other challenges, like delay in procurement of equipment, conflicts between contractors and engineers and repair and maintenance, impede the implementation process.

Availability of land and land acquisition for centralised or decentralised sewage treatment systems is an administrative challenge. Encroachment on the government designated areas is a common problem. There is a delay in administrative processing for solving land related issues due to social and political interventions.

The sewage management is usually neglected by the local authorities and there is limited allocation of funds towards treatment and conveyance networks. As a result, only few towns have sewage network using lined drains. It is clear that the creation of an infrastructure for conveyance of sewage within towns in India remains a challenge.

Last but not least, the availability of skilled manpower and their finances is a challenge. Most of the towns have very limited manpower as Sanitary Inspectors for ensuring the proper implementation of the systems. Therefore, administrative strategies must be set for sewage management as priority. These hurdles are faced during implementation of centralised as well decentralised water management schemes like NaWaTech.

Financial Challenges

While the water situation in India has not been as attractive as of now, reforms on the regulation and policy front have begun to take shape and success of these can create potentially huge investment opportunities in future. There are several issues related to the financing of water and sewage management infrastructures, as the majority of water supply and sewage management infrastructure depends on government funding. For many years, the water utilities and municipalities have been facing acute shortage of funds to develop, operate and maintain water supply-distribution infrastructures in an efficient and viable manner. With the increased involvement of the private sector, there will be a need for efficient water and wastewater management to improve operating efficiency levels, which is likely to require an investment in emerging wastewater technologies such as the Hybrid Reactor and Solid Aquifer Treatment (SAT) technologies. Urban water demand, water treatment and recycling are more attractive areas to investors compared to irrigation, given the increasing investment in urban renewal and the improvement in environment consciousness of corporations in India. Business opportunities revolve around four key themes viz. water demand management, water supply management, water infrastructure upgrading, and water utilities management (Ernst and Young, 2011).

This growth needs massive capital and O&M investment in urban infrastructure, as highlighted by various Finance Commissions and expert bodies. The High Powered Expert Committee (HPEC) Report on Indian Urban Infrastructure and Services estimates (at 2009-10 prices), the per capita investment needed for capital infrastructure in the water, sewerage and storm-water sector at Rs 13,329 and another Rs 840 annually for operation and maintenance. The total investment needed during 2012-2031 according to this estimation is Rs 7,54,627 crore for capital (approx. 89 billion €) and Rs 8,17,671 crore (approx. 97 billion €) for O&M, respectively. Thus, the water supply, sewerage and storm water drainage investments amount to about 24% of all urban sector requirements for capital and 41% for O&M respectively.

A sewage management system would be sustainable if there is a proper linkage between the expenditure to be incurred and the revenue generation. For example, at present there is no effective linkage between the cost of water supply and the cost of sewage treatment to be recovered from a consumer. In other words, if a consumer gets 135 LPCD water and generates 80% sewage amounting to 108 LPCD, then there is no provision to recover the cost incurred for sewage treatment. Mere collection of sewage tax in the form of property tax is not sufficient to sustain the operation and maintenance costs of sewerage and sewage treatment systems. The revenue generation for sewage management must be based on cost required to maintain sewage management systems and should not be a fraction of property tax. The other financial models based on recycling of treated sewage to reduce the cost needs to be checked. Another important feature of financial challenge is the additional load of sewage management on ULBs from unauthorised habitats. There is no revenue collection from unauthorised habitats, which generate sewage and discharge in sewer and drains. This has to be adequately taken care by the ULBs keeping provisions for additional sewage from such layouts. Apart from these challenges, it is observed that allocation of capital funds for sewerage and sewage management is never a priority, and therefore there is always a lack of availability of funds within ULBs. This trend has to be changed, as it was mentioned earlier, that "expense on sewage management is an investment rather than expenditure".

Natural Environmental Challenges

The aim of the NaWaTech approach is to synchronise and optimise the different water resources available in urban India. According to the Central Water Commission (CWC),the average annual water resource potential in India is assessed to be 1869 BCM (CWC, 1993). However, it is estimated that owing to topographic, hydrological and other constraints, the utilisable water is only 1123 BCM, which comprises 690 BCM of surface water and 433 BCM of replenishable groundwater resources. With an estimated per capita availability of 1,588 m^3/inh/y (CWC, 2010), India does not fall under the category of a water scarce country per se, rather it can be termed as a country under 'water stress'. Of all the rivers in India, 12 are classified as major rivers, whose total catchment area is 252.8 Mha. However, there is a considerable temporal and spatial variation with respect to river water availability. The Ganga-Meghna-Brahmaputra basin covers a land area of 33 % and accounts for 60 % of India's water resources, while the catchment of rivers flowing west is 3 % and they account for 11 % of the country's water resources. As a result, 71 % of India's water resources are available to only 36 % of the area, while the remaining 64 % has 29 % available (Verma and Phansalkar, 2007). The majority of the runoff is generated during the 3 to 4 months of the monsoon season. Brahmaputra, Barak and Ganga rivers account for as much as 60% of the total flow causing recurring floods. At the same time, large areas in Rajasthan, Gujarat, Andhra Pradesh, Karnataka and Tamil Nadu, which receive scanty rainfall, do not have perennial rivers and often face drought-like conditions. While the per capita water availability in Brahmaputra and Barak basin is very high, it is low in river basins such as Sabarmati, west flowing rivers in Kutch and Saurashtra.

India is the largest consumer of groundwater in the world, with an estimated usage of 230 km^3 per year (Addams et al., 2009; World Bank, 2010). As per the Department of Drinking Water and Sanitation (DDWS), nearly 90 % of the rural water supply is from groundwater sources. A growing demand for water, coupled with unreliable public supply schemes, has led to a growing dependence on the groundwater sources of the country, whereby it is being extracted not only through the municipal water utilities but also by private owners, through borewells and pumps (Shankar, 2009).

An unsustainable level of exploitation has put the groundwater resources at great peril, lowering the groundwater table in many areas and causing saline water intrusion in various parts of the country. The availability and proper utilisation of fresh water sources is a challenge for the ULBs. An integrated water management approach, like NaWaTech, has an inherent problem of availability of water scarce region. The inconsistent rainfall pattern, reducing the groundwater levels and polluted surface water sources is a major challenge of implementation of NaWaTech.

Technical Challenges

Water supply in most Indian cities is intermittent. No major Indian city has a continuous supply of water. McIntosh (2003) notes that consumers without 24-hour supply tend to use more water than those with continuous supply because consumers store water, which they then throw away to replace with fresh supplies each day. Based on a survey conducted in Delhi in 1995, Zérah (2000) estimated that each household on average spent around Rs. 2000 per year coping with unreliable supply of water, which is 5.5 times as much as they were paying the municipal authorities for their annual water consumption. Many households with private connections were found to have undertaken long-term investments in the form of water tanks, handpumps or tubewells. Households with water tanks install booster pumps on the main water line itself and pump water directly to water tanks. This increases the risks of contamination in the distribution network and reduces the pressure in the network for other users, causing them also to install motors on the main line (McKenzie and Ray, 2009).

Unaccounted for water corresponds to the percentage of water produced that does not reach the consumer. Unaccounted for water poses a significant challenge in urban water supply in India. It results both from leakages and illegal connections. In addition to the financial costs to the water utility, high levels of unaccounted for water are also a major reason for intermittency in the supply of water, since leaks and illegal connections lower water pressure in the distribution system and reduce the overall amount of water available. It is estimated that these losses account for 25-40% of water produced by utilities in the main urban areas in India. The consequence of high levels of unaccounted for water is that most urban water utilities in India are unable to cover even operating and maintenance costs out of the revenue generated, let alone provide capital for the expansion and improvement of the network (McKenzie and Ray, 2009).

To tackle the technical challenges in sewage management is the major concern of practicing engineers and scientists and most crucial of all the challenges (Pophali et. al, 2011). Technical challenges in India can be further divided into major categories as follows:

- **Sewage collection system:** the starting point for improving the performance of sewage management system is by improving the sewage collection. Sewer lines must be free of any kind of solids waste and as far as possible. Stormwater should not be allowed to enter sanitary sewers. Similarly, industrial effluent discharge into sewers should also be discouraged. However if it is necessary, then sewer size should be designed taking stormwater and industrial flow into consideration. Inadequate design of sewerage systems could lead to problems such as clogging and overflow. Sewerage system should be designed based on the primary data using latest state of the art software such as "Sewer CAD" etc.

- **Maintenance and safety issues of sewerage system:** These require special consideration as they are directly linked with human health. In India, the sewer workers are not trained enough to handle potential hazards of sewerage maintenance, nor do they have adequate sewer safety gadgets. Major hazards including sewer gases (CH_4, CO, H_2S, vapours), fire, biological, physical, electric shock, poor visibility and noise etc. are commonly encountered in sewerage maintenance and can prove to be fatal to sewer workers. Lack of availability of sewer safety gadgets, cleaning and rescue equipment, and skilled manpower pose a major challenge for sewerage maintenance. This challenge can be dealt with by hiring skilled manpower, training of staff, providing sewer safety gadgets and following safety norms.

- **Type of technology options for sewage treatment:** the type of treatment process to be implemented remains at the forefront of all the challenges, since a large number of technology options are available for sewage treatment. Technology option also governs other challenges, including that of financial issues since the sole objective any option is to maximise benefits by incurring minimum cost. In order to achieve this objective, it is necessary to assess primary data of various treatment alternatives to arrive at the most suitable treatment. This warrants delineation of key selection criteria, which includes various factors such as economics of treatment, treatment efficiency and ease of operation. Table 5.1 presents various factors of key selection criteria to arrive at the most suitable treatment option.

Tab. 5.1: Various factors of key selection criteria for selection of technology options

Economic	Technical (Treatment Efficiency)	Administrative
• Capital • O&M Cost • Land Area	• Primary Objective • BOD, COD, TSS removal • Secondary Objective • Nutrient (N, P) & Coli-form removal • Tertiary Objective • Treatment time, sludge generation & • Handling, Operating flow capacity • Advanced Objective • Permeate recovery, TDS removal & Rejects generation	• Ease of operation • Designated end use of treated effluent

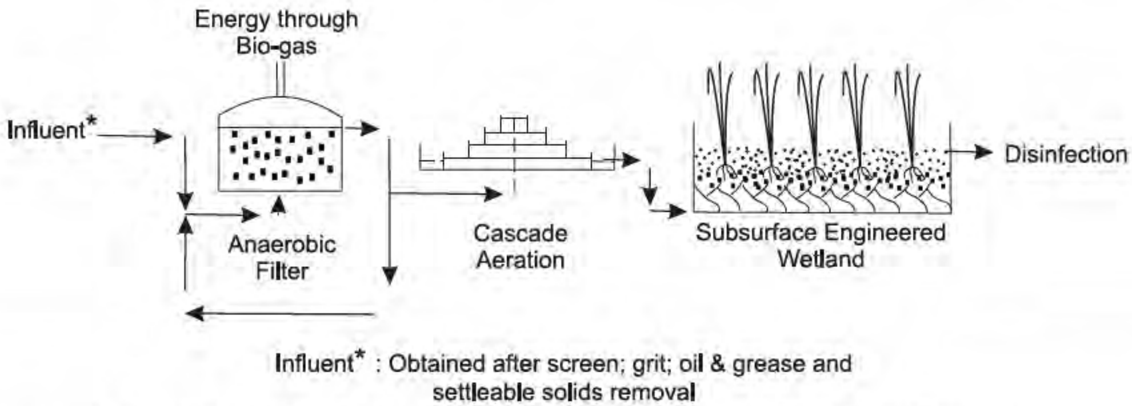

Fig. 5.2: Sewage Treatment Option with Low Capital, O&M costs; Energy Generation and Reuse of Treated Effluent for Small Communities

- **Operation and maintenance (O&M):** Effective and efficient O&M is crucial for the sustainable implementation and long-term functioning of water supply and sanitation systems. However, issues related to O&M services are often neglected in the design and set-up of systems, and thus non-functioning O&M services are a widespread challenge (Müllegger et al., 2010). It is clear that every technology that is implemented in a system requires proper O&M to function whereby different technologies at different steps in the system need different people and different responsibilities for O&M. The level of O&M is closely linked to ownership of a facility and the basic understanding of the technology and its functions (Müllegger et al., 2010). Therefore O&M is not a technical issue alone but also requires clearly defined roles, accountabilities and institutional responsibilities as well as effective mechanisms for cost recovery (see also the other chapters above).

Final remarks

All features of the 'water management cycle' comprising of 'challenges – opportunities – goals' (Figure 5.1) must be first visualised. It would be advantageous to initially assess the challenges and subsequently derive the opportunities to achieve the targets of resource conservation and sustainable development. All the challenges are manageable and are well within the capacity of society, institutions, administrators, government and technocrats, but only warrants integrated timely action. The Indian society can help to a great extent by keeping sewer lines free of solid and food wastes and institutions can have strict vigilance on sewer lines. Administrators and Governments have major role to play in policy decisions and facilitating adequate funds, skilled manpower and land, meanwhile technocrats can shoulder the responsibility of suggesting and implementing a techno-economic and environmentally sustainable treatment option, because the bottom-line is; it is imperative to look at water and sewage management as an 'investment' rather than 'expenditure'.

A programmatic approach that integrates planning for urban water supply and sewerage at the state level, which is further broken into targets and objectives for cities that are stratified according to their size, is the overarching method of implementing change. Full achievement of the service level benchmarks should occur in a phased manner, where intermediate targets are set, based on a number of parameters, such as the state of existing physical infrastructure, the definition of clear responsibilities for O&M, the technical and operational capacity of the ULBs and the private sector, availability of finance, etc.

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Chapter 6

NaWaTech Sustainability Criteria

NaWaTech Sustainability Criteria

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Illustration by Doyle 2013

Introduction

As has been presented in this Compendium, there are many natural and technical water treatment systems that have the potential to convert used water into a water source of acceptable quality for indirect potable reuse. The sustainability of such technological solutions depends on a variety of factors, which can be divided into technical, environmental, economic, health and social criteria. NaWaTech aims to identify and enhance technologies so far as they are ready for mainstreaming in urbanised areas of India. This means that they have been accepted or have potential to be accepted by end-users, service providers and decision makers. In this way the project translates the social sustainability into technical viability (robustness) and economic cost-effectiveness. To achieve sustainable implementation of technologies they have to be evaluated within the urban water cycle (see Chapter 3).

To define what sustainability means in the NaWaTech context and how sustainability can be measured the NaWaTech consortium has, as a first step, produced the ***NaWaTech Sustainability Criteria Catalogue*** (NAWATECH, 2012). The document comprises a list the different criteria selected for the five mentioned categories and their definition, a set of indicators with which to measure them with their definitions, and a guide on how to apply them. This Catalogue is available for download at www.nawatech.net. Due to the fact that sustainability is context-specific, no system can be considered universally sustainable. For this reason, the authors of this Compendium have opted not provide a sustainability ranking of the presented technologies, but to empower the users on evaluating the sustainability of the technology or technological systems in their specific cases.

Application of the NaWaTech Sustainability Criteria Catalogue

Defining the Objectives, obtaining Weights

As has been previously presented, there is a general consensus on the need to evaluate the sustainability of a technology or system in a given context (Gibson, 2006; Lennartsson et al., 2009; Weaver et al., 2006). Therefore, the first step to apply the NaWaTech Sustainability Criteria Catalogue is to define the objectives that need to be fulfilled in the evaluated case: this exercise will provide the different weights that the different criteria have, with which the decision can be taken. It will be often the case that, after evaluating several technological options, the same number of positively fulfilled criteria could be obtained, but for different ones. It is here where the correct identification of the objectives plays a major role. For example, for a system that needs to be installed in a densely populated, industrial and well-connected city, low land requirements are critical, and would be more important than for example low energy requirements – the first criteria would have a bigger weight than the second. Low noise and vibrations and low emissions to environment would be very important due to the proximity to households, as well as being conceptually accepted by local people. However, if the same implementation in an isolated or bad connected area is being considered, the use of local resources and materials and adaptability to future changes would be key aspects to be fulfilled in this case. In deprived areas, the benefits to the local economy (e.g. job creation, production of secondary materials, ...) would be a very important factor for the global sustainability of the system, but not so relevant in more prosperous regions. Ultimately, the context will provide the answer to what is more sustainable.

Evaluating Criteria Fulfilment: Use of Indicators

With the context and objectives clearly defined, the user can proceed with the sustainability evaluation of the different technological alternatives. It is important to evaluate the proposed system as a whole, and to recognise the importance of sustainability of services provided, and not only on sustainability of the technology itself. Inadequate focus on sustainability of services (operation and maintenance, clear division of responsibility between household and service provider) may render any wastewater treatment, however well designed and environmentally sustainable, a health hazard (Lennartsson et al., 2009). The NaWaTech Sustainability Criteria Catalogue provides a wide set of criteria with which to confront the system under evaluation.

It should be noted that the NaWaTech team aimed to provide a versatile tool with which users could assess sustainability under different scenarios. Therefore, not all the listed criteria may be relevant for all cases. Each criterion is accompanied by a definition for clarity. Table 2 of the *NaWaTech Sustainability Criteria Catalogue* (NAWATECH, 2012) provides a set of indicators with which to measure the fulfilment or not of each criterion. Some of the indicators can be measured quantitatively, while for others only a qualitative evaluation is possible. For quantitative measurements, care must be taken in that for some cases the best score should be awarded to the option presented the higher value, while for others the lower result will be the best case. These considerations are highlighted in the mentioned table.

Once all the different indicators are evaluated and so the fulfilment of the different criteria measured, the user is ready to compare the sustainability of the different options. The resulting of this is a technology matrix, as presented in Table 4 of the *NaWaTech Sustainability Criteria Catalogue* (NAWATECH, 2012), were the fulfilment of the different criterion by the different technological options can be visualised. It is proposed to use qualitative descriptors, as presented Table 6.1. A template for sustainability assessment is also provided as an annex to this Compendium.

Tab.6.1: Proposal for qualitative descriptors (NAWATECH, 2012)

Qualitative Descriptor	Meaning
++	the criterion is very well fulfilled by this technology
+	the criterion is fulfilled by this technology
O	the criterion is neutral to this technology
-	the technology does not fulfil well this criterion
- -	the technology does not at all fulfil this criterion
shaded	the criteria is not applicable for this technology

Final remarks

The NaWaTech system approach aims towards the sustainable implementation of natural and technical treatment technologies to cope with water shortages in urbanised areas in India. To fulfil this objective, the first step is to define what sustainability means in a particular context and how can it be measured. The *NaWaTech Sustainability* Criteria Catalogue provides an extensive set of criteria, organised under technical, environmental, economic, social, and health criteria. The Catalogue provides as well a set of indicators with which to measure the fulfilment of the different criteria. No system or technology can be claimed to be universally sustainable: sustainability should always be assessed within a given context. For this main reason, the authors of the NaWaTech Compendium of Technologies have opted not to provide a sustainability ranking of the presented technologies, but to empower the users on making their own assessment for case-specific needs.

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Recommended Readings
&
Annexes

Recommended Readings

The NaWaTech Website

www.nawatech.info

The NaWaTech Website is the main tool to ensure public awareness and acceptance of the NaWaTech technologies and a successful mainstream of indirect potable reuse of both reclaimed wastewater and storm water. This webpage enables a widespread dissemination of the NaWaTech project, its objectives, results and main events. The Website is continuously being up-dated and water practitioners are invited to visit it in a regular basis to discover the status and results of the projects in Nagpur and Pune, where actual NaWaTech systems are implemented to enhance the feasibility of natural and compact water systems and treatment technologies for Indian cities.

SSWM Toolbox

www.sswm.info

The Sustainable Sanitation and Water Management (SSWM) Toolbox is a tool for capacity building and information sharing that supports practitioners during the planning and implementation of initiatives in water, sanitation and agriculture at local level. The particularity of the SSWM approach is that it integrates a holistic approach to water management, sustainable sanitation and agriculture, promoting the systematic closure of the water and nutrient cycles. The SSWM Toolbox contains the most comprehensive collection of documents, guides and case studies presented in a didactic manner to facilitate the user's navigation. This knowledge platform was created by a group of recognised organisations, such as seecon, SDC, GIZ, Cap-Net, UN-Habitat, EAWAG, SEI, WSSCC, among others.

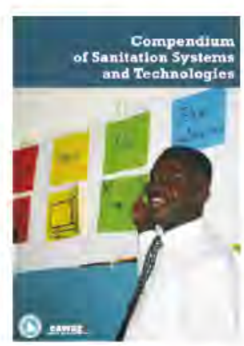
The Central Public Health and Environmental Engineering *Organisation(CPHEEO)Manuals*

http://cpheeo.nic.in/

"CPHEEO manuals" are developed and published by The Central Public Health and Environmental Engineering Organisation (CPHEEO), which is the Technical Wing of the Ministry of Urban Development, Government of India, and deals with the matters related to urban water supply and sanitation, including solid waste management in the country. The manuals on Water Supply, Sewage and other aspects of water supply systems are commonly used by water utility engineers and managers for smaller towns and cities across the country. The manuals are available on the CPHEEO website.

Compendium of Sanitation Systems and Technologies

http://www.eawag.ch/forschung/sandec/publikationen/compendium_e/index_EN



Abundant information exists about sanitation solutions but it is scattered throughout hundreds of books and journals; this Compendium aims to pull it all together in one volume. By ordering and structuring a huge rangeof information on tried and tested technologies into one concise document, the reader is provided with a useful planning tool for making more informed decisions.

The NaWaTech Project

NaWaTech is an Indian-European research and development initiative, which aims to explore, assess and enhance the potential of natural water treatment systems in order to improve their performance and reliability to cope with water shortages in India. The strategic objectives of NaWaTech are:

1. To assess the technical, financial and environmental potential of natural water treatment and compact technologies to cope with water shortages in urbanised areas in India.

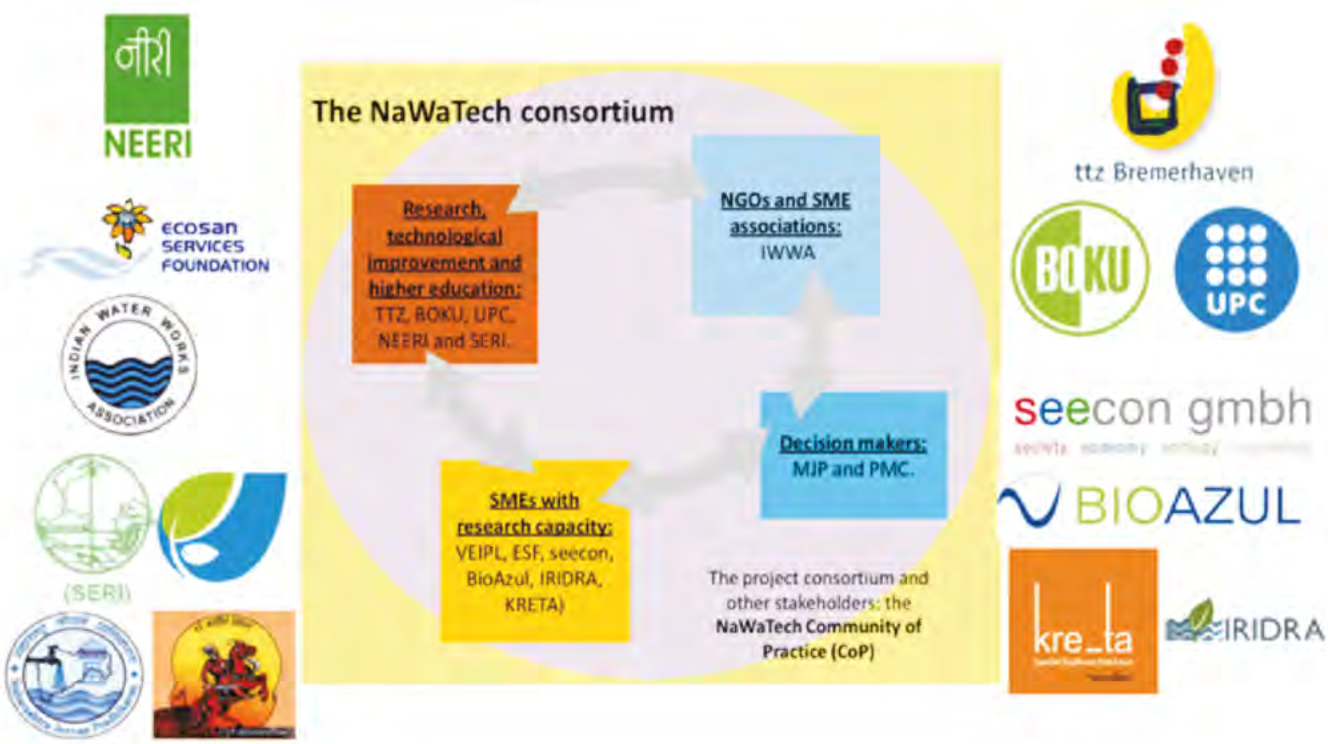
2. To enhance the natural water treatment systems and compact technologies for the production of recycled water to supplement water sources considering extreme climatic conditions and highly and widely varying pollutions loads (e.g. monsoon floods) and to implement 5 NaWaTech sites for the benefit of 4800 p.e. in Maharashtra.

3. To disseminate, exploit, and ensure the take-up in practice and mainstreaming of NaWaTech activities and outputs, by developing technical guidelines, tools, and manuals for design, implementation and operation and maintenance as well as policy briefs.

4. To ensure the interest and potential benefit to SMEs by supporting the development of a local market of natural water treatment and compact technologies.

5. To create an enabling institutional environment in order to allow the take-up in practice and mainstreaming of the results.

6. To establish foundations of a long-term cooperation between EU and India in water technologies as part of the Strategic Forum for International Science and Technology Cooperation (SFIC) and establishing bridgeheads among research institutions and ensure the take up of the NaWaTech approach in educational curricula.



NaWaTech

Template for Assessment of the Sustainability of a NaWaTech Technology in a given Scenario:

Evaluation + + : criterion very well fulfilled by this technology + : criterion is fulfilled by this technology 0 : criterion is neutral - : technology does not fulfil well this criterion - - : technology does not at all fulfil this criterion		Weight	Evaluation	Total
Health issues				
Prevents any risk of	Additional mosquitoes (or other insects) growth			
	Illness			
-Reduces exposure to pathogens	of users?			
	of waste workers			
	of resource recoverers /reusers			
	of "downstream" population			
- Increases health benefits				
- Hygienisation rate				
Impact to environment / nature				
-Conservational use of natural resources	Land requirements			
	Energy requirements			
	Local Construction material			
	Water amounts required for construction			
- Low emissions and impact to the environment	Water			
	Soil/ land			
	Air			
	Noise and vibration			
	Aesthetic			
- Good possibilities for recovering resources	Nutrients			
	Energy			
	Organic matter			
	Water			
- Good Landscape integration				
Technical issues				
- Simple construction				
-Local resources materials used and reproducibility				
- High robustness and long lifetime/high durability				
- Simple and low operational procedures				
-Simple and low maintenance procedures				
- Not reliant on a continuous supply of a resource (such as water or energy)				
-Adaptability to future changes				
- Quality of effluent (according to the receiving environment)				
-Low amount and easy treatment of generated sludge				
Economical and financial issues				
- Low construction costs (unit cost per household)				
- Provides benefits to the local economy (business opportunities, local employment, etc.)				
- Low operation and maintenance costs				
- Provides benefits or income generation from reuse				
Social, cultural and gender				
-Is conceptually accepted by local people				
- Low level of awareness and information to assure success of technology				
- Low operation & maintenance and little involvement by the users				
- High level of satisfaction of the local people regarding the implemented technology				
- No policy reforms at local, regional or national level.				
- Adds to the overall recreational and aesthetic value of the locality				

Partners:

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