Effluent Water Treatment: A Potential Way Out Towards Conservation of Fresh Water in India

S. Bej, A. Mondal and P. Banerjee

Abstract In modern age, rapid industrialization catalyses the steady magnification of the adverse effects. Released wastewater from various industries is of deepest concern which is highly responsible for aquatic pollution especially in India. An estimated amount of ~61,754 million litres per day (MLD) effluent water is produced in foremost metropolitans in India; however, the sewage management facility is only of ~22,963 MLD (approximately 37% of industrial effluents), and the remaining is disposed of untreated (according to the 2015 report of the Central Pollution Control Board 2015). The unscientific way of disposal causes severe diseases, responsible for environmental and ecological imbalance. This aquatic pollution is heading towards moderate to severe water shortages, brought on by the simultaneous effects of agricultural growth, industrialization and urbanization. In the forthcoming decades, the crisis of freshwater may lead to a major societal problem and political instability, if not the new option is found to supply the clean water. The development of cost-effective and eco-friendly wastewater management technologies and recycling could be the best way to solve the problem of potable water scarcity. Several conventional treatment technologies, i.e. adsorption, chemical coagulation, activated sludge management, membrane filtration, etc., have been implemented to eliminate the pollutants from effluent waters. In addition, it is straightforward, with good effectiveness and ability for degrading contaminants. This paper emphasizes the recent advancement and simultaneous use of wastewater treatment technologies in India to remove pollutants from wastewater like halogenated hydrocarbons, heavy metals, dyes and pigments, pesticides, herbicides, etc., which correspond to the main pollutants in wastewater. Movements like Swachh Bharat Mission (SBM), which has become the

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largest movement towards cleanliness, highly emphasizes the treatment along with recycling of these effluent waters throughout India.

Keywords Effluent water · Water pollutants · Heavy metals · Toxicity · Natural adsorbents · International society of waste management · Air and water

1 Introduction

Rapid industrialization and urbanization have been adversely affecting the global environment in addition to that the quality as well as quantity of the potable water resources for the past few decades. Pollution by inappropriate industrial wastes management is one of the chief environmental problems in India. The basic technical knowledge required to cope up with pollution is already known to us, but unfortunately, less concern about the fact leads us towards self-destruction.

Access of clean water is immensely indispensible for growth and development, as water is a lifeline for all forms of life on this earth, and it is basically acquired from two principal usual sources, natural surface water like rivers, freshwater lakes, streams, etc., and groundwater such as borehole water and well water. So, contamination of these water bodies creates a real day crisis of freshwater. Generally, the industrial development occurring along the banks of rivers exerts pressure on the water resources causing the shortage and contamination of surrounding water bodies. Moreover, disposal of untreated wastewater directly into the water bodies causes the surface and groundwater pollution. Normally, wastewater consists of ~99.90% water and ~0.10% suspended or dissolved solids mainly bio-organic in nature (human waste, vegetable matter, paper, etc.), various toxic metals and pathogens which consume available oxygen from water bodies resulting in the increase of BOD and COD level. The contamination of water bodies by toxic metals is a severe problem for all living organisms. The metals get bio-accumulated in the nature and consecutively get biomagnified next to the food chain. Though metals like Cu, Fe and Zn are vital micronutrients, but excess accumulation leads to several lethal effects (Kar et al. 2008; Nair et al. 2010). The heavy metals such as iron, cadmium, lead, zinc, chromium, vanadium, nickel, copper, platinum, silver, titanium, etc., are commonly released from various industrial sectors like tannery, textile, leather, pigment and dyes, paint, petroleum refining industries, etc. Thus, treating the effluent water in the industrial premises before discharging it into the environment is of extreme importance. Table 1 shows the maximum contaminant level (MCL) standards for some heavy metals established by USEPA (Tripathi and Ranjan 2015).

The amplifying demand of freshwater for various domestic purposes is met by groundwater, which is presently at high jeopardy due to continuous withdrawal. Treated wastewater can be a substitute to the groundwater for some domestic uses. Therefore, mitigation of water pollutants from industrial effluent becomes compulsory before disposing it directly into the environment. A series of approaches have

Table 1 The MCL values of the most hazardous heavy metals

Name of heavy metal	Toxicity	MCL (mg/L)
(i) Arsenic (As)	Skin manifestations, visceral cancers, vascular disease	5×10^{-2}
(ii) Cadmium (Cd)	Kidney damage, human carcinogen	1×10^{-2}
(iii) Chromium (Cr)	Headache, diarrhoea, nausea, vomiting, carcinogenic in nature	5×10^{-2}
(iv) Copper (Cu)	Liver damage, insomnia, Wilson Disease	25×10^{-2}
(v) Nickel (Ni)	Nausea, chronic asthma, coughing, carcinogen, Dermatitis	20×10^{-2}
(vii) Lead (Pb)	Damages the foetal brain, kidney diseases, circulatory system, nervous system	6×10^{-3}
(viii) Mercury (Hg)	Rheumatoid arthritis, kidney diseases, circulatory and nervous system	3×10^{-5}

been looked into such as coagulation, membrane technique, adsorption, foam flotation, reverse osmosis, catalytic degradation and other bio-techniques for the removal of contaminants from effluent water (Pontius 1990). Out of these processes, adsorption has come out to be one of the safest and cheapest alternative methods. Indian Government has already taken many steps to nurture the matter like 'Ganga rejuvenation' [a part of Swachh Bharat Mission (SBM)], according to the Environment Protection Act, 1986, as a planning, financing and monitoring for effective reduction of pollution and conservation of the river Ganga. This review article deeply concerns about the improper management of generated effluent water from industries in India and emphasizes the primary treatment systems available for treating wastewaters. To properly address the pollutants releasing from the industries, proper management of generated wastes and adoption of greener and cost-effective technology are being encouraged day by day.

1.1 A Historical Perspective

In the year 1900, scientist Louis Pasteur and other researchers showed that sewage-borne bacteria grow due to the contamination of human excrement and are responsible for severe infectious diseases (Henze and Harremoes 1983). Therefore, the contaminated water used to spread in large farms to be decayed by the action of micro-organisms. It was quickly investigated that the land converted to be 'sick' and unproductive. Later, attempts indulged direct disposal of effluents into the surface water which caused the aquatic pollution. But, it was soon realized that environment might not act as an unlimited dumping reservoir. Basic methods of effluent water treatment were first advanced in response to the adverse circumstances caused by the unscientific disposal of effluent water to the nature and public health. Furthermore, due to the urbanization, inadequate land was available for wastewater treatment and clearance. Moreover with population explosion, the quantity of effluent water produced per day increases rapidly and goes beyond the self-purification capacity (Spellman 1999; Rosen et al. 1998). Therefore, other treatment methods were developed and resulted an upliftment of the technologies from 1900 to the early 1970s that aims at-

(i) Removal of unwanted suspended materials from wastewater
(ii) Treatment of chemicals along with biodegradable organics (COD and BOD removal)
(iii) Inhibition of lethal pathogenic micro-organisms.

Major objective is to attain efficient and prevalent wastewater treatment technology to get better quality of water. Since 1990, effluent water treatment has been started by increasing scientific knowledge and various Government campaigns which are still continuing, but the emphasis has been shifted to the cause and removal of pollutants to improve the degree of treatment.

1.2 Distribution of Total Water on Earth's Surface

The circulation of total water on the Earth's surface is shown in Fig. 1, which states that only ~3% of water sources on the surface is fresh (among which, ~69% in glaciers, ~30% underground and ~1% in lakes, rivers and swamps); the remaining ~97% exists in the ocean. Hence, it is clear that only 1% of the water source on the surface of Earth is usable.

2 Category of Effluent Water

Effluent water is a side product of domestic, industrial, agricultural activities, surface runoff or any sewer infiltration (Tilley et al. 2016). The qualities of wastewater vary depending on the sources and the degree of contamination. It may be wastewater released from households, municipal wastewater (sewage) coming from societies or industrial wastewater from industrial sectors. Effluent water generally contains

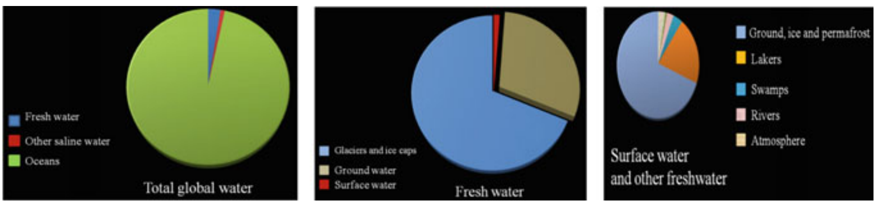

Fig. 1 Distribution of earth's water

physical, chemical and biological pollutants. Basically, they are categorized into three broad classes: Black water, Grey water and yellow water (CPCB 2005).

2.1 Black Water

It is used to describe the effluents coming from the toilets, contaminated with various pathogens.

2.2 Grey Water

Grey water or Sullage is all kinds of effluent water generated from households or offices, except the wastewater from toilets. It contains lesser pathogens and therefore easier to treat and reuse for other purposes like sanitation, crop irrigation, etc. Reuse of grey water provides enormous benefits to reduce the demand of freshwater and minimizes the generation of wastewater.

2.3 Yellow Water

Water basically mixed with urine gathered from specific channels which are not polluted with either black water or grey water.

2.4 Sources of Effluent Water

Effluent waters originate from various sources like residences (household wastes), commercial sectors (schools, hospitals, offices, hotels, etc.) and industries. Apart from these, wastewaters are generated from non-pointed sources such as storm water, contaminated rainfall runoff from agricultural lands and entrance of the groundwater to the wastewater collection system. The resource of wastewater generally determines the qualities of the contaminated water, based on which the treatment procedures must be designed.

2.4.1 Domestic Sewage

This includes effluent water from homes and offices, typically contains contaminants such as vegetable, faecal matter, oil and grease, detergents, rags and sediment.

2.4.2 Industrial Wastewater

Industrial effluent water is one of the prime sources of water pollution, includes toxic chemicals, organic and radioactive wastes, large amount of sediments, high-temperature waste or acidic/caustic waste. During the last century, a large amount of industrial wastewater was disposed directly into the environment without any treatment. The main concern is that the local farmers unconsciously use this raw sewage to irrigate their lands, and the agricultural products are marketed locally. Therefore, the pollutants may indirectly enter the food chain causing serious problems to the eco-system and human's life. In Durgapur industrial belt, severe incidents took place due to drastic consequences of wastewater pollution (Javed et al. 2013). Some of them are mentioned below:

(i) In 1973, thousands of fishes and frogs died, and ~240 hectares of cultivated lands were lost in the left bank irrigation canal at the Durgapur Barrage of the Damodar Valley Corporation (DVC).
(ii) In 1978, a huge number of cattle are died after drinking contaminated canal water.
(iii) In 1983, ~500 domestic animals died, and ~8000 quintals of processed crops were demolished. All the three catastrophes occurred due to the disposal of toxic chemicals into the Damodar canal water by the nearby small- and large-scale industries.

2.5 General Characteristics of Industrial Wastewater

A vivid idea of the chemical composition of wastewater is important since this helps to know the probable reactions with the organic and inorganic matters (Roila et al. 1994). Generally, the effluent water released from different industrial sectors can be separated into two broad categories: (i) inorganic industrial wastewater and (ii) organic industrial wastewater.

2.5.1 Inorganic Industrial Wastewater

This kind of wastewater is generated largely in the mining industries, nonmetallic minerals industries and metal surface processing industries (iron pickling, electroplating plants, etc.).

2.5.2 Organic Industrial Wastewater

Organic industrial effluents are released from several organo-chemical industries, which mainly use organic materials for reactions and contain organic contaminants such as phenol, organic sulphur, volatile organic matters, surfactants, etc. Table 2 describes the general parameters of effluent waters coming from different industrial sectors (Kaur et al. 2012).

The large amount of produced effluent water destroys the eco-system, mainly marine lives. Hence, it becomes a burning issue to purify the wastewater properly. Therefore, we should be keen to control the production of the wastewater, consumption of clean water in different sectors and cost of the treatment of wastewater (Fig. 2).

Table 2 Categories of industrial effluent water

Industrial sector	General contaminants
(i) Steel and Iron	High BOD and COD, oil and grease, high pH, acids, phenols, cyanide, heavy metals like Mn, As, Hg, Cd, Ti, V, Sb, Th, Pb
(ii) Leather and textiles	High BOD, solids, sulphates
(iii) Paper and pulp	High BOD and COD, solids, chlorinated organic compounds
(iv) Refineries and petrochemicals	Mineral oils, BOD, COD, phenols, chromium
(v) Chemicals	Cyanide, carbon-based chemicals, heavy metal ions, SS, COD
(vi) Non-ferrous metals	Fluorine, suspended solids
(vii) Microelectronics	Organic chemicals, COD
(viii) Mining	Suspended solids, metals, acids, salts

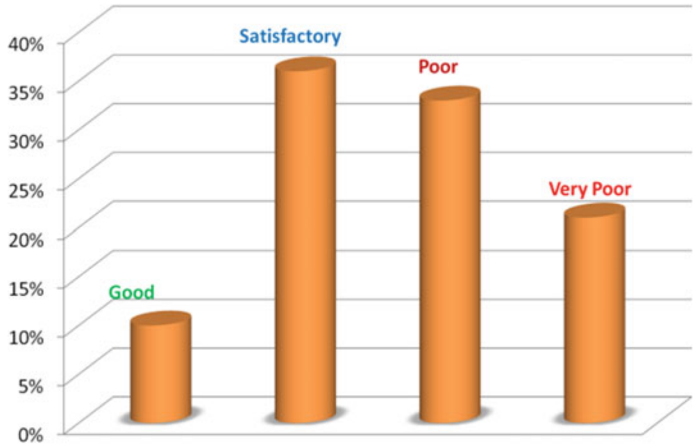

Fig. 2 Wastewater treatment plants in India under different grades

2.6 Present Status of Effluent Water Conundrum and Treatment in India

In India, climate alteration in the monsoon has huge implications on agriculture that makes India more vulnerable because >60% of countrymen are relying on cultivation for survival, and ~two-thirds of the nurtured terrestrial is fed by rain. Simultaneously, the government has launched ambitious programs like 'Smart City Mission', 'Swachh Bharat Mission', and the 'Make in India' campaign which needs to be reviewed from water and environmental aspects. Moreover in urban areas, freshwater resources are at high risk because of the increasing demand of freshwater. Apart from this, contaminants from various industrial sectors pollute the local water bodies making the freshwater endangered. Hence, a proficient solution is essential for viable water treatment. Therefore, reuse of purified effluent water would be of immense significance in achieving freshwater security and water conservation.

In India, a regular rainfall of ~1170 mm occurs corresponding to a yearly precipitation of ~4000 BCM (Billion Cubic Metre). However, based on the constraints like substantial variation in rainfall, evaporation throughout the year, etc., ~1123 BCM (690 from surface plus 433 (28%) from groundwater resources), gained from precipitation, is utilizable. Moreover, ~ 688 BCM of water is used for watering, which may upsurge to 1072 BCM in 2050. The average amount of ground water renewal is 433 BCM in a year, out of which ~212.5 BCM is utilized for watering, and ~18.1 BCM is spent in domestic and industrial usage (CGWB 2011). However, by 2025, the demand of water used in industrial and domestic purposes may rise to ~29.2 BCM (Fig. 3).

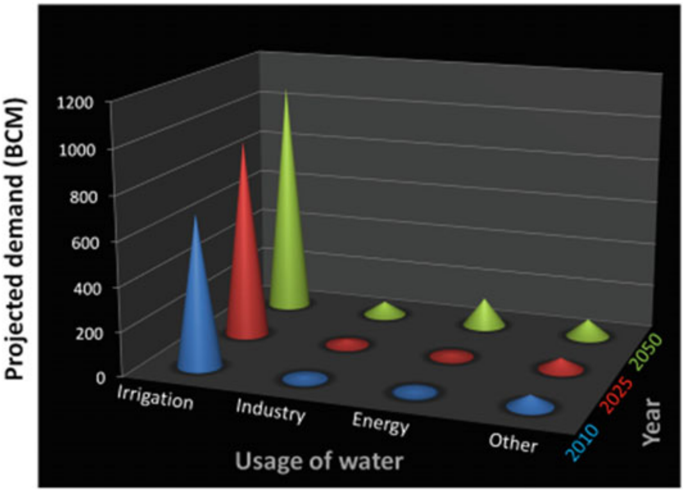

Fig. 3 Projected water demand at different sectors (CWC 2010)

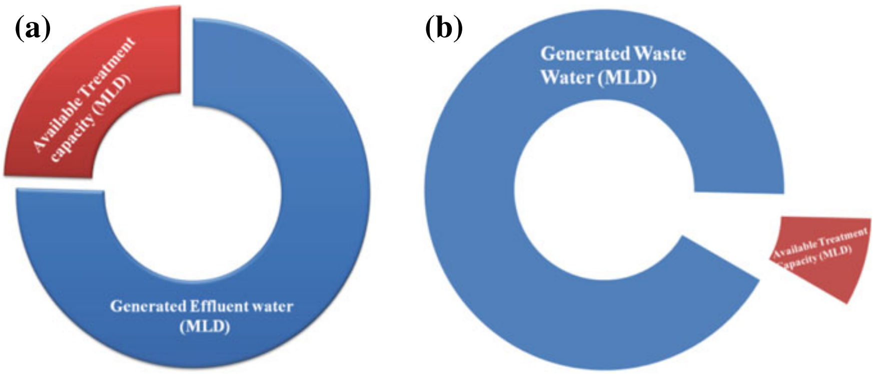

Fig. 4 Treatment capacity and sewage generation in class-I cities (**a**) and class-II townships (**b**) in India (CPCB 2009)

With rapid development of urbanization and domestic water usage, production of grey water is growing day by day. According to CPHEEO (The Central Public Health and Environmental Engineering Organization), ~70 to 80% of the water supplied for domestic usage transfers into wastewater. Survey reveals that wastewater production in class-I cities as well as class-II towns is ~98 lpcd (litres per capita per day). According CPCB (Central Pollution Control Board), the total generated wastewaters by 498 Class-I cities and 410 Class-II towns in India are ~35,558 and ~2696 MLD (millions of litres per day), respectively, while the installed sewage treatment capacity is just 11,553 and 233 MLD, respectively (Fig. 2). Five States in India, viz Delhi, Uttar Pradesh, Maharashtra, Gujarat and West Bengal are the foremost contributors of effluent waters (63%; CPCB 1999, 2007; CWC 2010). Further, according to WWAP and UNESCO (2006), it is anticipated that in 2050, ~48.2 BCM of wastewaters would be produced, which will further widen this gap (Bhardwaj 2005). Thus, entire study reveals that in near future, a double-edged problem will arise to deal with: reduced sources of pure water and increased effluent water production. Hence, there is an acute requirement for effectual water management (Fig. 4).

2.7 *Wastewater Treatment Technologies*

A host of new technologies for proper management of wastewater is being developed worldwide. However, new methodologies include natural procedures and are intended with feasibility. The techniques described below provide some basic idea on the miscellany, tractability and future utility.

2.7.1 Physicochemical Treatment Technologies

Physicochemical technique (Gupta et al. 2012) may be described as a treatment process in which biological and physical-chemical processes are mixed to get a hybridized treatment technique (Fig. 5).

The primary treatment includes decontamination and elimination of unwanted toxic elements depending upon some physical methods like screening, sedimentation, coagulation, flotation, etc. Secondary treatment deals with the biological process as aerobic, anaerobic, etc.

In the tertiary treatment, wastewater is converted into freshwater by using methods like distillation/evaporation/solvent extraction/advanced oxidation/precipitation/micro- and ultrafiltration, etc.

Adsorption is the most efficient and a universal technique used in the elimination of a wide variety of contaminants like colour, odour and various organic and inorganic impurities. The main advantage of this process lies in its low cost, straightforwardness and less sludge generation. Apart from this, reverse osmosis processes a widely used wastewater purification technique, but contains comparatively high cost for maintenance.

2.7.2 Bio-chemical Treatment Technology

Bio-chemical technology (Seow et al. 2016) including biofilm technology, aerobic granulation and bacterial fuel cell are a few useful methods for wastewater purification. Biofilm, a cluster of micro-organisms, is devoted to an exterior part. Dental plaque, for example, is one of the biofilms, comprises ~500 microbial species (MSU Center for Biofilm Engineering, 2008). The various species in biofilms, like, fungus, algae, yeasts, protozoa, etc., form groups by creating an ‘extracellular polymeric substance (EPS)’. The cells develop three dimensional, hardy communities by making sugary molecular strands which excrete glue-like material to permit them to stick to an exterior of nearly any kind.

The biological wastewater treatment is often carried out by conventional treated sludge systems, which require bulky surface areas for management and biomass segregation units because of the deprived settling nature of the sludge.

Aerobic granules, having compactness, regularity, smoothness and good settling ability, can self-immobilize flocks and micro-organisms into spherical and strong compact structures.

Microbial fuel cell (MFC), a bio-chemical device, uses bacteria as a biocatalyst to transform chemical energy present in biological matter into electricity. MFC shows high energy conversion efficiency due to direct conversion of chemical energy within substrate to electricity.

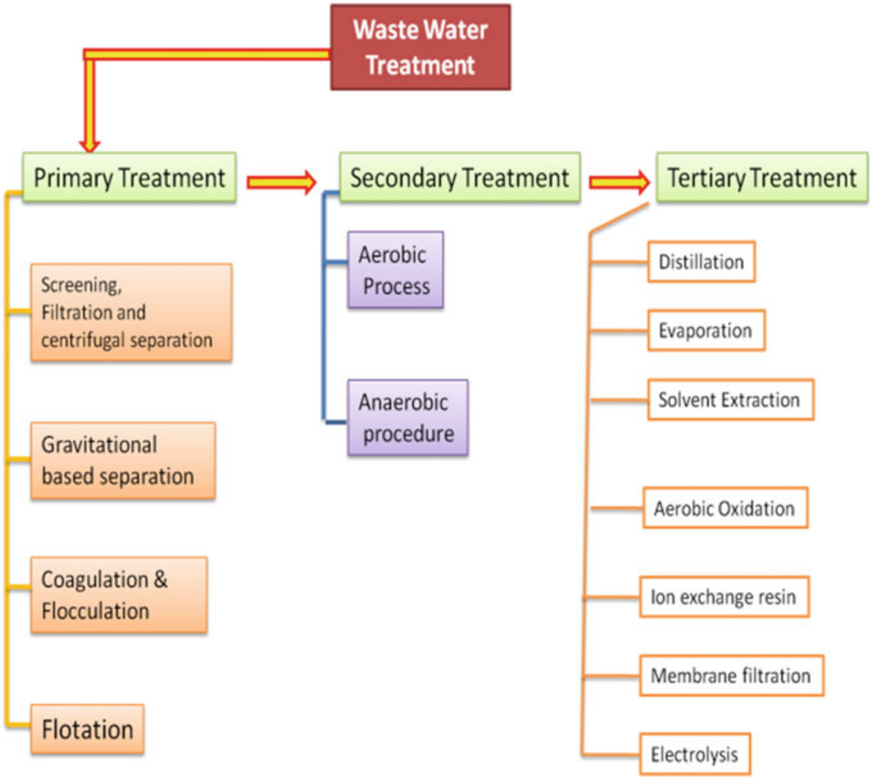

Fig. 5 Steps involved in chemical treatment methodologies are briefly demonstrated using a flow diagram

2.7.3 Bio Mediated Treatment Technology

Aquatic plant-based treatment systems (Dixit et al. 2011) using ponds or artificial wetlands are effective for purifying domestic and industrial drainage water. Biosorption is a proficient substitute of conventional techniques for elimination of noxious metals from effluents released from industries. Slower the flow and longer the retention time, greater will be the removal. Aquatic plants show remarkable absorption of metals (like N, P, S, Ca, Mg, Na, Fe, Mn, Zn, Cu, etc.) and nutrients. Removal of aquatic vegetation on timely basis is an important step; otherwise, died plants will decay releasing their absorbed nutrients to the water, thereby further degrading the water quality.

2.7.4 Membrane-Based Treatment Technology

Membrane-based separation technique is presently used as a replacement of conventional wastewater treatment processes and is the main market driver (Hamingerova et al. 2015). These technologies provide membrane separation based on selective separation through apertures of various sizes and contain four core membranes: microfiltration, ultrafiltration, nano-filtration (CNT-silicon nitride membranes, Ag particles impregnated membrane) and reverse osmosis (CPCB 2007; Noy et al. 2007). Micro and ultrafiltration are used for unwanted particle removal, whereas nano-filtration and reverse osmosis are used for softening or desalination. Handling of organic and inorganic contaminants typically requires modified sludge treatment by using a dipped membrane.

2.8 Proposed Wastewater Treatment Prototype

Because of the growing demand of potable water supply in the domestic sectors, there is an urgent requisite to prepare an inexpensive, gravitational-based domestic wastewater purification system (Fig. 6) that would convert contaminated water to

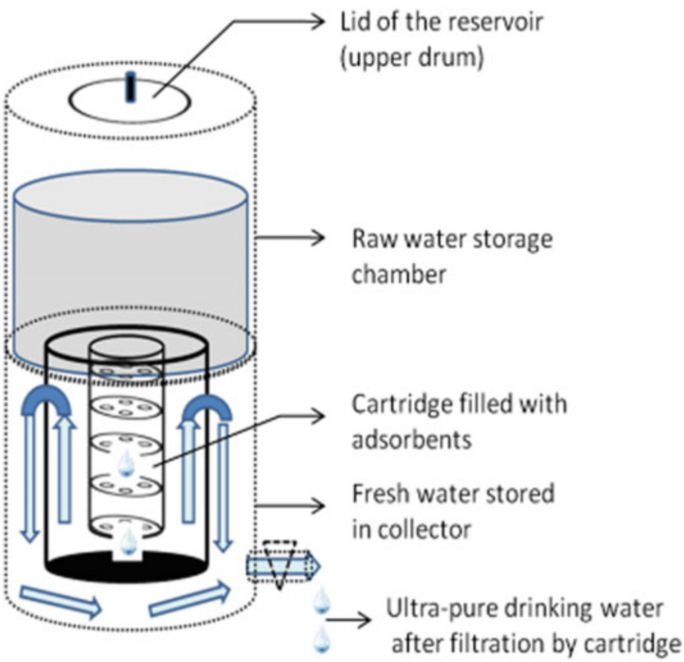

Fig. 6 Domestic wastewater treatment unit

potable water. The emphasis in this regard is to use naturally abundant adsorbent materials (e.g. sand, gravels, brick dust, etc.) for treatment purposes. The treated water will serve the required domestic purposes like gardening, washing, etc.

2.9 Conclusion

Clean potable water is indispensable for human activities. The demand of healthy drinking water is enhancing proportionally with increasing population. Hence, there is a pressing requirement for an effectual water management and wastewater recycling technology. In this milieu, nanotechnology is fast replacing traditional concepts, which depend on the improvement of newer multi-functional materials with unique properties and specific attraction towards certain contaminants. But, these approaches are convoluted, tedious and costly. Therefore, exploration is going on to develop inexpensive, but effective water treatment techniques. In a developing and heavily populated nation like India, large amount of effluent water is being produced from different sectors. This review article draws attention about concerning issues and technological options connected to the wastewater collection followed by treatment systems.

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