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A Snapshot on Urban River Water Characterization and Advances in Remediation Strategies for its Restoration: A Global Perspective

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Abstract: The quality of surface water in many parts of the world, especially in developing nations is being challenged by rapid economic growth, demographics and climate change leading to widespread and severe degradation of fresh water ecosystems. With many rivers still in good condition, there are opportunities to prevent pollution and begin restoration. However, severe organic pollution is already affecting around one in seven rivers across Latin America, Africa and Asia. This poses a growing risk to public and environmental health, food security and the economy. Freshwater systems in both developed and developing nations are facing growing pressure from the discharge of harmful chemicals, such as hormone disrupters. Unfortunately, municipal water treatment has become increasingly costly and developing countries in particular have problems matching expanding public water supplies and sewerage, with inadequate treatment facilities for the newer/higher wastewater flows. As a result there is a significant risk to vital activities like inland fishing, which accounts for some 60 million jobs and almost a third of fish harvested for human consumption. Yet, until now, insufficient collection and evaluation of data has made it difficult to grasp the intensity and scope of deteriorating water quality. Sound knowledge is critical to understanding the underlying causes and developing the evidence based policies to improve it, including source control, waste treatment, ecosystem management and new forms of local and global governance. By providing a snapshot of the current situation, success stories and future challenges, this review offers a baseline to measure progress, a framework for global assessment and a pathway towards sustainable solutions for river water remediation and restoration which will assist countries looking to establish their own planning, monitoring and guidelines.

Keywords: River water pollution, Impacts, Remediation, Policies, Benefit

Abbreviations: BOD (Biological Oxygen Demand), DO (Dissolved Oxygen), COD (Chemical Oxygen Demand), NGS (Next Generation sequencing), PCR (Polymerase Chain Reaction), IRBM (Integrated River Basin Management), RBF (River Bank Filtration), WHO (World Health Organization), UNICEF (United Nations Children's Fund), WWAP (United Nations World Water Assessment Programme), MPCB (Maharashtra Pollution Control Board), CPCB (Central Pollution Control Board), ICWRMIP (Integrated Citarum Water Resource Management Investment Program), PRRC (Pasig River Rehabilitation Commission), CWR & MEP; China (Water Risk & Ministry of Environmental Protection, China)

I. INTRODUCTION

Water is most precious natural source which is required for the survival of life and economic development of every nation. Since last few decades, environmental pollution is one of the major challenges of today's civilization. Worldwide growth and expeditious industrialization have led to the recognition and increasing understanding of the interrelationship between pollution, public health and environmental well being (Kaushik *et al*., 2012; Spina *et al*., 2012). World Water Development Report (2012) predicts 47% of world population will be living in areas of high water stress by 2030. The developing countries of the world have a major share in water pollution. According to the United Nation's World Water Assessment Programme (WWAP, 2015) around 90% of the total waste in these countries is diverted to sources like rivers and lakes, without subjecting it to proper treatment which has caused gross contamination of rivers and lakes within and around urban centers with known and unknown pollutants. In developing countries like India and China, the rapid urbanization is causing a burden on their natural water resources and hindering their sustainable development. It is found that, in India one-third of total water pollution comes in the form of industrial effluent discharge, solid wastes and other hazardous wastes posing a potential hazard to the natural surface water systems like rivers and lakes (Deepali 2012; Kansal *et al*., 2011). However, in China the construction of the water infrastructure is still lagging far behind the environmental and social development, with only 32.7% of sewage in the district being treated and rest discharged into water resources without primary treatments (Liu and Ma, 2011). As the surface water is the main source of industries for wastewater disposal, untreated or allegedly treated industrial effluents have enhanced the level of surface water pollution up to 20 times the safe level in 22 critical polluted areas of the India (Rana *et al*., 2014).

Figure 1. Current status of World's some of the most polluted rivers, mostly located in Asia

Rivers act as lifelines of nations. In many Asian countries like India, Thailand, Philippines, Sri Lanka, Bangladesh, rivers enjoy a special place in prayers and their traditional practices from ancient period. The river Ganges is regarded as one of the most holy and sacred rivers of the world from time immemorial. However, disregard for their maintenance by releasing untreated industrial, medical and sewage waste along with food, leaves for ritualistic purposes have hampered the integrity of river ecosystem (Fig 1). One example is the Ganges-Brahmaputra basin, an international river basin shared by India, Bangladesh and Nepal. Irrespective of their sacred status, the River Ganges and Yamuna are listed as one of the highly polluted Indian rivers along with small rivers and water stream flowing from major Indian cities (Kazmi *et al*., 2013). Similar is the fate of rivers flowing through other parts of the Country. For instance, the iconic historical Mula-Mutha River famous in the Maratha Empire, which was once used as a major source of drinking water for metropolitan City of Pune in Maharashtra, has now become a dumping ground for sewage and unprocessed industrial and medical wastes (Phadnis, 2014). Due to high levels of pollution, including 125 MLD of untreated sewerage water being discharged into the river by the Pune Municipal Corporation (PMC), the Maharashtra Pollution Control Board (MPCB) has classified the water quality to be of *Class-IV* (MPCB, 2014). Considering the global scenario, the number of people living in the basins of major polluted rivers around the world, Asian basins of Ganges, Yangtze, Yellow and Huai, Indus tops the list (Wen *et al*., 2017).

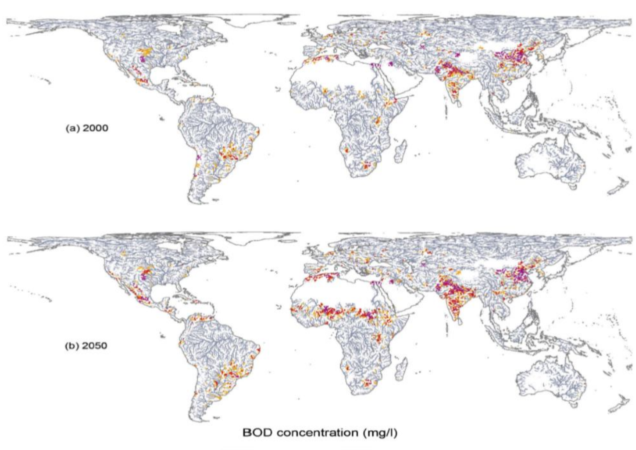

Figure 2. Global patterns of computed river BOD concentrations caused by organic pollution in the years 2000 and 2050. (Adapted from Wen *et al*., 2017)

The global pattern of computed biological oxygen demand (BOD) concentration, the major indicator of water quality for the year 2000 indicated regions like Indian sub-continent, mid-eastern China, South Korea, Brazil, Mexico, as well as smaller regions in Africa, south-eastern Asia suffering from wastewater treatment inefficiencies to keep BOD concentrations below 5 mg/L (Fig 2); however, by 2050 the biggest deterioration is projected to occur in India, sub-Saharan Africa and Mexico, with many smaller regions all over the world also facing substantial challenges (Wen *et al*., 2017).

Taking in to consideration the growing concern of freshwater pollution, this review aims to report the global scenario of degrading conditions of natural surface water ecosystem with the main focus on rivers from developing nations, which are loosing their pristine status rapidly. Various case studies reported in this article will shade light on the causes of river pollution; their impacts on human health and aquatic biodiversity; socio-economic aspects and will provide solutions towards reviving deteriorating rivers using biological and advanced nanoremediation and next generation sequencing tools. Best management practices involving bio-engineering approaches, environmental policies and public involvement for river water quality improvement in urban areas of rapidly growing developing nations are also discussed critically along with the challenges ahead.

A. Sources of River Water Pollution

Figure 3. Major sources of river water pollution

The rivers have been the focus of national and international intervention for past few decades to identify and establish causes and impact of anthropogenic activities on river water quality.

Point and non-point sources such as Pharmaceutical companies, electronic plants, textile and paper industries, tanneries, fertilizer manufactures, oil refineries, agricultural farms, animal husbandry are some of the other polluting industries that discharge hazardous wastes like hydrochloric acid, heavy metals, bleaches, dyes, pesticides and polychlorinated biphenyls into the river (Fig. 3). Further, burning of dead bodies on river banks as a part of religious practices and discharge of municipal sewage water increases the toxic load of the water (Vaseem and Banarjee, 2013). Direct discharge of sewage into the river without any treatment or partially treated, affected the quality of river water which contributed to 75% of total river pollution in India (CPCB 2014).

World's most polluted river Yangtze in China was exacerbated by the discharge of waste from livestock farms, agricultural runoff as well as of untreated industrial and municipal sewage.

The annual discharge of sewage and industrial waste in the Yangtze River has reached about 25 billion tons, which is 42% of the China's total sewage discharge, and 45% of its total industrial discharge; with 92% of the nitrogen discharged into the Yangtze is from agriculture. Shipping discharges are also to blame for the river's declining health (CWR & MEP; China Water Risk & Ministry of Environmental Protection, China). In September 2012, this caused the Yangtze River near Chongqing district to turn red from eutrophication (Fig 1a). Ganges river basin, ranked second most polluted river basin of the world which was comparatively free from anthropocentric activities until the 1940s, became a disposal site for agricultural, industrial and sewage wastes after independence of India in 1947 (Singh, 2010). Ganges plain is one of the most densely populated regions of the world, due to its availability of water, fertile soil and suitable landscape.

Today, over 29 cities, 70 towns and thousands of villages extend along the Ganges banks. Nearly all of their sewage—over 1.3 billion liters per day—goes directly into the river, along with thousands of animal carcasses, mainly cattle (Bhardwaj *et al*., 2010). Domestic and industrial wastewater constitute as a constant polluting source, whereas surface runoff is a seasonal phenomena mainly controlled by climate (Singh *et al*. 2004).

Cultural and religious tourism on the banks of the river Ganges along with heavy influx of tourists has been one of the reasons of deterioration in water quality (Farooquee *et al*., 2008) (Fig. 1b). Unwarranted activities such as location of toilets within submergence area of the river beach during rainy season, disposal of untreated liquid waste, garbage, has affected the quality of river water. Religious activities such as the Kumbh Melas contribute to the significant change in water quality due to mass bathing (Bhutiani *et al*., 2014).

Clogged with domestic waste, and contaminated by harmful chemicals, Citarum River is ranked sixth most polluted river in the world, has become an unrecognisable part of the Parahyangan region of Indonesia (Integrated Citarum Water Resource Management Investment Program, ICWRMIP, 2014) (Fig 1c). Unregulated factory growth since the area's rapid industrialization in the 1980s has choked the Citarum with both human and industrial waste. Over 200 textile factories lining the river banks, the dyes and chemicals used in the industrial process - lead, arsenic and mercury amongst them - are getting churned into the water, changing its color and lending the area an acrid odor.

Plastic, packaging, and other detritus floats in the scummy water, rendering the river's surface invisible beneath its carpet of junk (ICWRMIP, 2014). In another instance, one of the main rivers of Philippines, River Pasig once renowned for its beauty, has now been ranked the eighth in the top 20 polluting rivers as predicted by the global river plastic inputs model (Greenpeace Philippines and the Pasig River Rehabilitation Commission, 2017) (Fig. 1d).

The study said the river dumps up to 63,700 tons of plastic into the ocean each year. Metro Manila produces 7,000 tons of garbage a day without proper and effective facilities to dispose of it adequately (Gorme *et al*., 2010); therefore, much of it approximately 1,500 tons is thrown into streams, tributaries and the bay. Approximately 30% of river pollutants come from industries with 65% of the pollution in Pasig River comes from household waste; the river is now known as the "toilet bowl" of Manila (Gorme *et al*., 2010).

In addition, modern agriculture practices have revealed an increase in use of pesticides to meet the food demand of increasing population which has resulted in contamination of the fresh water resources.

The increasing levels of organic pollution in a river, commonly expressed by the BOD, has mainly resulted due to wastewater discharge from cities, agricultural practices and intensive livestock farms. Organochlorine pesticides (OCPs), mainly isomers of hexachlorohexane (HCH), dichloro-diphenyltrichloroethane (DDT), endosulphan, endrin, aldrin, dieldrin, and heptachlore, were found in potable water samples (Agarwal *et al*., 2015). Central Pollution Control Board (CPCB), Delhi, India had found α and β isomers of endosulphan residues in the Yamuna river. High concentrations of γ-HCH (0.259 µg/l) and malathion (2.618 µg/l) were detected in the surface water samples. The Industrial Toxicology Research Centre (ITRC), Lucknow (UP) reported similar results in other water samples collected from Ganges river basins in India.

Plastic, is another class of emerging pollutant becoming an environmental concern because of their persistence at water sources and adverse consequences to marine life and potentially human health. A recent study conducted by Lebreton *et al*., (2017) estimated that between 1.15 and 2.41 million tonnes of plastic currently flows from the global riverine system into the oceans every year. The top 20 polluting rivers mostly located in Asia (Fig 1) accounted for more than 67% of the global annual input while covering 2.2% of the continental surface area and representing 21% of the global population. Surface samplings at the Chinese Yangtze River mouth showed considerably higher plastic concentrations than any other sampled river worldwide with a reported 4,137 particles per cubic meter (Zhao et al., 2014).

II. HEALTH AND ENVIRONMENTAL IMPACTS

Relatively high levels of pollution are found in rapidly developing nations characterized by urbanizing populations and expanding economies that have not yet implemented comprehensive control and treatment of pollution sources. This has lead to serious concerns about human health, rapid loss of biodiversity and ecological imbalance. This section is designed to highlight the impacts of river water pollution on human health and environmental well-being.

A. *Human Health Impacts*

Health Hazards	Water Related Causes	Sources of Problems
• Communicable diseases: • Dysentery • Hepatitis • Salmonellosis • Cholera	• Pathogens in: • Drinking water • Recreational water • Irrigation water • Fish consumption	• Insufficient water supply • Sewage contamination • Manure
• Acute intoxication and chronic diseases	• Toxic substances in: • Drinking water • Irrigation water • Fish • Recreation water	• Inadequate water treatment • Sewage contamination • Manure • Agrochemicals • Industry, hazardous wastes • River/road traffic
• Allergies and skin Irritations	• Proliferation of toxic cyanobacteria	• Nutrient overloading from: • Sewage contamination • Manure and Agrochemicals
• Skin and eye infections and infestations	• Insufficient household hygiene	• Insufficient water supply

Table 1. Polluted water mediated human health hazards

An increasing pollution load of pollutants from industrial water streams containing many inorganic and organic matters, which are toxic to the various life forms of the ecosystem, have caused great harm to the rivers, posing major health risks (Seth *et al*., 2013). UNICEF (2008) estimates that 3.4 million people die each year from diseases associated with pathogens in water, including cholera, typhoid, infectious hepatitis, polio, cryptosporidiosis, ascariasis and diarrhoeal diseases (WHO, 2014b). Worldwide about 4 billion cases of diarrhoea are caused each year by the ingestion of water contaminated by faecal matter, as well as by inadequate sanitation and hygiene (WHO, 2014b), and of these cases 1.8 million are fatal. Worldwide more than 40 million people were treated for schistosomiasis in 2013 (WHO, 2015b) and as many as 1.5 billion people are infected with soil-transmitted helminth infections (WHO, 2015c). All of these diseases are largely excreta-related and many of them are due to the presence of human waste in water. For example, before the Three Gorges Dam, world's largest hydropower station on Yangtze river basin in China, health impacts in the area were already substantial including intestinal infectious diseases such as hepatitis A and dysentery incidence rates some 50% higher than the national average; *E.coli* bacteria being rampant in water sources, and as high as 15,000 *E.coli*/L in some parts of the city (CWR & MEP; China Water Risk & Ministry of Environmental Protection, China). Sewage, containing metals of variable toxicity, persistence of which in the aquatic environment leads to their bioaccumulation and biomagnification in the food chains is another leading cause of diseases in human. Cumulative effects of metals or chronic poisoning may occur as a result of long-term exposure even to low concentrations.

While the international community has goals for reducing the number of people exposed to unclean drinking water, less attention has been paid to another important route through which people are exposed to pathogens, namely through direct contact with polluted rivers, lakes and other surface waters (WHO, 2014b). The median concentration of faecal coliform bacteria amongst African (N=215), Latin American (N = 1,725) and Asian (N = 4,131) rivers; Africa, (about 50% of all measurements) exceed the severe pollution level of 1,000 cfu/100 ml compared to in Asia and Latin America which was about 25% (WHO, 2015b). The poor in rural areas of developing countries often use surface waters for bathing, washing clothes, as a source of cooking water and sometimes for drinking water. In both developing and developed countries surface waters are used for recreational bathing, for fishing and as a water supply for irrigation. Many different types of pathogens in water, including protozoan, parasites, bacteria and viruses, cause diseases. Table 1 summarizes the human health impacts mediated through polluted freshwater ecosystem.

B. Eco-toxicity of Aquatic Life

The discharge of various types of wastes without adequate treatment often contaminate the river water, estuarine and ultimately the coastal water with conservative pollutants (like heavy metals), many of which accumulate in the tissues of resident organisms like fishes, oysters, crabs, shrimps and seaweeds. Cumulative effects of metals or chronic poisoning may occur as a result of long-term exposure even to low concentrations. The accumulation of heavy metals varies depending upon the species, environmental conditions, and inhibitory processes.

A study by Mitra *et al*., (2012) showed elevated concentrations (approximately 10.0 ppm) of zinc, copper, lead, and cadmium in finfish and shellfish species in the Gangetic delta, above permissible limits (2.0 ppm) set by WHO. Similarly, a field study conducted by Vassem and Banarjee (2013) to examine different physico-chemical properties of water and various haematological and biochemical parametres of the fish *Labeo rohita* from the Ganges River was found to be greatly contaminated with a number of dissolved metals (Fe, Cr, Zn, Cu, Mn, Ni and Pb) whose concentrations were above the safe limits (Fe,1,353.33%; Cr,456%; Mn,553.33%; Ni, 4,490% and Pb,1,410%) suggested by Bureau of Indian Standard (BIS) for drinking water. The metal accumulation detected in the fish blood of selected species was recorded very high (Fe, 2,408%; Cr, 956.57%; Zn, 464.90%; Cu, 310.57%; Mn, 1,115.48%) in comparison to the control fish. Lower values of the various haematological parameters (total erythrocytes count, haemoglobin, haematocrit, mean corpuscular volume and O_2-carrying capacity) in the river fish in comparison to the control indicated toxic manifestation exerted by the contaminated river water on the fish. The higher level of total leucocytes count further illustrated stressed condition of the river fish. The toxic impact of the Ganges water was also expressed in the fish by the presence of higher levels of cholesterol, glucose, elevated activities of the enzymes aspartate amino transferase and alanine amino transferase, and lowered protein concentration.

A recent study was conducted by Rimayi *et al*., (2018) to quantitatively assess 15 environmental pollutants, including 10 pharmaceuticals, 1 pesticide and 4 steroid hormones of emerging concern in the Hartbeespoort Dam catchment area in South Africa. The Jukskei River, which lies upstream of the Hartbeespoort Dam, was also assessed. Five year old carp (*Cyprinus carpio*) and catfish (*Clarias gariepinus*) used from the Hartbeespoort Dam to study bioaccumulation in biota as well as to estimate risk associated with fish consumption reported the presence of 11 emerging pollutants with the highest concentration of 593 ng L^{-1} in the order efavirenz > nevirapine > carbamazepine > methocarbamol > bromacil > venlafaxine. The toxicants present in the aquatic ecosystem also exerted their effect on the cellular and molecular levels which has resulted in significant changes in biochemical compositions of the organisms.

III. RIVER WATER REMEDIATION TECHNOLOGIES

Rivers are naturally dynamic. Urban development and historical engineering activities has affected this natural balance causing morphological damage and loss of important habitats (SEPA 2007). Degraded streams and rivers that drain urban areas are not only characterized by high nutrient loads and concentrations of contaminants, but they also have altered stream morphology and reduced biodiversity (Zhou et al. 2012). In recent times, river restoration is globally accepted as an alternative way to protect ecosystem health and preserve water resources (Andrea et al., 2012; Kurth and Schirmer 2014; Wortley et al., 2013). Increased funds available for restoration projects in various countries through systematic changes in government policies has resulted in an increased number of restoration projects around the world (Kurth and Schirmer 2014; Schirmer et al., 2014; Wortley et al., 2013). River Thames Restoration in London is the best success story, which has shown the world the efficacy of river management practices that could transform once dead Thames River in 1957 to one of the cleanest rivers in the world to date. This section will discuss physical, chemical, biological and upcoming nanotechnology and next generation sequencing based approaches to address the river remediation goals in sustainable manner.

A. Bioremediation

The status of water quality in rivers and the changes produced due to anthropogenic activities is the first step towards establishing an efficient water management system. Physical remediation approaches using (a) Aeration: can restore and enhance the growth and the vitality of micro-organisms to improve the water quality; (b) Water Diversion: feasible to control river pollution through water diversion where the clean water could dilute polluted rivers, resulting in the black and stink of water body to eliminate quickly and to improve the self-purification capacity of water body; (c) Sediment Dredging: a kind of sediment dredging method *in situ*; are available (Ateia and Yoshimura, 2015) though now regarded expensive, conventional, inefficient and may cause secondary damage to ecology. The flocculation and sedimentation method of chemical remediation be used to the water treatment with a large number of suspended solids and algae, which was simple to operate, easy to maintain and effective to treat, however, the infrastructure costs reported were high (Wang et al., 2012). Chemical agents such as copper sulphate, bleaching powder, alum, poly aluminum and ferrous sulfate are reported for effective algae removal. The experimental research on the treatment of cyanobacterial bloom based on chemical algicide with main ingredient of acetic acid was carried out in Xuanwu Lake in Nanjing, China in 2005, and the total algae of the experimental area reduced by 82.8% after treatment (Wang et al., 2012). As bio-engineering technology for river pollution control, the bioremediation has advanced rapidly from 1990 and has now become a promising technology. There are many advantages of the bioremediation technology over aforementioned physical and chemical approaches, such as reduced cost, low environmental influence, no secondary pollution or pollutant movement, reducing pollutant concentration by the maximum extent, available for the sites where regular pollution treatment technology is difficult to be applied, and so on. Bioremediation is a way towards sustainable and economically viable approach which uses plant and microbes based interactions on the principle of biostimulation and bioaugmentation to reduce the toxicity of pollutants in the water.

1) *Plant Based Bioremediation (Phytoremediation):* Various plants and algae growing in littoral zone of river are of particular importance to monitor pollution level as they accumulate metals inside their tissue and have been used in phytoremediation as a part of constructed wetland system. Some algal forms undergo certain changes and adapt themselves to the stress environment, while sensitive species exhibit toxic responses in a qualitative and quantitative manner. Constructed wetland systems mimic the treatment that occurs in natural wetlands by relying on plants and a combination of naturally occurring biological, chemical and physical processes to remove pollutants from the water (Rai et al., 2012). Various aquatic plants of different life forms (floating, submerged, rooted and emergent) growing in catchment area of river possess property of accumulation and detoxification of metal present in the river water (Rai et al., 2011). In Jiaxing City, Zhejiang Province of China, an integrated floating island system consisting of aquatic vegetation near riversides and mosaic floating island with adsorptive biofilms was constructed to purify eutrophic river water. This study indicated average removal rates for total nitrogen, NH_4+-N, NO_3−-N NO_2—N and total phosphorus in addition to reduced concentrations of total suspended substance, *Escherichia coli* and heavy metals over the period of eighteen months (Zhao *et al*., 2012). Izumi River in Japan once known as 'Sewage River' in 1970's has now been restored by planting growing woods in slopes of the river bed and by creating green zones which has resulted in improved water quality (ARRN 2009). In another case, Ythan River, in Scotland suffered from several water quality issues in 2000, that resulted in the eutrophication of the Ythan estuary (a Ramsar wetland and site of special scientific interest), which in turn impacted the waterfowl population in the natural reserve (OSPAR 2006). Discharges from sewage treatment facilities, diffused pollution from agricultural runoff further hampered the quality of Ythan River. From 2001 till 2005, restoration efforts were carried out by creating riparian fencing, wetlands and buffer strips using native plant species. Decrease in suspended solids, phosphates and nitrates were noted as success indicators of the restoration efforts. In a similar case reported for the low or no flow in the Kissimmee River channels in Florida, USA resulted in vegetation encroachment of floating species like *Pistia stratiotes* (water lettuce) and *Eichhornia crassipes* (water hyacinth). This resulted in organic matter accumulation up to 3 m in the river bed causing eutrophication and consumption of DO in the river, leading to a chronic reduction of DO. This led to the replacement of local fish like largemouth bass to species tolerant of low DO regimes. Adopting best management practices such as wetland restoration along with canal backfilling, river channel recarving has resulted in minimizing eutrophication in remnant river (SFWMD 2015). A study conducted by Subhashish *et al*., (2011) successfully proved the role of woody perennials in the Ganges river basin in modifying the run-off quality as influenced by atmospheric deposition of pollutant aerosols. Maximum nutrient retention (4.30 % to 33.70 %) and reduction in run off (nutrient 6.48 %–40.66 %; metal 7.86 %–22.85 %) was recorded for *Bougainvillea spectabilis* with metal retention capacities were found highest for *Ficus benghalensis* (5.15% to 36.98%). These signifies an important contribution of catchment vegetation in reducing nutrient/metal transport to Ganges river water which has relevance in formulating strategies for river basin management.
2) *Microbes Based Bioremediation:* The bio-film technology utilizes biomembrane attached to the natural river bed and micro-carrier to move the pollutants in the river through adsorption, degradation and filtration under the conditions of artificial aeration or dissolved oxygen. Further, biofilm processes, such as aerated bio-filter biological fluidized bed, suspended carrier biofilm reactors (SCBR), etc., are commonly used in surface water remediation. In another approach, Bio-ceramics were used as the carrier to treat a polluted river in Shenzhen Province of China, where the average removal rates of NO_2- N, NO_3- N, COD, turbidity, color, Mn and alga were 90.8%, 84%, 21.4%, 62%, 47%, 89% and 68% respectively. With the biological filter media laid on the polluted river surface in Shenzhen, China recorded the average removal rates of COD, ammonia nitrogen and total phosphorus as 40.00%, 36.43% and 43.02% respectively (Wang *et al*, 2012). Cao *et al*., (2012) also used filamentous bamboo as a biofilm carrier (Biocarrier) for bioremediation of polluted river water with the removal rates of COD, Mn, NH_{4+}–N, turbidity, and bacteria were 11.2–74.3%, 2.2–56.1%, 20–100%, and more than 88.6%, respectively. Hence, it was

recommended that filamentous bamboo be widely used for the bioremediation of polluted river water instead of conventional bio- carriers and phytoremediation techniques. Biocord, a man-made bio-reactor substrate was developed and manufactured for water management using microbe activity to passively treat wastewater in oceans, rivers, lakes, marshes and manmade reed beds (Xingcheng *et al*, 2012). Research results illustrated that the bio-cord exhibited good filtration performance and effectively removed COD, NH_3–N and TN with 26%, 65%, and 50% respectively providing suitable conditions and support media for microbial growth. After comparing and analyzing different techniques and clarifying the concepts of *in-situ* remediation technologies, approaches to alleviate the surface water pollution problem should utilize the bioremediation as the primary technique, followed by the physical and chemical remediation as the supplementary means.

B. *Nanoremediation*

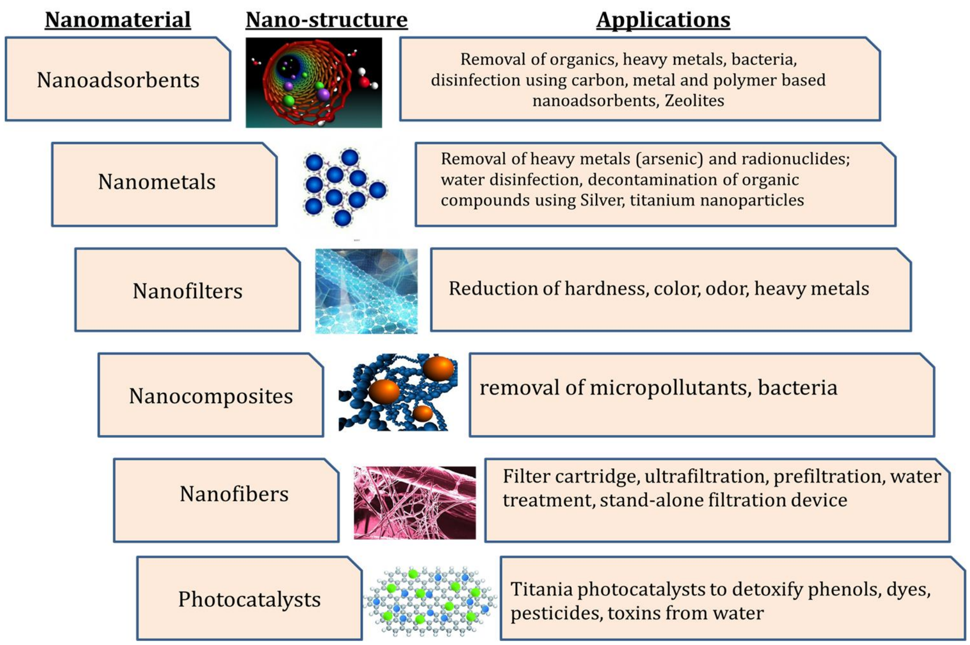

Figure 4. Types of nanomaterials, their structure and applications towards water and wastewater remediation

The rapid evolution of nanoscale science and technology has dramatically expanded the nanomaterials application potential towards development of innovative and cost-effective functional materials and sustainable processes for water treatment and purification. This has led to the development of innovative and efficient water detoxification technologies exploiting solar energy and nano-engineered titania photocatalysts in combination with nanofiltration membranes (Patil *et al*., 2016).

In this approach, nanostructured titania with high UV– visible response are synthesized and stabilized on nanotubular membranes of controlled pore size and retention efficiency as well as on carbon nanotubes exploiting their high surface area to achieve photocatalytically active nanocomposite membranes (Gherke *et al*., 2015). Comparative evaluation of the UV–visible and solar light efficiency of the modified titania photocatalysts for water detoxification is intensively investigated on various target pollutants ranging from classical water contaminants such us phenols, pesticides and azo-dyes to the extremely hazardous cyanobacterial toxins and emerging endocrine disrupting compounds in order to evaluate/optimize the materials performance and validate their competence on water treatment. Particular efforts are devoted to the analysis and quantification of degradation products as well as their toxicity. All these are crucial components for the fabrication of innovative continuous flow photocatalytic-disinfection-membrane reactors for the implementation of sustainable and cost effective water treatment technologies based on nanoengineered materials (Likodimos *et al*., 2010). As wastewater discharged from the several manufacturing industries is a major cause of river water pollution, nanotechnology is coming with novel approaches towards water and wastewater remediation. Fig. 4 gives an overview of different ways that nanomaterials are getting applied in such industries for secondary treatments of wastewater to improve its quality before water being discharged into rivers.

A key issue arising from the extensive use of nanotechnology is how to control the development and deployment of nanoremediation technologies to maximize desirable outcomes and keep undesirable outcomes at an acceptable minimum.

Numerous studies including toxicity tests, life cycle analysis, technology assessment, and pathways and dispersal of nanoparticles in water bodies have been carried out in order to evaluate the potential risks of nanomaterials to aquatic flora and fauna and human health (Patil *et al*., 2016). Every country has to take environmental regulatory steps to prevent any environmental damage, including to aqueous organisms, plants, and human beings, when nanomaterials are applied. Another more technical limitation of nanoengineered water technologies is that they are rarely adaptable to mass processes, and at present, in many cases are not competitive with conventional treatment technologies (Gehrke *et al*., 2015). Nevertheless, nanoengineered materials offer great potential for water innovations in the coming decades, in particular for decentralized treatment systems, point-of-use devices, and heavily degradable contaminants for freshwater ecosystems.

C. Next Generation Sequencing to the Rescue

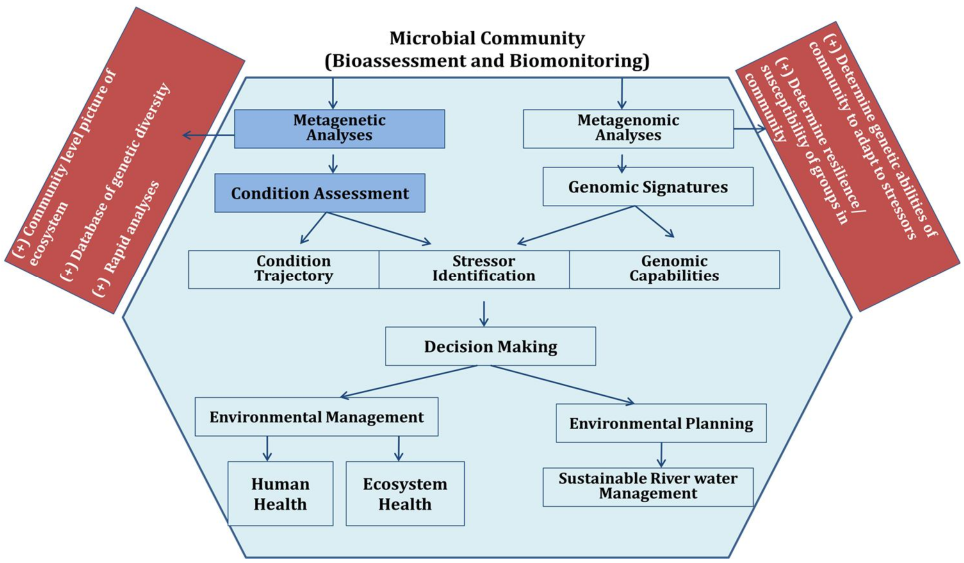

Figure 5. A conceptual model of the future of environmental biomonitoring and bioassessment using high-throughput DNA next generation sequencing. Likely benefits of using genomic community data are in white (side boxes). The darkly shaded boxes denote the areas where current efforts are focused.

In recent years, mass sequencing of environmental samples has been at forefront of ecology and biodiversity research. Current advanced next-generation sequencing (NGS) technologies are providing new insights into the ecology of microbially mediated processes that influence fresh water quality such as algal blooms, contaminant biodegradation, and pathogen dissemination (Adetutu *et al*., 2015). Sequencing methods targeting small subunit (SSU) rRNA hypervariable regions have allowed identification of signature microbial species that serve as bioindicators for sewage contamination in these environments. Furthermore, metagenomic and metatranscriptomic analyses of microbial communities in fresh water environments are revealing the genetic capabilities and interplay of waterborne microorganisms, shedding light on the mechanisms for production and biodegradation of toxins and other contaminants, microbial source tracking, characterizing the distribution of toxin and antibiotic resistance genes in water samples, and investigating mechanisms of biodegradation of harmful pollutants that threaten water quality (Tan *et al*., 2015)) (Fig. 5).

A next-generation, Illumina-based sequencing approach was first used by Staley *et al*., (2013) to characterize the bacterial community at along the Upper Mississippi River to evaluate shifts in the community potentially resulting from upstream inputs and land use changes. *Proteobacteria, Actinobacteria, Bacteroidetes, Cyanobacteria* and *Verrucomicrobia* accounted for 93% of all sequence reads, indicating bacterial communities associated with sewer, generic faecal, and human-specific faecal contamination. High levels of fecal bacteria are a concern for the aquatic environment, and identifying sources of those bacteria is important for mitigating fecal pollution and preventing waterborne diseases. Hence, a study by research team led by Gomi *et al*., (2014) performed fecal source tracking in Yamato river water; Japan by NGS based technology using host-specific *Escherichia coli* genetic markers. Whole genomes of 22 *E. coli* isolates from known sources (9 from humans, 2 from cows, 6 from pigs, and 5 from chickens) and identified candidate host-specific genomic regions were sequenced. As a result, 4 human-, 2 cow-, 3 pig-, and 4 chicken-specific genetic markers useful for source tracking were identified, and developed a multiplex PCR and dual index sequencing-based method to quantify these markers in environmental *E. coli* isolates further indicating that humans constituted a major source of water contamination in the Yamato river.

The NGS approaches have also proved its potential in river ecosystem or biodiversity assessment to further extend the application of DNA information for routine biomonitoring applications to an unprecedented scale. Hajibabaei *et al*., (2011) demonstrated the feasibility of using 454 massively parallel pyrosequencing for species-level analysis of freshwater benthic macroinvertebrate taxa commonly used for biomonitoring. Experiments were designed in order to directly compare morphology-based, Sanger sequencing DNA barcoding, and next-generation environmental barcoding approaches. The results of this study showed the ability of 454 pyrosequencing of mini-barcodes to accurately identify all species with more than 1% abundance in the pooled mixture; evidence that DNA based analysis may provide a valuable approach in finding rare species in bulk environmental samples. The application of the environmental barcoding approach by comparing benthic macroinvertebrates from an urban region to those obtained from a conservation area was also demonstrated as a potential of an environmental barcoding for biomonitoring programs.

The industrial or anthropogenic activities can have impact on nearby freshwater ecosystem. Hence the main aim of the study conducted by Yergeau *et al*., (2011) was to evaluate the potential impacts of oil sands mining on neighboring aquatic Athabasca River and its tributaries microbial community structure. Microbial communities were sampled from sediments in the Athabasca River and its tributaries, Canada as well as in oil sands tailing ponds. Bacterial and archaeal 16SrRNA genes were amplified and sequenced using NGS technology; 454 and Ion Torrent. This study revealed that river sediments in close proximity to oil sands tailings ponds were chemically and microbiologically more similar to each other and to those from the tailings ponds than to samples obtained from further away. Several taxonomic groups of *Bacteria* and *Archaea* showed significant correlations with the concentrations of different contaminants, highlighting their potential as bioindicators that can help monitor and mitigate oil sands mining impacts on the Athabasca watershed ecosystem.

Metagenomic profiles of antibiotic resistance genes (ARGs) patterns were reported using NGS Illumina HiSeq platforms in the human impacted Pearl River estuary, China which suggested enrichment of mobile genetic elements and high resistance to sulfonamides, fluroquinolones, aminoglycosides and beta-lactams, tetracycline (Chen *et al*., 2013; Li *et al*., 2015). Moreover, metagenomic platforms such as Roche 454, Illumina HiSeq, Illumina MiSeq towards microbial community assessments were implemented to identify microbial species associated with human-fecal and sewer materials, investigating role of chemical variables on community dynamics in wastewater treatment plants in mixed urban environment (McLellan *et al*., 2010, 2013; Newton *et al*., 2015; Shanks *et al*., 2013; Ye and Zhang, 2011).

The applicability of NGS methods for water quality assessment has so far not been broadly investigated. In order to translate the novel methods and findings into useful and accessible solutions for the practitioner in the water field, research and future development will have to supply standardized laboratory procedures and, in particular, data analysis pipelines and software tools as well as specialized sequence databases tailored to the requirements of water quality assessment (Vierheilig *et al*., 2015). However, the continuing decreasing costs of NGS and the increasing availability of data offer exciting opportunities to better understand the relationship between microbial communities and anthropogenic activity in aquatic environments and may lead to improved understanding of water quality and effective monitoring practices.

IV. BIO-ENGINEERING APPROACHES TOWARDS RIVER WATER REMEDIATION

Bio-engineering approaches towards river water remediation rely on biological knowledge integrated with engineering tools to seek tangible, economical, effective solutions. Some of these approaches are discussed in this section.

A. Integrated River Basin Management

As described by Global Water Partnership (2000) **Integrated River Basin Management** (IRBM) is defined as “process of coordinating conservation, management and development of water, land and related resources across sectors within a given river basin, in order to maximise the economic and social benefits derived from water resources in an equitable manner while preserving and, where necessary, restoring freshwater ecosystems". The main purpose of the IRBM is to achieve a balance between the existing natural functions of the river system and the developed aspects of the system. The IRBM management actions have proven to be useful for society, agriculture, industries and nature management. IRBM is not a technical solution; rather, is an approach to water resources management that takes into account all factors linked to land and water resources, including social and economic activities. World Wildlife Fund for Nature, China has successfully deployed different strategies of IRBM effectively in the Yangtze River basin especially in sectors like institutional setup and legislation related to water management in China (Boekhorst et al., 2010).

The internal consistency of models and data, effective communication, and functional flexibility are essential to warrant a proper balance between scientific standards, the availability of models, and the requirements of users for effective Decision-Support System (DSS) for IRBM (Jean-Luc de Kok et. al., 2009). Integrated, catchment-scale plans for the protection and restoration of aquatic ecosystems must be developed as part of integrated river basin management (IRBM). Clearly scientific knowledge and technical acumen are absolutely necessary components of successful IRBM (Surridge and Harris, 2013). Hence, IRBM would invariably address the integration of natural limitations, social and economic demands, legal, political and administrative processes as a part of river water remediation action plan.

B. *Riverbank Filtration (RBF)*

River losses water into the adjacent groundwater aquifer through the hydraulic interconnection which is recognized as Riverbank Filtration (Schon 2006). RBF systems can significantly reduce the concentrations of many surface-water pollutants (Kuehn and Mueller, 2000; Shubert, 2000; Wang et al., 2000) however, predicting and quantifying those reductions is difficult. RBF takes advantage of the infiltration of river water into a well through the riverbed and underlying aquifer material. This is a natural filtration process in which physico-chemical and biological processes play a role in improving the quality of percolating water. After a certain zone of mixing and reducing, filtrated water is at its cleanest; almost all river contaminants are removed. Wells are installed in this zone to pump the water to be used for drinking. The purity of this water and its suitability for drinking is outstanding, even in examples where there is an event that introduces a shock load of contaminants in to the river. According to Shamrukh and Wahab (2008) physicochemical and microbiological characteristics of produced water from RBF plant located in Upper Egypt as part of Nile Valley are better than allowable standards for drinking purpose. RBF in the saturated percolation has potential to improve the infiltration water quality and the nitrogen removal rates were more than 95% in Kuihe River, China (Wu et al., 2007). Hence, the physical, chemical, and biological processes in RBF can significantly improve the infiltrating river water quality under favourable conditions (Hiscock and Grischek 2002; Weiss et al., 2005).

C. *Tertiary Wastewater Treatment Practices*

Point sources have direct impact on deterioration of river water quality. Tertiary water treatments are used for treating sewage or effluent discharged from various industries to make it safer before it’s discharged into water ecosystem such as rivers, lakes. Advancements in these tertiary treatments have shown its efficacy towards improving the quality for wastewater and been employed to reduce the level of water pollution.

V. BENEFIT QUANTIFICATION

It is indeed a development paradox that people are clamoring for a better quality of life, and yet their economic, social, and environmental conditions are not improving according to their expectations, many times because of steady degradation of the environmental conditions (Joshi et al., 2012). The overall philosophy of national growth should be that economic development of the city–state could not be sustained and the quality of life of its people could not be significantly improved, unless environmental factors were considered as important as development issues. Unlike the earlier newly industrializing economies of Asia like South Korea, Taiwan, and Hong Kong, India, China who adopted the ‘‘industrialization first and dealing with consequences later’’ approach, are now facing the serious environmental issues like water scarcity, increased surface and ground water pollution, antibiotic resistance amongst microbes in water resources and degradation of natural ecosystem impacting human and aquatic life well being. Hence, it is utmost important to restore the deteriorating conditions of river ecosystem, which are interlinked with socio-economic benefits of the nation.

The benefits arising from improving river water quality can be classified in two categories - (a) direct benefits and (b) indirect benefits , Direct benefits comprises of abstraction for agriculture, municipal by providing safe resource of water. It avoids wear and tear of industrial equipments caused due to polluted water. Cost of water treatment plants decreases due to supply of cleaner water sources for industries and agriculture sectors. It also saves health expenditure by reducing health risks arising due to polluted water (Bradley, 2010). In addition, it provides direct benefit to commercial fisheries and water-contact recreation such as swimming or boating. Indirect benefits include non-contact river recreation to flourish local tourism by promoting activities like sport-fishing, bird watching, photography, aesthetic values and sustainable benefits. Indirect economic benefit improves health of people which leads to improved work efficiency. Sustainable benefit is another indirect advantage as it passes on cleaner and better rivers for next generation. Nowadays, Cost-Benefit Analysis in environment plays vital role in cost improvement of water quality is much lesser than the treatment of water quality and mitigates its adverse effect on social health as well as national and international economy.

VI. ENVIRONMENTAL POLICIES, POLITICAL VISION AND PUBLIC INVOLVEMENT

There is a significant importance of Environmental Policies & Political Vision of individual countries in the betterment of river ecosystem. Environmental policies are the set of principles adopted by the Country/organization in order to safeguard environment. Most of the Countries have their own National Environmental Policies. The goal of environmental policy is to protect the environment for future generations while interfering as little as possible with the efficiency of commerce or the liberty of the people and to limit inequity in who is burdened with environmental costs. However, Environmental Laws establish regulatory structures for Environment Management and helps regulators to manage environmental impacts using plans, policies, standards, licenses and incentives. In addition, it gives right to public to take active participation in management action plan as well as allow the people to challenge the legal decisions taken by the regulators to save the environment.

At International Level, Conferences, including 1972's United Nations Conference on the Human Environment, 1983's World Commission on Environment and Development, 1992's United Nations Conference on Environment and Development and 2002's World Summit on Sustainable Development have been particularly important. Multilateral environmental agreements sometimes create an International Organization, Institution or Body responsible for implementing the agreement. Conferences give birth to laws, policies and protocols to protect the natural river habitat. These international laws promote nations to adopt various environmental principles like Precautionary Principle, Polluter Pays Principle, etc. These principles provide basic skeleton to form laws in various countries. The Indian Constitution has given fundamental right to a ‘wholesome, environment in terms of Article 48A responsibility to people to take care of Environment in Directive Principle 51A(g). National Green Tribunal has been established on 18.10.2010 under the National Green Tribunal Act 2010 for effective and expeditious disposal of cases relating to environmental protection. M.C Mehta India’s renowned Environmentalist in 1985 issued a writ of mandamus to restrain leather tanneries and the municipal corporation of Kanpur from disposing of industrial and domestic effluent in the river Ganges. These "Ganges Pollution Cases" has become the most significant water pollution litigation in the short history of Indian Environmental Law. The various organizations in developing and developed nations and their roles towards water quality management are listed in Table 3. Moreover, for the effective implementation of environmental legislation and policies there must be an appropriate framework of organizations and administrative systems with right political vision. For example, Government of India launched, ‘Namami-Ganges’ action plan with a hope to clean the holy River Ganges through Integrated Ganges Conservation Mission /Programme under National Ganges River Basin Authority Programme. Namami-Ganges Mission, envisaged as an umbrella programme, aims at integrating past and current ongoing initiatives by enhancing efficiency, extracting synergies and supplementing them with more comprehensive and better coordinated intervention. Singapore River and Kallang Basin Clean Up operation during 1977 till 1986, is an another example which highlights the fundamental value of political vision and political will that has to be in order to make any vision a reality (Joshi et al., 2012). As the catchments represented 30% of Singapore’s area, it was a challenge for the planners to propose how to prevent polluting activities of very varied nature which were also located far from the rivers. However, the targeted vision of The Ministry of Environment, Finance and Drainage Departments resulted in uplifiting the socio-economic standards of community alongside Singapore River and Kallang Basin.

Public involvement, Non-governmental organizations (NGOs) and Government bodies are considered as integral three pillars of prevention and control of water pollution program. It is generally felt that, ‘unless the public is convinced that by protecting the environment and controlling pollution its health will be safe-guarded, all the best legal pronouncements and administrative mechanism would remain only in book.’ The historic clean-up of Thames River, London is successfully achieved by active participation of volunteer.

VII. CONCLUDING REMARKS

Recent past has witnessed a gradual downfall in the quality of river waters around the globe, with more severity in developing world. The quest for rapid growth has often left negative impacts on these freshwater ecosystems, which in turn is posing a risk to public and environmental health, with a considerable number of rivers are either dead or on the verge of getting so. The ever growing population has not helped the cause either and river pollution problems are aggravating to the worst levels. Unfortunately though, in spite of it being such an alarming situation, we are yet to optimally use comprehensive and cross-disciplinary remediation approaches such as integrating advanced tools like bio-nano-technological approaches with the help of effective policies and public participation, for bringing back life to these deteriorating river ecosystems. Through this comprehensive and critical review, we have presented herein a snapshot of the current situation of river water in different geographical and geo-political locations, and discussed the availability of potent tools for remedies and possibilities as well as challenges involved in developing model systems for river remediation with global outlook. The extent of river water deterioration is worrisome and necessitates more inclusive investigations involving advanced multi-tier remediation approaches are need of the hour. Comprehensive investigations aimed on identifying advanced materials and technologies for river water remediation are therefore advocated. However, there are some noteworthy success stories, and the learnings from the successful remediation of highly polluted or dead rivers should be used effectively while developing strategies for cleaning the polluted river waters.

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