EMERGING APPROACHES IN BIOREMEDIATION INNOVATION SYSTEM IN INDIA: A CASE STUDY OF YAMUNA RIVER IN DELHI

Dissertation submitted to the Jawaharlal Nehru University
in partial fulfillment of the requirements for the award of the Degree of

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JYOTI

ज. ने. वि.
JNU

CENTRE FOR STUDIES IN SCIENCE POLICY
SCHOOL OF SOCIAL SCIENCES
JAWAHARLAL NEHRU UNIVERSITY
NEW DELHI – 110067
INDIA
JULY 2016

Jawaharlal Nehru University
New Delhi-110067, INDIA

ENTRE FOR STUDIES IN SCIENCE POLICY
:HOOL OF SOCIAL SCIENCES-I

Tel. : 011-26704461
Fax : 011-26741586
Web. : www.jnu.ac in/sss/cssp

Date 25:07:16

DECLARATION

I declare that the dissertation entitled *"Emerging Approaches in Bioremediation Innovation System in India: A Case Study of Yamuna River in Delhi"* submitted by me for the award of the degree of MASTER OF PHILOSOPHY of Jawaharlal Nehru University is an original research work and this dissertation has not been submitted for any other degree of this University or any other University/Institutions.

Jyoti
Research Scholar

CERTIFICATE

We recommend that this thesis be placed before the examiners for evaluation.

Dr. Madhav Govind
Chairperson

Dr. Modho Govind
Chairperson
Center for Studies in Science Policy
School of Social Sciences-1
Jawaharlal Nehru University
New Delhi-11

Prof. Pranav N. Desai
Supervisor

PRANAV N. DESAI
Professor
Centre for Studies in Science Policy
School of Social Sciences
Jawaharlal Nehru University
New Delhi-110 067

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LIST OF ABBREVIATIONS

ABR: Anoxic Bioremediation

AE: Atomic Energy

BOD: Biochemical Oxygen Demand

BRIS: Bioremediation Innovation System

CLC: Carrier Lined Channel

COD: Chemical Oxygen Demand

CPCB: Central Pollution Control Board

CSE: Centre for Science and Environment

CSIR: Council of Scientific and Industrial Research

DDA: Delhi Development Authority

DNA: Deoxy Ribonucleic Acid

DRDO: Defence Research and Development Organization

EBB: Eco Bio Block

EC: Electrical Conductivity

EJC: Eastern Yamuna Canal

EMS: Environmental Management Systems

EnvRP: Environmental Research Programme

GEMS: Global Environment Monitoring System

GOI: Government of India

IIT: Indian Institute of Technology

IITR: Indian Institute of Toxicology Research

ISRO: Indian Space Research Organization

JNU: Jawaharlal Nehru University

MINARS: Monitoring of Indian National Aquatic Resources System

MLSS: Mixed Liquor Suspended solids

MoEFCC: Ministry of Environment, Forest and Climate Change

NEERI: National Environmental Engineering Research Institute

NGOs: Non-Governmental Organization

NGRBA: National Ganga River Basin Authority

NGT: National Green Tribunal

NInC: National Innovation Council

NIS: National Systems of Innovation

NMCG: National Mission for Clean Ganga

NRCD: National River Conservation Directorate

NRCP: National River Conservation Plan

nZVI: Nanoscale zero-valent iron

OECD: Organization for Economic Co-operation and Development

PAC: Poly Aluminum Chloride

PCC: Pollution Control Committee

PPP: Public–Private Partnership

R&D: Research and Development

RIS: Regional Systems of Innovation

S&T: Science and Technology

SI: Systems of Innovation

SMEs: Small and Medium Scale Enterprises

SPCB: State Pollution Control Board

SSI: Sectoral System of Innovation

STPs: Sewage treatment plants

TDS: Total Dissolved Solids

TERI: The Energy and Resources Institute

TSS: Total Suspended Solids

UNEP: United Nations Environment Programme

UNICEF: United Nations international Children's Emergency Fund

WJC: Western Yamuna canal

WWF: World Wide Fund for Nature

YAP: Yamuna Action Plan

CHAPTER 1

INTRODUCTION

1.1 The Context

The River Yamuna is the major tributary of River Ganga. This river is as prominent and treated sacred as the great River Ganga itself. It has been revered as a holy river in Indian mythology and various pilgrimage centres e.g. Yamunotri (Uttaranchal), Paonta Sahib (Himachal Pradesh), Bateshwar, Mathura, Vrindavan, & Allahabad (all in Uttar Pradesh) are situated at the banks of this river. Large metropolitan centres e.g. Yamuna Nagar, Sonepat, Delhi, the political centre of India, Gautam Budh Nagar, Faridabad, Mathura, Agra and Etawah are also recognised on its banks. The Yamuna River has a total catchment basin of 3,66,223 sq.km which conceals 42.5% of the total Ganga basin area and around 11% of the total landmass of the country. Large industrial focal points have also been developed either on banks or in its basin. In fact, Yamuna basin is proficient in agricultural front as well, it is one of the highly fertile and high food grain yielding basins, especially areas in Haryana and Western district in Uttar Pradesh. All this reveals the significance of River Yamuna not only as a sacred river but also as a contributor to economy of the country. These days it is hugely pointed as a dirtiest river of the country. The river has been disposed to the issues imparted by urbanization, industrialization and rapid agricultural developments alike other riverine system.

It has been reported that in India, rivers are mostly polluted near their sources. However, the cause of pollution in the plains is mainly because of domestic sewage, run-off from agricultural land and untreated industrial effluents. The water is highly unfit for drinking near cities and industrial areas in these rivers.

A recent report by India Water Portal has revealed that polluted river stretches in the country have risen 14 times in the last 26 years from 22 in 1989 to 302 now. According to environmentalists, this is because of the ineffective clean up measures by the Central Pollution Control Board despite spending so much money.

It is necessary to gauge the extent of the threat by tracing the river's flow. For that the river has been separated in five segments based on hydro-geomorphological and ecological characteristics from down to its terminating points. It has four distinct flow patterns. Its first segment is from Yamunotri to the Tajewala barrage (172 kms). The second segment is from the Tajewala barrage to the Wazirabad barrage (224 kms). And the third point is through Delhi, from the Wazirabad barrage to the Okhla barrage (22 kms). The final segment of the river is Gokul till it converges into the Ganga (approx. 817 kms) away at Allahabad.

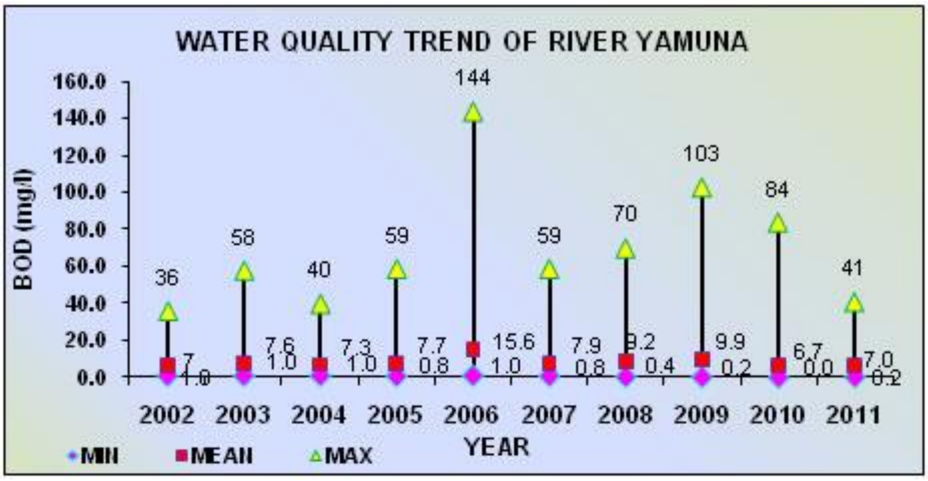
Figure 1.1 Picture showing the study area

Source: Google Maps (06.05.16)

In Delhi the course of Yamuna enters at Palla village 15 km upstream of Wazirabad barrage, which acts as a reservoir for Delhi and releases a very small amount of water into the river. The course of the river downstream of Wazirabad is only of industrial and sewage effluents especially during summer time. Due to lesser discharge it lessens river flow and thus, causing higher intensity of pollution. The river in Delhi exits from the Okhla barrage, which subdivides meeting the Agra canal. The condition is more critical in the dry months; there is almost no water released from this barrage to downstream Yamuna. Instead, at downstream of the barrage Shahadara drain is directly discharged which bring effluents from east Delhi and Noida into the river. This is the second major contaminator of the river after the Najafgarh drain.

Studies have ascertain that entire course of Yamuna through Delhi the BOD (Bio-chemical Oxygen Demand) values range from 30 to 35mg/1, which marks that the BOD level is ten times above the standard level. The faecal coliform is in the range of 1 million per 100 ml which exceeds the standard level 400 times. Delhi produces somewhere between 3400 to 3600 million litres per day (mld) of wastewater and contrastingly, the treatment capacity existing is for about 2330 million litres only.

Fig.1.2 Water quality trend of Yamuna river



Source: http://cpcb.nic.in/water.php (11.02.16)

Along the Okhla stretch the Yamuna doesn’t look like containing much water because most of it is chocked by water hyacinth which is a weed, exemplifying eutrophication. This causes death of fishes in the river once the arrival of monsoon takes place. The reason is rapid intensification of pesticide and other pollutant levels. Wastes are also discharged into the river from large industrial units (22 in Haryana, 42 in Delhi and 17 in Uttar

Pradesh) and many small industrial units. Astonishingly, yet Delhi occupies only 2% of the catchment area, it contributes to 80% of the pollution of the river.

According to a recent study (2014-15) conducted by Central Pollution Control Board (CPCB), “urban areas are responsible for sewage generation each day estimated about 57,233 mld. Against this, 682 Sewage Treatment Plants (STPs) having a total treatment capacity of 21,478.69 mld were available (37% of the sewage generation). Considering that in addition to the installed capacity, 217 STPs with a treatment capacity of 3099.73 mld were under construction/proposed for construction”. Thus, it is important to notice while the installed treatment capacity has nearly doubled over the last 5 – 7 years, the great expanse of urbanization and urban population has created a void between sewage generation and treatment capacity available.

Centre has spent a huge amount of money since 1993, which is estimated to be Rs 1,500 crore under the Yamuna Action Plan (YAP) I and II to clean the river but remained ineffective. After a study by the Japan Bank for International Cooperation (JBIC) the first phase of YAP was launched covering Delhi, eight towns in Uttar Pradesh and six towns in Haryana. In second phase YAP II, the 22-km critical stretch of the Yamuna in Delhi, was taken up. To resolve the secondary issues of Yamuna river pollution, additional contamination reduction works in the State of Delhi, Haryana and U.P. have been presented for funding by JBIC under Yamuna Action Plan Phase-II. The total cost of project is estimated at Rs. 637 crore (15,607 billion in Japanese yen). The “National River Conservation Directorate (NRCD) under the Ministry of Environment, Forests and Climate Change (MoEFCC), GOI were the executing agencies for the YAP project in association with Uttar Pradesh Jal Nigam (UPJN) in UP, the Public Health Engineering Department (PHED) in Haryana, and the Municipal Corporation of Delhi (MCD) in Delhi, being the principal Project Implementing Agencies (PIAs)”.

1.1.1 Issues encompassing floodplains of the region

The problem has not only entrapped the river part, but the land part is also degrading with the same disgrace. The drastic tapering of floodplains itself noticed between 1980 and 2014 – prominently. This simply projects that there could be chances of an enormous flooding in Delhi sooner or later.

A study published in the International Journal of Research in Engineering and Technology in 2014, reported that "The topographic and satellite maps of Delhi from 1980 to 2014 indicate temporal variation in channel geometry and the position of river Yamuna. It is observable that after 1980 the remaining floodplain areas were rapidly occupied by settlements, civic structures, roads, bridges, flyovers, playgrounds and metro stations,".

In a study conducted by The Energy and Resources Institute (TERI) and UNICEF called "Yamuna, the Poisoned River," in 2012, collected soil samples from Yamuna river bank to determine the contamination levels in the flood plains. The report revealed that, "these levels exceeded commonly used international reference values for nickel and chromium levels in soil. Lead levels ranged from below detection to 40 times over the permissible limits. Mercury concentrations too were much higher than permissible standard at all locations. Wazirabad and Okhla barrage showed high levels of different metals. While the Wazirabad section of the river receives wastewater from Najafgarh and its supplementary drains, the Shahdara drain releases its load downstream at the Okhla barrage. A possible reason for this is the industrial effluents."

There is a massive flooding of river water, during the monsoon season, washing off the land from where contaminates reach the soil. It absorbs all the contaminants at which vegetables are grown. Root vegetables like spinach, cauliflower, and radish grown in the flood plains are found with concentration of heavy metals which is highest in spinach, followed by cauliflower and the least in radish. According to the above research findings which suggest that leafy vegetables absorbs and accumulates high quantity of heavy metals. These vegetables are then enters and carried through our food chain.

Large number of dam constructions and barrages in the upstream courses of the river has considerably reduced water in downstream region, excluding the monsoon season which would have been cleansed otherwise by river's natural flow by diluting the pollutants flowing into it. Presently, the Yamuna turns into desiccated river for up to nine months in Delhi and what we perceive to be water in the river is just the untreated sewage of the city.

This has also affected the socio-economic conditions of the region. As Yamuna floodplains in Delhi supports hundreds of families because of the prevailing agricultural activities. But it banned later on, due to heavy contamination of pesticides. Else, these farms could help the city purged its sustenance, apart from providing it with fresh vegetables and fruits. Instead of discouraging farm activity alongside of the river, there could have been other alternatives like shifting to organic farming would have made the situation reviving.

It is very important to retain that nearly half of the colonies in Delhi are illegal, unlicensed or unauthorized which contributes 50 percent of the sewage that enters the Yamuna in Delhi and remain untreated. The situation is further worsen because sewage water all over the world is treated through three stages (called as tertiary level treatment) but in India, especially in Delhi, the sewage water is treated only up to its secondary level ignoring tertiary level due to odd environmental reasons that chemically removes the remaining pollutant.

1.2 The approach

A number of contaminated sites spread across our nation due to toxic waste dispersed in environment directly. The incapability to treat the contaminants to acceptable level is ineffectiveness of the existing treatment technology comprising physico-chemical and biological methods. Either past or present, every one of us is being exposed to contamination from industrial practices, emissions in natural resources (air, water and soil) even in the distant locations. Not only environment but human health is at risk which is raising with time and evidences like global epidemic of cancer, and other degenerative diseases points the culprit to be these cocktail of pollutants.

In this view, it is challenging to evolve with innovative and cost-effective solutions to cleanse contaminated environments, to make them safe for human inhabitation and consumption, and to safeguard the working of the ecosystems which support life. There is immense advancement has been made in developed countries like UK, USA, Canada, Australia, Japan and European countries. Nevertheless, in India there is a pressing need to appraise the encouraging developments coming out of several laboratories.

The advancement in science and technology facilitated to unveil the potential of biological diversity for pollution abatement which is named as Bioremediation. This is an evolving and effective innovative technology for treatment of wide-ranging contaminants. This technology consists of phytoremediation (plants) and rhizoremediation (microbe and plant interaction). "Rhizoremediation, is the most developed process of bioremediation involving the removal of particular contaminants from contaminated sites by symbiotic interaction between plant roots and suitable microbial flora" (Prasad, 2015). Bioremediation acts as a valuable instrument for broader application in the environment. Currently, this approach is applied to contaminants in soil, surface water, groundwater, and sediments including air. These technologies have strikingly turned out to be alternatives to conventional technologies for clean-up. It relatively poses low capital costs and presents an inherently aesthetic nature in its application.

A large number of plants, transgenic, natural, or related with rhizosphere micro-organisms are unusually active in removing or immobilizing pollutants by their biological interventions. These, diverse microbes are sufficiently active agents, fungi and their strong oxidative enzymes in degrading/ decontaminating recalcitrant polymers and xenobiotic chemicals as well. Human skill and technology integrating geology, hydrology and biology resulted into wetlands construction which people have made since ancient times and operated constructed wetlands to treat wastewater.

At present, bioremediation technology has become much more advanced and versatile. They have enhanced significantly since they were first revealed and will keep progressing under scientific research. It always becomes a matter of speculation or debate, whenever a new technology is introduced primarily revolving around the safety of the use of the products of biotechnology, in order to avoid this from continuing to occur throughout industry applications adequate guidelines for safety have been suggested and enforced by law. However during the time it was first installed, much speculation and debate was raised as it was not fully understood how these complex processes occurred in the means of converting hazardous wastes or pollutants into less harmful forms.

The biotechnology equipped with recombinant DNA technology is now adequately perfecting the bioremediation technology by refining pollutant–degrading microbes through strain development and genetic modification of specific regulatory and metabolic genes that are vital in emergence of dynamic, non-toxic and cost-effective techniques for bioremediation.

Although having risks (uncertain), this technique has more of advantages, if compared to other working technologies. This has not gained much attention in view of policy makers this is quite evident because there is no such clear cut policy regarding the adoption and rare prevalence of this technology. Government is pumping money and there is no remarkable output. Recently, Delhi development authority (DDA) in a detailed action plan mentioned it to National Green Tribunal (NGT) that cleaning of the river Yamuna will require additional Rs 4,000 crore over three years in order to set up secondary sewage line while the implementation of the primary sewage network may take up to two decades. This "prioritized work" is aimed to take away sewage flow into storm water drains that instead meant to carry excess rain water.

The social dimension of bioremediation techniques involves the general public's perceptions, knowledge, and attitudes towards bioremediation. Community participation in prompting the development and application of bioremediation techniques varies in different countries, but could significantly influence the continuous and prolonged use of this technology for the remediation of contaminated sites especially of a holy river- Yamuna in context of India. Little research is available on this topic because these are relatively new techniques that are yet to be explored well. The term bioremediation is not yet widely known by the general public in most countries. In developing countries like India, where non- availability of food, clothing and shelter are still under vicinity, adopting or taking into consideration about such technologies that too with such grassroots level makes it critically difficult to reach at par. This is what we have as a real challenge, which can be overcome by the support of our government, concerned authorities and people who are well aware about the potential of this technology in our scenario. We need to customize this technology to bring it to the level of our scope and situation where it could be used with its maximum efficiency.

This work will be mainly highlighting the following objectives:

1) To explore bioremediation and its application to contaminated sites in India (in general).
2) To analyse the mechanisms for bioremediation and new methodological breakthroughs in bioremediation.
3) To identify the role of actors and institutes those are actively involved in research of bioremediation in India.
4) To study the effectiveness of bioremediation and its impact on socio-economic dimensions of the technology.

1.3 Outline of the dissertation

The dissertation is compilation of seven chapters. In the introduction part, attempt was made to get the grasp of River Yamuna, its location and certain features. It focussed on the issues prevailing in Yamuna these days due to contaminated water generated by industrial effluents and sewerage system. The failure of government attempts towards its cleaning and use of unsuccessful conventional treatment measures is making the situation worse instead of improving. It has also discussed about bioremediation as an alternative technology for reviving the river system which includes both water and land part.

Chapter 2 discusses the theoretical framework of this study. The framework which is adopted to endure with the study is eco-innovation which has elaborated more in the chapter. This is quiet relevant in making the sense of this issue as it relates to innovation and environmental policies at one time. It has helped in developing the concept of bioremediation innovation system and its evolving potentials for the present research problem.

Chapter 3 emphasised on the procedures that have been followed to organise the study well i.e. the research methodology of the study. The study is exploratory in nature and made use of semi-structure, open-ended questionnaires. It has adopted case study as a research method followed by the interview schedules and discussions. The collected data has been managed by certain methods, discussed in the chapter.

Chapter 4 sheds light on the socio-economic characteristics of the study area. This has been an attempt to reflect on the substantial literatures and analysis of the information gathered for this study. The aim of the chapter is to show the picture of study area with a different perspective which is more or less important to have a deeper understanding of the issue. It would also look upon, at what extent these components have evolved with time.

Chapter 5 addresses one of the objectives of the study i.e. to identify the role of actors and institutions that are very much part of bioremediation innovation system. It has differentiated the roles of actors and attempted to describe each of them separately. The chapter has also worked on the policy augmentation part of this study which is needed to cover the whole issue.

Chapter 6 provides an important part of the dissertation which tries to analyse the collected data and information gathered during the field work. The data were analysed empirically, drawing on literatures, discussions and observations.

Chapter 7 discusses about the key findings and results obtained after analysis of data. The conclusions were made in accordance with the research objectives and research questions. It would also elucidate on the implications of the study and how it could be applied in other contexts as well. It would also point out some of the limitations encountered in this study.

CHAPTER 2

REVIEW OF LITERATURE – MAKING THEORETICAL ORIENTATION

2.1 Overview

The chapter is an attempt to gather needful knowledge of the proposed research area. The aim of the chapter is on critical evaluation of different theoretical framework and methodologies used in this field with the purpose of identifying the suitable approach for exploring the research questions. This has focussed on the features, the technology (bioremediation) and theoretical linkage to the issue.

Literature reviewed includes peer-reviewed journal, articles and books of the prevailing theoretical concepts and also, government reports, research papers and tangible information by bioremediation servicers involved in the response to, estuarine, spills in inland and marine environment.

The chapter has five sections including the overview section. Section 2 gives a brief introduction of innovation and further illustration of Systems of Innovation and its various definitions. Section 3 discusses about the eco-innovation- introduction and forms of eco-innovation and how it is different from Systems of innovation. Section 4 describes bioremediation innovation system- introduction, types of bioremediation and evidences to its advancement. Lastly section 5 tends to explain how eco-innovation is being applicable for the present study.

2.2 Innovation: in brief

Innovation is neither a simple task to perform, nor it's easy to define it with a simple definition, because Innovation is a complex concept as there are a number of forms of innovation. Then thinking of an Innovation system as a whole, which could be as complex or as simple as the case may be. Due to this system only, it produces innovative outcomes that further accomplish development of a particular field or a product. This is why there are a lot of literatures or thoughts could be found in order to unfold the idea of this concept.

Schumpeter (1912) has defined innovation as the introduction of new product, application of new methods, opening of new markets and creating new industry structure by generating or abolishing the monopoly position. He also claimed innovation to be an essential driver of competitiveness (Porter & Stern, 1999). He added innovation that drives economic dynamics (Hanush & Pyka, 2007). Schumpeter proposed a term called 'creative destruction.' He related it to innovation by claiming it as "a process of industrial mutation that persistently revolutionizes the economic structure from within, incessantly destroying the old one, and creating a new one" (Schumpeter J. A., 1976).

Freeman (1982) has defined innovation from the economic point of view, "as the first commercial transactions of a new product, process, systems or device". In contrast, Nelson and Rosenberg (1993) have suggested that innovation to be, "the process by which firms master and put into practice product designs and manufacturing process that are new to them". The generation, acceptance and implementation of new ideas, processes, products or services can be defined as innovation (Thompson, 1965). Innovation can also be seen as a means of changing an organization in response to the external environment including new product or service, process technology about organization supporters (Damanpour, 1996). It could be understood particularly for technological innovation, according to Beije (1998) "as in a group of private firms, public research institutes, and other facilitators of innovation who interactively promotes the creation of one or a number of technological innovations (within a framework of) institution which promote or facilitate the diffusion or application of these technological innovations". In line with Oslo Manual, "innovation is the implementation of a new or significantly improved ideas, product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations" (Tanaka, Glaude, & Gault, 2005).

“Innovation and innovation systems are becoming increasingly interesting to policy-makers these days for achieving their economic and social goals” (Schrempf et al. 2013).

2.2.1 Systems of Innovation (SI)

In this section, the basic ideas of the SI approach, followed by a brief outline of the three main sub-concepts of the framework have been discussed. The National Systems of Innovation (NIS) and the Regional Systems of Innovation (RIS) approaches use geographic demarcations to describe the systems. “The Sectoral System of Innovation (SSI) approach emphases on certain sectors of the economy, for example, genetic engineering” (Schrempf et al. 2013).

In 1985, B.-Å. Lundvall introduced the concept of 'Systems of Innovation'. The system of innovation approach is based on the idea that processes of innovation are, extensively recognized by interactive learning. “It could be argued that some kind of systems of innovation approach is innate to any perspective that sees the process of innovation as interactive; this interactivity paves the way for a systemic approach” (Edquist, 2011). The SI approach is a highly preferred framework for describing, analysing, and understanding the innovation process on a number of levels, and how it can be influenced by policy measures. Lundvall’s definition is like so:

“ a system of innovation is constituted by elements and relationships which interact in the production, diffusion and use of new and economically useful, knowledge ... a national system encompasses elements and relationships, either located within or rooted inside the borders of a national state” (Lundvall, 1992, p.2).

The Systems of Innovation (SI) approach has existed and enhanced because of the pivotal work by Freeman (1987), Lundvall (1992) and Nelson (1993). The SI approach has become very established in a very short period of time and commonly used in academic settings and also as a framework for innovation policy-making (Edquist, 2001).

Among the various dimensions of SI approach, the most important one might be that innovations are normally seen as "based on learning that is interactive between organisations in the SI approach; firms do not generally innovate in isolation" (Edquist 1997: 7, 20- 22) "Another important feature is that institutions are considered to be crucial elements in all versions of the SI approach" (Edquist 1997: 24-26). "The institutions shape (and are shaped by) the actions of the organisations and the relations between them. In addition, all versions of the SI approach consider innovation processes to be evolutionary – which might be problematic in the sense for some" (Edquist 1997: 5-7). "These characteristics of the SI approach constitute major advances in the study of innovation processes and strengths of the SI approach have made it absolutely central for the current understanding of innovation processes" (Edquist 1997: 24-26).

2.2.2 The Three Main Systems of Innovation Approaches

1) National Systems of Innovation

In the 1980s, the idea of National Systems of Innovation was developed and is largely pioneered by three authors: Freeman (1987), Lundvall (1992) and Nelson (1993). "The concept brought a new style to innovation and its governance and stimulation as comparing with the more neoclassical, market failure approaches" (Soete, Verspagen, and Ter Weel, 2010).

Lundvall (1992) laid emphasis on "the role of interaction for the production and the propagation of new and valuable knowledge, changing from a sectoral view towards a far-reaching view of the national institutional environment". He outlines three major building blocks of an NSI that emphasise the role of the nation state. The first one deals with the sources of innovation and the actions of agents which lead to innovation, such as exploration and learning. The second building block differentiates between two types of innovation, namely incremental and radical innovation. Lastly, the third building block is formed by nonmarket institutions. For these, Lundvall make a distinction between user-producer collaboration as an important form of knowledge exchange and institutions and their improbability reduction function. These institutions act as a key participant in the NSI concept (including all other SI frameworks).

The NSI approach has been widely accepted among policy-makers as it provides a more wide-ranging outlook delivering more opportunities for input than in case of the traditional market failure approach, which seeks rectification through policy involvement. Consequently, the NSI approaches have been used nationally, for example in Finland and Sweden, as well as at supra-national level, such as at the OECD (OECD, 1997, 1999).

Implementing an overall vision of innovation instead of concentrating on secluded parts of the process, the NSI approach put emphasis on the interaction of actors involved in innovation and analyses how these interactions are moulded by social, institutional and political factors (Fagerberg and Verspagen, 2009). The approach is now being used in academia and policy perspectives as it had achieved a remarkable success in a short period of time (Teixeira, 2013). It is mostly used as an analytical framework (Sun and Liu, 2010) for reviewing the differences between countries regarding their innovation systems and production (Álvarez and Marín, 2010).

2) Regional Systems of Innovation

The NSI approach adopts uniformity within countries, but this is not essentially the case. On several indicators (e.g. poverty, R&D investment, and economic performance) parts within countries can differ considerably. Consequently, a regionally based approach of innovation system thinking was needed which have been developed by researchers and scholars of innovation systems. The 'Regions' generally denotes to a "geographical area inside a country". Hence, the Regional Systems of Innovation (RSI) concept has a research focus based on the relationship between technology, innovation and industrial location"(D'Allura, Galvagno, and Mocciaro Li Destri, 2012). According to Asheim and Gertler, (2005) "spatial concentration remains important for innovative activities, despite the argument that modern information and communication technologies would render spatial distances between communication partners unimportant". The leading example for a region with great innovative capacity usually referred to Silicon Valley.

The highpoint of RSI approach is the regional dimension of the production and the deployment of new knowledge, in this manner helping to clarify regional differences in economic power and innovation capability.

As stated by Doloreux and Parto (2005), “RSI research focuses mainly on the interactions among actors and the role of institutions supporting knowledge exchange and innovation within a region”. To develop typologies of RSI the institutional set-up has been widely used, through which several types can be found (Tödtling, Lengauer, and Höglinger, 2011). Cooke (2004) has suggested “one of the most prominent typologies of RSI by differentiating three types of RSI based on the prevailing type of governance in the system”.

According to Schrempf et. al. (2013) an important input of “the RSI concept to the innovation system discussions is the notion that there is no single one-size-fits-all policy”. They think that policy instruments should always be specific to the context and essentially amended to the regional circumstances. They also emphasised that policies at the regional level may focus the regional structure at several points, for example they may affect all actors of a region or just firms or even an individual.

3) Sectoral / Technological Innovation Systems

The sectoral along with the technological innovation system approaches assume a certain technology (across numerous sectors) or the sector in which it is used (including various technologies) as their system periphery. The notion brought out by Dick Pavitt (1984) that particular sectors have different technological trajectories. It was first developed by Pavitt that there are taxonomy according to the sources of technology, the requirements of users and the appropriate regime. These are as follows:

1. Supplier-dominated sectors – mostly traditional manufactures such as textiles and agriculture, which depends on external sources for innovation

2. Scale-intensive large firms producing basic material and consumer durables such as autos, white goods; sources of innovation are both internal and external to the firm

3. Specialised suppliers – producing technology to be sold to other firms

4. Science-based 'high tech' goods which rely on in-house and publicly funded research eg. Pharmaceuticals

Malerba (2002) further developed the concept of sectoral innovation systems while the development of the technological approach can be drawn back to Carlsson and Stankiewicz (1991). Comparing with the NSI and the RSI approaches both the concepts are more inadequately developed and have a lesser overall impact. In both approaches relations between firms and other organisations are represented as taking place as a result of the technological interdependence of their knowledge (Chang and Chen, 2004).

The concept of SSI given by Malerba (2003) comprises three building blocks, which are the knowledge and technological domain, the institutions, and the actors and networks.

Alike all SI approaches, "institutions have a greater role in the SSI concept and form the interactions and actions of agents in the system and provide a directed activities of agents in a particular direction" (Coenen and Díaz López, 2010). Nevertheless, the sectors are affected differently by the national institutions. The code of practice (regulation) for instance patenting rules and property rights may support one sector (e.g. the pharmaceutical industry) and impede another (e.g. the food industry). The effects are different among different countries.

There are certain factors that are susceptible for sectoral systems to change which may be caused by the technology and learning system in the sector, and by the characters of innovation. A transformation occurred in the knowledge base lead to partnership within the sector if a new design becomes prevailing and established, or may cause major alterations in the industrial setting if new proficiencies are required.

Within the SSI approach, lastly an important policy aspect to consider is the role that policy can play in times of fundamental change in a sector. An active role played by the government in supporting the change by performing, for instance, as a chief consumer of the new technology. According to Schrempf et al., (2013) in this situation, “it may help to overcome sectoral inertia caused by reactive rather than active responses to technological changes”.

The above discussed frameworks do not emphasise on the sustainable development and innovation that is directed towards environmental benefits and its sustenance. With this perspective, sustainable development and eco-innovation are greatly anticipated in today’s industry practices and policy. In recent years, these conceptions have become popular with business leaders and policy makers and they inspire business resolutions and entrepreneurial ideas for confronting environmental challenges (OECD 2009). As the present study is based on environmental decontamination, it requires an innovative strategy to resolve the issue. So, eco-innovation has been discussed in detail in the following section.

2.3 Eco-innovation: an integrated framework

Undoubtedly, the increasing demands because of population explosion lean towards lessening availability of natural resources are worsening environmental settings. This has become a big challenge to sustained prosperity and economic growth. This stressful change has further exposed the need for a re-evaluation of the traditional economic models that are mostly based on increasing consumption (Technopolis report, 2012).

The previous policies were more onto the revival of industrial activity, job markets and competitiveness, today there are simultaneous approaches taking place in order to confront “global environmental challenges” such as climate change and natural resources inadequacy (OECD, 2012). To promote economic activity, countries are prominently seeking more innovative ways. According to OECD Green Growth Strategy (OECD, 2011) “green growth policies should motivate innovation, as this can enhance efficiency in the use of natural capital and foster new economic opportunities from the emergence of new green activities.” The rapid and expansive diffusion of “eco-innovation” can have a substantial leveraging effect on environmental, along with economic and social improvement, by facilitating collaborations among the countries worldwide (OECD, 2012).

Rennings (1999), had defined eco-innovations with “measures of relevant actors (firms, politicians, unions, associations, private households) which develop new ideas, behaviour, products and processes, apply or introduce them and which contribute to a reduction of environmental burdens or to ecologically specified sustainability targets.”

United Nations Environment Programme (UNEP)[1] gives its operationalized definition that eco-innovation “works through a new business strategy that incorporates sustainability throughout all business operations, based on life cycle thinking and involves partners across the value chain. By implementing a set of coordinated modifications to products (goods / services), processes, market approaches and organizational structures, eco-innovation enables the creation of novel solutions leading to enhanced sustainability performance and competitiveness”.

The above definitions give the unified meaning to eco-innovation. It is in the sense that it is a much needed framework these days. “These days the acquisition of environmental policy area has become much greater and gained more vital place than earlier, this has influenced policy orientation to put major effects on the global economy” (Andersen & Foxon, 2009).

2.3.1 Forms of Eco-innovation

In the terminology of Norgaard, different kinds of innovation “co-evolve”. As said by Freeman (1992) (p. 124): “Successful action depends on a combination of advances in scientific understanding, appropriate political programs, social reforms and other institutional changes, as well as on the scale and direction of new investment. Organizational and social innovations

[1] http://www.unep.org/ecoinnovationproject/ <D.O.A. 25.05.16

would always have to accompany any technical innovations and some would have to come first."

Rennings (1998) suggested that "eco-innovations can be developed by firms or non-profit organizations, they can be traded on markets or not, their nature can be technological, organizational, social or institutional". It has been distinctively discussed in the following:

1. Technological and Organizational Eco-Innovation

Technological eco-innovations can be understood as restorative and anticipatory technologies. Restorative technologies mend damages (e.g. contaminated soils) whereas preventive or anticipatory technologies attempt to avoid them. Anticipatory technologies consist of additive and integrated technologies. Additive or end-of-pipe technologies consist of methods such as dumping procedures and recycling technologies happening after the definite manufacture and consumption process. Organizational changes are basically the modification in the management instruments, for instance, at the firm level like eco-audits. Eco-innovations is seen relevant especially in the service sector when the substitution of material products to less-material intensive services takes place (e.g. demand side management in energy and transport, waste management) which are certainly of increasing importance for innovation (Rennings,1998).

The present study has demarcated some of the distinct features of organizational eco-innovation. As govt. sector is outsourcing the technologies from private companies it is indicative of Public-Private Partnership (PPP) which further gives a space to organizational innovation. This has been well-explained in the analysis of the data (Chapter 6).

2. Social Eco-Innovation

As given by Scherhorn et al., (1997) "When there are changes of life-styles and consumer behaviour observed it is generally defined as social innovations". Any innovation, whether technological, organizational or institutional in its nature, if it is successful it has to weave into peoples' values and life styles. “These social innovations may go along with better technologies, services and infrastructure” (Rennings, 1998).

An environmentally sound and sustainable advancement coming through innovations is highly accepted by the people. In the present study, it could be clearly understood that if situation of Yamuna River gets improved and better with time, contemplated by any form of innovation, would anyways be a beneficial option.

3. Institutional Eco-Innovation

We understand innovation progress simply as innovation in firms, strongly focussing on technological advancement. Since most of the issues related to sustainable exploitation of natural resources as well as land are not mainly technological questions, this points to a “technology bias”. Natural resources can mostly be characterised as “open access regimes”, and unjustifiable usage curtails from unsuitable organized provisions. As stated by Freeman (1992, p. 191), these institutional or organizational measures should be supplemented by a realignment of the world R&D system so that these environmental objectives were given a high priority in the work of industrial, university and government laboratories. This reorientation would be needed to assure the rate and direction of technical change necessary to achieve the first objective (sustainable development) (Rennings, 1998).

2.3.2 Approaches to Eco-Innovation

Having defined and discussed the forms of eco-innovation broadly, the question arises that how one should analyze eco-innovation and what ecological economics can contribute to research. The section is mainly to discuss the most appropriate approaches for innovation research, neoclassical and evolutionary concepts and their likely contribution to eco-innovation research.

The use of neoclassical methods mainly means that methodological independence can be applied to evolutionary approaches and could also be incorporated in it. Though, the difference is worthwhile for analytic reasons because just about all studies follow a single approach and vary generally from the other by using different sets of assumptions. Perhaps, with the support of interdisciplinary research ecological economics can create an added value. In line with Rennings (1999) “Methodological heterogeneity as it is established in ecological economics would be very valuable for eco-innovation research because co-operation between the different disciplines (innovation and environmental sciences) and schools (neoclassical vs. evolutionary concepts) is still rather poor.”

1) Neo-classical approach

Eco-innovation in neoclassical economics has placed the matter of eco-innovation at the fringe in the middle of two different economic sub disciplines, ‘environmental economics’ and ‘innovation economics’. It would be very helpful to adequately analyse, with interdisciplinary research approach of both disciplines. Environmental economics conveys “how to assess environmental policy instruments”, whereas innovation economics gives “insights about the complexity of factors influencing innovation decisions.” The role of state regulation to stimulate innovation is important to take this integrated approach further. Yet, these types of integrated approaches have been rarely found in the literatures.

The role of environmental economics is crucial as the “superiority of market-based instruments like taxes and tradable permits has been the basic lesson in it concerning innovation for a long time” (Rennings, 1999). These instruments have been recognized as environmental policy mechanisms with high innovation efficiency providing cost-efficient emissions reductions. On the other hand, regulatory regimes driven by official criteria (either in a command-and-control system or in a regime of voluntary agreements in which standards are negotiated between government and industry) are not cost-effective and the motivations for improvement in emission reduction disappear after the standards are met.

According to Cleff and Rennings (1999) “environmental product innovation is significantly driven by the strategic market behaviour of firms (market pull effect), while environmental process innovation is more driven by regulation (regulatory push/pull effect).”

The innovation processes involving long-term radical changes, however may be too narrow in neoclassical models assuming marginal changes and equilibrium situations. To improve our understanding of radical system changes broader concepts of evolutionary approaches have been emerged. It has been elaborated further in the evolutionary approach.

2) (co-)evolutionary approach

With deterministic nature of neoclassical models it has certain merits, especially for analysing incremental or marginal changes encouraged by varieties of incentives, they exhibit little importance to analyse the radical changes of technological systems as well as the societal and organizational context. According to Freeman (1992) (pp. 77–81), "incremental innovations can be characterized as continuous improvements of existing technological systems (i.e. they fit in existing input–output tables) while radical innovations are discontinuous (i.e. they require new lines and columns in input–output tables)." Evolutionary approaches emerged to uncover the 'black box' of revelations being associated with "radical changes: unpredictable interactions of sub-systems, irreversibility, path-dependency, lock-in effects of technological trajectories or bifurcation" (Rennings, 1998). It could be inferred the evolutionary approaches are highly engrossed in the analysis of transition and learning processes than in equilibrium states and assume bounded rationality and rules of thumb rather than optimization. Co-evolutionary framework appears to be applicable to analysing eco-innovations for these two reasons: "It includes all sub-systems, i.e. co-evolving social, ecological and institutional systems avoiding any ranking of their importance, and it underscores the importance of their interactions" (Rennings, 2000).

It could be concluded that both neoclassical and (co-)evolutionary approaches have their advantages and disadvantages relating to eco-innovation theory and policy. The evolutionary approach is comprehensive and practically viable for innovation process that avoids generality. It is beneficial while understanding stochastic phenomenon, which are common particularly in case of radical innovation. Therefore, “evolutionary approaches are appropriate as far as long-term, radical changes including path-dependencies, irreversibility, transition processes, discontinuous and unpredictable events are concerned” (Rennings, 2000).

Though, the theoretical and empirical work on eco-innovation is still evolving as very few literatures have been found. So, theoretical approaches and methods are highly needed in addition to data.

2.3.3 Determinants of Eco-Innovation

After understanding the approaches to eco-innovation, it is significant to know the driving forces of eco-innovation by identifying its determinants. There are four aspects that have been originated to be the key determining factor of eco-innovation given by Horbach, Rammer and Rennings (2012):

1) Regulation- it has been recognized as an important determinant of eco innovation in various experimental studies (e.g. early studies from Brunnermeier and Cohen, 2003; Cleff and Rennings, 1999; Green et al., 1994; Rennings and Zwick, 2002) and is known as the “regulatory push/pull effect” (Rennings, 2000, recent overview in del Rio Gonzalez, 2009) Del Rio Gonzalez (2005) identified “regulation pressure and corporate image as the main drivers of adopting cleaner technology in a survey in the Spanish pulp and paper industry.” Frondel et al. (2007) find that “policy stringency is generally an increasingly important driving force for eco-innovation rather than the choice of single policy instruments”. A related outcome was found by Arimura et al. (2007) for “the effect of regulation on green R&D.” This might be assumed that environmental R&D tends to be higher in the facilities fronting very rigorous environmental regulation. Frondel et al. (2007) draw attention to different environmental technology fields where impact of regulation may vary. A robust policy is highly needed to incur environmental benefits giving it a value in the marketplace through regulations/commands in the form of taxes and tradable emission rights. Government as an actor can systematically provide a means for its

expansion and “eco-innovation is also supported by innovation policy, industrial policy and sectoral policies” (Kemp and Oltra, 2011).

2) Market pull- Kammerer (2009) contributes to the conversation of “market pull factors” as determining factor of eco-innovations by “introducing the concept of customer benefits, which is well known in marketing literature.” Although regulation has an important role in controlling the environmental threats and also to overcome the double externality problem, studies have shown that there is no incentive in considering eco-innovation from the demand side as eco-friendly products are far expensive (Rehfeld et al., 2007). In the finding of Kammerer (2009) study, it has been observed that the customer benefits significantly impacts eco-innovation the moment product brings additional value to the customer.

3) Technology Push and Firm Specific Factors -Environmental Management Systems (EMS) can be understood as environmental organizational innovations (see Rennings et al., 2006). Khanna et al. (2009), Rehfeld et al. (2007), Rennings et al. (2006), and Wagner (2008) have shown and emphasised on the prominence of environmental management systems for ecoprocess and eco-product innovations. They have suggested that organizational innovations are also important triggering product and process innovations. For that reason, and support of other literatures it gives the impression of its importance to including indicators for the usual organizational structure of a firm including organizational innovations after empirically clarifying eco-innovation activities. However, certain areas of environmental impact demands different types of policy intervention or market expectations such as energy and material use; pollution of air, water, or soil; recycling or climate policies; or abatement technologies reducing noise or toxic substances may be affected in a different way.

2.3.4 Challenges to Eco-innovation

The above discussion elaborates an integrated policy framework, including policy features and specific measures that can be applied to reduce the obstacles to eco-innovations. It has been drawn from the literatures that elements constraining the progress and acceptance of eco-innovations are complicated and curtail from diverse sources. As per the systems view, which highpoints the multidimensional notion of the difficulties to eco-innovation, appeals for a grouping of environmental and technology policies amended to the different hurdles and features of the technologies.

Due its narrow focus on just the environmental technology it rises a demand for its an expanded notion. "Eco-innovation is thus seen as an overarching concept which provides direction and vision for pursuing the overall societal changes needed to achieve sustainable development and eco-innovation as 'a new field of techno-social innovations that focuses less on products' functions' and more on the environment and people"(OECD, 2009).

Hence, the need to date is bearing in mind the possible significant impact of policies on business models, the strategy of public policies assisting eco-innovation would search how to take account of new business models along with leveraging new representations.

2.4 Bioremediation- an Evolving Technology

2.4.1 A Brief History[2]

The Romans in 600 BC have first discovered Bioremediation. Even though their natures of the practice aren't as developed as todays, they still used it skilfully. The use of bioremediation was mainly to clean the water. Much earlier, George Robinson, in the 1960's, had officially invented bio-remediation. He did experiments with polluted glass jars that contained microbes. Rigorous research work took place on these microbes to increase their abilities. Until 1972 these microbes were placed to the experiment in the real world situation. Scientists have attempted and clean out fuel tanks on the RMS Queen Mary. Fortunately, the attempt was effective and from the time when 1972, humans have been using and refining these microbes. The researchers are getting highly focused to make these microorganisms

[2] http://bioremediation2.weebly.com/history.html

potent and efficient, besides using them to help clean oil spills and other contamination situations.

2.4.1.1 Approaches to Bioremediation

Due to high contamination in air, water and soil there is a need to promote innovation in pollution abatement technologies, to protect the environment from existing pollutants. “After various international environmental agreements, governments of different countries have focused on green product and process innovations to minimize environmental risk, but there has been little interest in developing eco-friendly technologies for removing the environmental pollutants” (Saraswat, 2014).

The natural system for waste water treatment have been existing in nature as swamps, bogs, marshes the stimulation of which can be built and used for treatment of waste water. One such method of treating the sewage and making its quality better for its use in various fields is through microbial treatment i.e. inoculation of bacterial strains into the raw sewage and improving the quality of sewage water. The sewage or waste water may harbour many pathogenic organisms and the immediate and greater risk to health might arise due to microbial contaminations of water which invariable result from faecal contamination (Straub et al., 1993).

In view of this, a technological development to clean up the polluted sites either aquatic or terrestrial, in an effective, sustainable way without producing secondary wastes, bioremediation has increased its prominence. It encompasses naturally occurring organisms to neutralize or break down organic and inorganic pollutants into nontoxic or non-hazardous forms. There are certain bioremediation related technologies such as rhizofilteration, phytoremediation, biostimulation, bioaugmentation, bioreactor, composting, and landfarming. In the process of bioremediation, phytoremediation involves metal accruing plants for eliminating toxic wastes through adsorption, absorption, and abstraction of contaminants from soil and water (De et al. 1995, 1998). This simply marks its significance on its wider application to contaminated sites by attaining eco-innovative bioremediation technology.

Vidali (2001), in his paper suggested that "bioremediation is an option that offers the possibility to destroy or render harmless various contaminants using natural biological activity." The paper emphasised on the use of bioremediation due to its, low-technology techniques and relatively low-cost, which is preferred by public and give it a high acceptance and can be applied on site. On the other hand, the paper discussed the limitations it bears with it. As the range of contaminants on which it is effective is limited, it will not always be suitable, the time scales involved are relatively long, and the residual contaminant levels achievable may not always be appropriate. He also suggested that even though the methodologies employed are technically simple, substantial experience and know-how may be requisite to design and implement an effective bioremediation program, due to "the need to thoroughly assess a site for suitability and to optimize conditions to achieve a satisfactory result.

Now, it is important to understand the process of bioremediation before taking into account advancement of the technology these days. Bioremediation is the use of biological interventions of biodiversity for mitigation (and wherever possible, complete elimination) of the noxious effects caused by environmental pollutants in a given site. It functions with the principles of biogeochemical Cycling. There are two ways to conduct the process, one is in-situ bioremediation, where the process occurs in the same place affected by pollution. In second, i.e. ex-situ bioremediation deliberate relocation of the contaminated material (soil and water) to a different place takes place to accelerate bio catalysis. "Bioremediation has been successfully applied for clean-up of soil, surface water, groundwater, sediments and ecosystem restoration" (Prasad, 2015).

According to Ma et al (2011) and Schroeder and Schwitzguebel (2004) "bioremediation is generally considered to include natural attenuation (little or no human action), bio-stimulation or bio-augmentation, the deliberate addition of natural or engineered micro-organisms to accelerate the desired catalytic capabilities". Therefore bioremediation, with phytoremediation and rhizoremediation contribute considerably to the removal of hazardous waste and utilized further to eliminate unwanted matter from the environment.

2.4.2 Advancement and Potentials of Bioremediation

Hine and Kapeleris (2006) gave a brief discussion on the evolution of biotechnology from where bioremediation co-existed. According to the book, "in the1950s and 1960s, the biotechnology industry was restricted to relatively established activities in the food and beverage, primary and secondary metabolite fermentations, and waste treatment industries". The paper further elaborated on the expansion in the basic science underpinning modern biotechnology occurred; newer developments in microbial genetics, enzyme and cellular technologies, and bioremediation drove the development of the science in the industry. With the on-going development of recombinant DNA techniques, opportunities in both the science and the commercialization of the scientific research blossomed.

"Biotechnology and systems biology approaches are also implicated in bioremediation and are gaining considerable importance in fostering bioremediation" (De Lorenzo, 2008; Van Aken, 2009). It is strongly believed that there are three dimensions for the effectiveness of vital bioremediation process, i.e., chemical landscape (nutrients-to-be, electron donors/ acceptors and stressors), abiotic landscape and catabolic landscape of which only the catabolic landscape is ‘‘genuinely’’ biological. The chemical landscape has a dynamic interplay with the biological interventions on the abiotic background of the site at stake. This includes humidity, conductivity, temperature, matrix conditions, redox status, etc. (De Lorenzo, 2008).

Bioremediation has been prominently used worldwide these days, including Europe, with variable outputs. Undoubtedly, the improvement is seen as better understanding and knowledge are grown, and indeed bioremediation is proving it's prospective for dealing with certain types of contamination on site.

In the study conducted by Buvaneswari et al. (2013), it was found that the fungal isolate with higher bioremediation potential, out of the three species isolated from the sugar mill effluent the percentage of reduction potential produced in different parameters were compared. It was understood that there was a higher reduction percentage of EC, TDS, BOD and COD when the sugar mill effluent was inoculated with Aspergillus niger fungal species when compared to other fungal species and hence Aspergillus niger was proved to possess higher bioremediation potential.

M.N.V. Prasad edited a book, ‘Bioremediation and Bioeconomy’, which has considerably given the amazing ways how bioremediation could be used to encourage economy out of it along with the environmental cleaning. It has the ambition to address the research gap at the interface between pollution mitigation and boosting the bio-based economy aiming at sustainable development. There is pressing need for pollution abatement and there is an even more pressing need to create viable value chains from contaminated substrates especially in developing economies.

Ministry of Environment and Forest (MoEF), GOI, came out with a report of “Guidelines For Support To Environmental Research” in July 2012. This report aimed at guidelines to enunciate the vision and mission of environmental research supported by the Ministry, thereby providing direction and purpose to research activities. The identified broad thematic areas aimed at focusing the efforts in environmental research. Special attention has been given to pollution amelioration, biodiversity conservation, ecosystem studies, bioremediation, ecological restoration of degraded ecosystems, development of cutting-edge technologies, socio-economic issues relating to the environment, etc. Through these Guidelines, a mechanism has been put in place for the wider dissemination of research findings and the scaling up of those outcomes and innovations, which are generated through research projects and are of societal relevance. It has in one of its objectives stated about bioremediation of contaminated sites and water, which is quite encouraging in directing further towards programmes under the R&D Scheme in Environmental Research Programme (EnvRP).

“Convincing evidences are forthcoming highlighting its potential for addressing contemporary environmental agenda, with synergies that involve the product development from plants used for bioremediation and integrating them with ecosystem service providers" (Dickinson et al 2009).

Though having discussed and known about its effectiveness on decontaminating the polluted sites, there are certain contestations that are needed to explore and investigate more on this part of the technology. Some have been mentioned in the subsequent section.

2.4.3 Challenges

The control and optimization of bioremediation processes is a complex system of many factors. These factors include: "the existence of a microbial population capable of degrading the pollutants; the availability of contaminants to the microbial population; the environment factors (type of soil, temperature, pH, the presence of oxygen or other electron acceptors, and nutrients)".[3]

Some limitations[4] have been mentioned in the following:

1) Bioremediation is mainly applicable for biodegradable compounds. It is not necessary that all compounds are disposed to rapid and complete degradation.

2) Concerns regarding products of biodegradation may be more persistent or toxic than the parent compound. Biological processes are often highly specific. "Important site factors required for success include the presence of metabolically capable microbial populations, suitable environmental growth conditions, and appropriate levels of nutrients and contaminants".

3) To deduce from bench and pilot-scale studies to full-scale field operations is a challenging part.

4) "Research is needed to develop and engineer bioremediation technologies that are appropriate for sites with complex mixtures of contaminants that are

[3] http://www.moef.gov.in/assets/re_guidelines_f_indd.pdf
[4] Bioremeadiation Of Oily Sludge- A Review. (n.d.). Retrieved from http://ijaresm.net/Pepar/VOLUME_1/ISSUE_5/17.pdf

not evenly dispersed in the environment". Pollutants may be found as solids, liquids, and gases.

5) "Bioremediation often takes longer than other treatment options, such as excavation and removal of soil or incineration".

6) "Regulatory uncertainty remains regarding acceptable performance criteria for bioremediation".

As bioremediation techniques are still emerging technologies, the social, economic, policy, and business implications are not well known. It is clear that these technologies have significant effects on societies, and that the social, economic, policy, and business dimensions of society affect the development and use of bioremediation techniques.

2.4.4 Bioremediation Innovation System

Earlier, it was considered that environmental issues cause a liability into business, as somewhat related with costs and restrictions which assumed to impair companies' competitiveness. In the paper by Andresen, (2004) it revealed that "The first 20 years after the rise of the environmental agenda, i.e. during the 1970s and 1980s, companies had purely reactive strategies to environmental issues, for some companies even obstructive strategies and by the 1990s the environmental agenda was well consolidated in the richer economies and the beginning emergence of proactive environmental strategies was seen". It depicts that that "green competitiveness goes beyond consumerism". Also, "a range of surveys point to the broad range of incentives companies experience in relationship to their environmental, social and broader ethical work, a factor that is little recognized by policy makers so far" (Erhvervsministeriet, 2000, Rutten, 2001, Kemp, Andersen and Butter, 2004).

This study would be an attempt to investigate the potential of the bioremediation innovation system for aligning innovation and sustainability issues in building strategies for green competitiveness. It needs to be placed in the Indian Scenario more firmly and strategically. But, constructing these strategies are highly subjected to creating greater synergies between environmental and innovation policies and that is no easy venture. It requires rethinking into certain aspects on "policy regimes, economic and other social theories besides wider societal understandings", if we explicitly look upon this.

Nowadays, "environmental activities are increasingly seen as a potential source of competitive advantage, they offer an element of quality, a source of savings, and part of the social contract with society necessary for the continuity of the company" (Rutten, 2001). In order to solve the problems related to environment, the role of companies are central as they have an important part to play because they are the ones converting inventions into value creation on the market as well as creating knowledge.

The point that is of our concern in this study is that how Bioremediation Innovation System propels itself in the existing scenario of Indian Research and Development projects. From the points discussed above it has been found that there is a neglect or gap between environmental policies and innovation policies formulation.

2.4.5 Implementing the framework of Eco-Innovation

This work is an attempt in taking on the implication of the linkages or interactions among the institutions and concerned people involved in development of the technology (Bioremediation) in inferring the efforts and yields on a bigger issue of Yamuna Cleaning which marks its importance presently.

In a very general term, innovation is meant to link with progressive strategy, but in this research the adopted framework would be seen with the purpose of reactive approach for its novel application. There are many ways on how to build upon these approaches, but when it comes to the case of Eco-innovation, it makes its dimension and dynamics to get altered in a very diverse fashion. "There are certain differences in rationales and instruments underlying both environmental and innovation policies" (Andresen, 2004).

When we approach into the discussion of these differences, arguably there is a kind of discord between environmental policies which aims at "addressing reactive behaviour and innovation policies aims at addressing proactive behaviour which hampers the development of a socially responsible market economy". Therefore, it is necessary to recognize the "differences in rationale between the different policy areas" in order to promote the integration of the two (Andersen,2004).

"Like any innovator, an eco-innovator must deal with changeovers. The adjustments depend on the state of technology and contextual factors such as prices and infrastructure and these adjustments are conducive to various technological compromises which shape the technological trajectories of firms" (Oltra and Saint Jean, 2005). It could be inferred that this is significant where product innovation's diffusion depends on the consumer benefits. It is highly recommended for facilitation of diffusion, to expand the combination of eco-innovation with environmental performances to get an optimum output. This could be equally applied for the production of cleaning methods or technologies such as bioremediation: processes and methods that combine resource efficiency benefits with environmental benefits can diffuse more quickly and widely because of these double benefits.

It can be supported with the approach that says innovation policy can help to cut the costs of technological, institutional and social innovation especially in the phases of invention and market introduction, e.g. by financial support for pilot projects. And in the diffusion phase it may help to improve the performance characteristics of eco innovations. At least "in the diffusion phase, however, coordinated action between environmental and innovation policy seems to be necessary to achieve significant ecological impacts" (Rennings, 1998).

It would be interesting in this manner to approach with systemic fashion to relate the Bioremediation technology which is the subject for environmental policy regime with the innovation policy regime. It is the need of an hour to come up with the steps and ideas that could be directly used in the concern of rising pollution. Due to the contamination of atmosphere, our basic essentials are on the stake, mainly the drinking water and air to breathe.

CHAPTER 3

ANALYTICAL FRAMEWORK OF THE STUDY

3.1 Overview

Several theories have been discussed in the literature review about innovation. In order to conduct the study a framework has been derived from the review of literature i.e. eco-innovation, which would support a well-directed procedure to cover the overall picture of the research.

The study is exploratory in nature, based on both qualitative and quantitative data. This chapter will provide a comprehensive description of the field work and the use of methods and its methodology. However, there are two main objectives of the field work concerned with particular context of this research:

1) The first objective was to have a deeper understanding of the problems created in Yamuna River due to untreated waste water, industrial effluents and failure of Sewage Treatment Plants (STPs) and what solutions being made at present and policy related aspects.
2) The second objective was to understand the mechanisms responsible for bioremediation and the policy study explained for possible implementation on a variety of contaminated and polluted sites in Yamuna River. Also, how new methodological breakthroughs enhance the potential of this technology.

This chapter has four sections including the overview. Section 2 discusses how eco-innovation is being applicable as a theoretical framework in congruent with Systems of Innovation (mainly NIS). Section 3 describes how information was gathered in order to identify the actors that are actively involved in research of the subject area. Section 4 gives an insight how the field work was being implemented.

3.2. Eco-innovation in Congruent with Systems of Innovation (mainly NIS)

In the general understanding of framework of Systems of Innovation (SI), innovation is basically used to bring a value addition or as in incremental forms. But it is interesting to note here that innovation system is used to prevent or reduce something. It is in the sense that innovation perspective has been sought to find how the pollution is being reduced in given study area i.e. Yamuna River in Delhi.

Innovation which is directed towards environmental and sustainable pathways inter-mingled with Systems of Innovation gives a unique conjugating effect, could be called as Eco-Innovation. The idea that comes into this study revealing various dimensions of this approach is sparingly mixed into our present policy regime. Yet there have been several attempts being made to understand where the gap lies and how to resolve the issues revolving around it.

The study has been conducted with a systemic approach which is more or less enriched by the collaborations among actors to bring experienced insights to the situations and problems related to the field of study. It also tried to analyse environmentally sustainable innovation, or eco-innovation for short, from the perspective of existing theories of innovation, so as to establish the prevailing arrangements of such innovations and present flaws, along with productive ways in its advancement.

"Eco-innovation provides a gainful solution to improving economic competitiveness and sustainability as it starts at the company strategy level and extends influence beyond the company doors to the supply chain. It aims at reducing impacts on the environment, enhancing resilience to environmental pressures, or achieving a more efficient and responsible use of natural resources. The growing market, reputational and regulatory pressures in response to rising resource scarcity and environmental degradation strengthen the commercial case for eco-innovation"[1].

Drawing on evolutionary[2] perspective of eco-innovation, the study tries to shed light on "the appropriate combinations of conditions and instruments that are most effective to encourage eco-innovation, considering different

[1] http://www.unep.org/resourceefficiency/Business/Eco-Innovation/tabid/78761/< D.O.A: 25.05.16
[2] It has been discussed in the literature review (Chapter 2).

barriers and eco-innovation types (process/product, mature/immature, and radical/incremental)".

3.2.1 Eco-Innovation as the Framework

Based on the understanding developed through the review of literature, the study tries to intricate more on the regulation, process and organizational structures taking it as key parameters to shoulder the study further. It is required to clarify how innovation is understood in bioremediation innovation system drawing on these factors.

Firstly, the role of regulation i.e. command and control of the Environmental Management System (EMS) was studied, which was required to find out the current policies and anticipated policies for the abatement of pollution in water bodies in general and the given study area in particular. This was acquired through various modes which have been discussed later in the chapter.

Secondly, the emphasis was laid on the process of the technology, whether it has been advanced or evolving with time. The contemporary biotechnological proficiencies are working progressively in enhancing the potential of this technology. This was found through interviews and secondary data, discussed further in the chapter.

Thirdly, the understanding of organizational structures was crucial to study the innovations being carried out through changes of new infrastructure and system. This was found out by the discussions and interviews of the resource persons.

3.3 Research Methods

3.3.1 Case Study as a Research Method

In social sciences, there are several ways of doing the research and case study is one of the ways among surveys, experiments, histories and analysis of archival information. "Each method has its own significance, advantages and disadvantages depending on the type of research question, control on actual behavioural events and focus on contemporary vs. historical phenomena" (Yin,1984).

For an exploratory research, case study provides a suitable and imperative tool as it makes use of varieties of evidence from different sources such as documents, interviews, artifacts, and observations. It works well with the real situations and issues pertaining to research field.

3.3.2 Data Collection

The collection of data took place by both the sources i.e. primary data and secondary data. The primary data source included certain observations, discussions and interviews of the resource persons and concerned authorities which are elucidated in the course of field work (later section). Also, Interviews were conducted to know the challenges and situation faced by people residing nearby due to river pollution and scarcity of clean potable water.

For the secondary data information was gathered in order to identify the actors/experts/institutions that are actively involved in research of the subject area which was procured through journals, articles, library sources and books. The secondary data helped in arriving at a convenient framework for the study.

3.3.2.1 Questionnaires

The questionnaires were formulated keeping in mind the research objectives and research questions. It was mainly semi-structured and open-ended questionnaire prepared differently for diverse respondents. These patterns of questions gave more scope for resourceful data by providing more space for explanation and discussions.

3.3.2.2 Interviews

The in-depth interviews of the concerned people were prearranged through E-mails and telephonic conversations. Interviews were followed by discussions with some. Then interviews were conducted on the scheduled timings. People residing near the given study area were approached directly and it proceeded more like the conversations.

Based on the above theoretical framework and methodology, certain research questions have been formulated, which are as follow:

1. What could be the factors limiting the diffusion of bioremediation and its R&D?

2. How can scientific innovations be more efficiently exploited to achieve bioremediation?

3. How could bioremediations be employed as a potential and sustainable alternative especially to the case of Yamuna River around Delhi?

4. Why the present environmental policies are not concurring with the innovation policy?

3.3.3 Identification of Actors

In order to answer the research questions, it is required to identify the actors, concerned authorities and stakeholders to enrich the study with realistic approach and ideas. The actors were mostly identified through literatures including journals, articles and research papers that qualify them in formulation of the policies that are being executed today. There are a number of actors, agents and institutions working in this field, they have been pointed in the following:

- Ministry Of Water Resources, River Development and Ganga Rejuvenation
- National Mission For Clean Ganga
- Central Water Commission
- Ministry Of Environment, Forest and Climate Change
- National River Conservation Directorate
- Department Of Irrigation and Flood Control
- Central Pollution Control Board
- Delhi Jal Board
- Delhi Development Authority

- Research Institutes Such As IIT, JNU, Teri University, NEERI etc.
- Private Companies such as JM Environ Pvt Ltd

The respondents included the stakeholders from the above list and the farmers and people who are involved in the activities near the bank of Yamuna River and adjoining floodplains.

3.3.4 Course of Field work

The field work was conducted near the areas of Yamuna River in Delhi mainly the extreme stretches i.e. Wazirabad barrage to Okhla barrage.

Field work was carried out in different phases. Firstly, the visit to Wazirabad barrage and Yamuna floodplains took place. The visit was mainly to have the first-hand experience of the location and the real situations faced by the River as well as people residing in surrounding areas. Observations and interviews were deployed to know the attitudes surrounding actions taken for cleaning or pollution control of Yamuna River and people's perspectives on issues that are faced by them. Near Wazirabad Barrage, there is a Water Works Station run by the Delhi Jal Board (Delhi Government), where second visit was made. An interview was taken from one of the water analyst who is an assistant chief water analyst there. With his help many information got collected about the technology and methods for treatment of polluted water.

The third visit was made to Okhla barrage, which is located at other extreme of Delhi meeting the Agra Canal. The site is heavily polluted worse than Wazirabad region. The water stinks and looks complete black. Interviews were conducted with the people who were working on the barrage. Then the next visit was to the office of Okhla Barrage, where a Junior Engineer in Okhla Barrage was interviewed. He gave information about how they maintain the flow of river water but nothing is being done to treat the poisonous[3] water.

[3] A report by CPCB has shown that Yamuna River has BOD>30mg/l and BOD exceeding 6mg/l on all occasions

Fig. 3.1 Pictures showing condition of Yamuna River at Wazirabad Barrage

Source: Field visit to Wazirabad Barrage

The fourth interview was conducted with a consultancy firm J M Enviro Pvt Ltd, which was required to understand how the role of private sector is being invested into the present regime.

A visit to Ministry Of Water Resources, River Development and Ganga Rejuvenation was made. A government official in Policy and Planning, Ministry of water resources had been interviewed. He explained very well about the policy related aspects handled by the ministry as such.

Fig.3.2 Pictures showing condition of Yamuna River at Okhla Barrage

Source : Field visit to Okhla Barrage

Further, the interviews were conducted in National Mission for Clean Ganga (NMCG) and National River Conservation Directorate (NRCD), where the policy related and technological aspects on cleaning projects of rivers were understood and further information was collected.

One of the faculties from Teri University, working on the research of bioremediation, was interviewed.

Lastly, faculty from School of Environmental Sciences, JNU, who are actively working on the field of biodegradation and bioremediation of the pollutants, was interviewed.

The efforts were made to get more grasp on research related aspects of the study, but due to unavailability and reluctance of the people to be interviewed or to spare some time, it could not happen. Due to paucity of time in MPhil research work, it was difficult to wait further and conduct interviews at the later stage. So the information collected from the above mentioned interviews was analysed in the sixth chapter.

3.3.5 Data management

The data generated from the survey was handled through different methods. Data collected through the interviews and discussions was helpful to answer the research questions of the study on diffusion, exploitation, and policy related aspects of the technology for treatment of the contaminated sites. Data were in the form of notes and voice records.

3.3.6 Transcription

Primary data collected through interviews and discussions, were converted into a detailed transcript through the process of transcription. The voice records of the respondents and participants were converted into a written form of information and data. The narrations were expressed in text form. The transcript obtained was further used in the analysis of the data. The objectives of the study were mainly accomplished by the transcript.

3.4 Implications to the Framework

With equipped by above information, the focus then moves to the mechanisms of policy impact. While the Supreme Court and Green Court[4]judgement unquestionably targeted river pollution and was motivated by evidence of health concerns, the link between the two may be driven by other factors. The relative importance on the ruling may have improved citizen information about both pollution and health, and encouraged them to bring change in their attitude. This is particularly an issue in the Yamuna Basin, where informational campaigns were part of the policy response.

The other dimension is socio-economic conditions which have been discussed in the next chapter. Furthermore, there was significant concern about the economic impacts of regulation on the industrial and agricultural practices that was such a major source of employment near the region.

[4] National Green Tribunal-It is a specialized body equipped with the necessary expertise to handle environmental disputes involving multi-disciplinary issues.

CHAPTER 4

SOCIO-ECONOMIC CHARACTERISTICS OF STUDY AREA

4.1 Overview

After following the adopted framework i.e. eco-innovation as a part of methodology, a well-directed discussion followed and certain observations were made. It was realized during the course of field work that if the pollution caused in the Yamuna River is more or less due to human interventions, mooring the river into a death like situation. Then it would not be unlikely to say that, people are facing a havoc kind of a situation due to its contamination levels shooting up.

Therefore, this chapter tries to examine how pollution in Yamuna River has affected the socioeconomic characteristics of the region in order to understand its state in context to present study. This will try to relate the region's population, households, and employment patterns which help to characterize an area - be it urban, suburban, or rural. The contaminated river (Yamuna) of an area exerts enormous influence on the choice of the residence by the people and their work, population, household, and employment patterns. Henceforth it is relevant to analyse the socio-economic characteristic in order to understand how different social processes and activities affect and shape the economic activity of the study area.

This chapter has been divided into four sections including the overview. Section 2 discusses the different segments of Yamuna River and its distinct purposes in each segment. Section 3, will cover the social aspects of the study area and its various features within the region and illustrates the economic activities prevailing within study area. Lastly, section 4, will lead to the discussion on how socio-economic characteristics affected by or affected the Yamuna River in Delhi.

4.2 Segmentation of Yamuna River

The change in water flow characteristics of Yamuna River from monsoon to non-monsoon seasons is highly considerable. The construction of various barrages and interruption in the flow of water obstructs the constant flow of the river. Therefore, in dry season (almost nine months), the river becomes segmented in four distinguished independent segments which directly effects the use of water significantly and impacts the socio-economic conditions indirectly.

Segment I:

"This segment (length 157 km) is identified from Yamunotri and terminates at Hathnikund / Tajewala barrage. The major source of water in this segment is the melting of glaciers. The water flow in this segment terminates into Western Yamuna canal (WJC) and Eastern Yamuna Canal (EJC) for irrigation and drinking water purposes in command areas" (CPCB, 2006).

Segment II:

"This segment (about 224 km) lies between Hathnikund / Tajewala barrage and Wazirabad barrage. The main source of water in this segment is ground water accrual. Few small tributaries also contribute water in this segment. The water is diverted in this segment from WJC through drain No. 2 to fulfil the raw water demand for drinking water supply in Delhi. The water segment is terminated into Wazirabad reservoir formed due to stagnation of water at Wazirabad barrage. The reservoir water is pumped to the various water works as raw water for treatment to met drinking water demand of the capital city. No or very little water is allowed to flow downstream Wazirabad barrage during lean seasons" (CPCB, 2006).

Segment III:

"This 22 km segment of Yamuna River is located in between Wazirabad barrage and Okhla barrage. This segment receives water from seventeen sewage drains of Delhi and also from WJC and Upper Ganga Canal via Najafgarh drain and Hindon cut canal respectively. Little contribution of water is also made in this segment by Surghat, where Ganga and Yamuna water is provided for bathing purposes. This river segment terminates into Agra Canal, which is used to augment its flow for irrigation in the states of Haryana and Uttar Pradesh" (CPCB,2006).

Segment IV:

"This Segment of Yamuna River is about 973 km long initiate immediately downstream to Okhla barrage and extends upto confluence to Ganga River at Allahabad. The source of water in this segment are ground water accrual, its tributaries like Hindon, Chambal, Sindh, Ken, Betwa etc. and waste water carrying drains of Delhi, Mathura-Vrindavan, Agra and Etawah. The water of this segment is used for drinking and industrial uses at Mathura & Agra. At Mathura, recently Gokul barrage has been constructed to trap the Yamuna river water for drinking purposes. Due to low drinking water demand only part of water is pumped out and rest flows downstream. As the water demand will increase in future. It is likely that no water will be allowed to flow downstream like Wazirabad and Okhla barrage. This may create further segmentation of segment IV into two segments of 154 & 804 km. With the construction of another barrage near Sikandara at Agra the river would be further segmented" (CPCB, 2006).

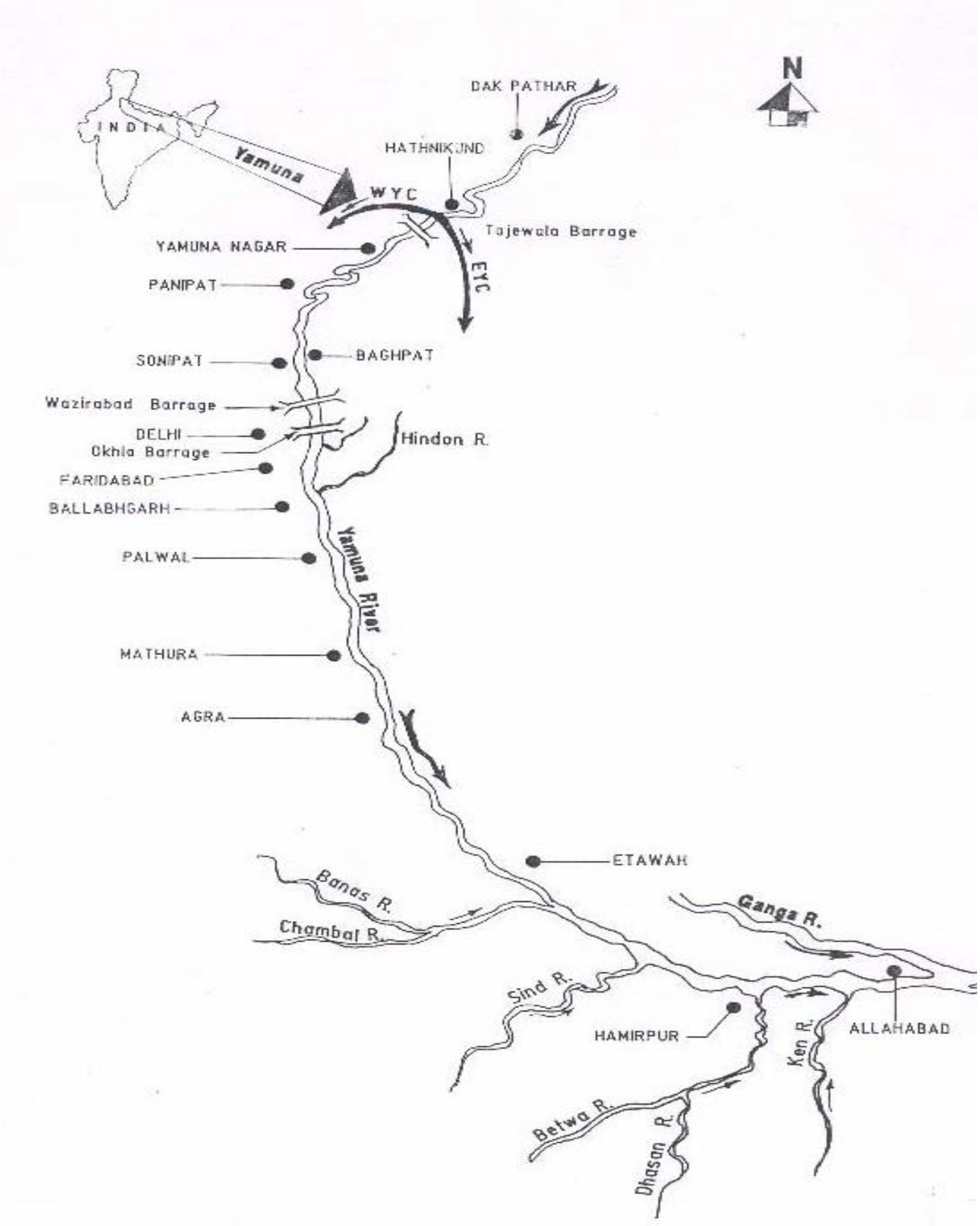
4.3 Socio-economic Characteristics

This section looks at the socio-economic situation of people living in Delhi, which encompasses a significant impact on the Yamuna River basin. There are certain indicative parameters that have been discussed in order to relate it with the study.

1. Demography

Census data represents one of the most important components of the information system and serve as the basis for many other statistical activities related to food, agriculture, education and infrastructure. This is also crucial for agriculture & infrastructural development planning and formulation o

Fig.4.1 Location of Major Cities along Yamuna River



Source: CPCB, 2006

policies. According to baseline report of YAP 2 (2010), Yamuna basin covers 365,868.84 sq km area. Delhi constitutes lowest as 0.40 per cent of the area of Yamuna basin. Total population in the Yamuna basin is 200,383,131 and Delhi shares 11.0 per cent of population on the basin.

Table 4.1 Population share of states in the Yamuna basin

State	Population	Per cent population share of the entire basin
Himachal Pradesh	1,343,548	0.67
Uttarakhand	2,644,655	1.32
Haryana	18,605,095	9.28
NCT of Delhi	16,753,235	11.0
Uttar Pradesh	71,280,992	35.57
Rajasthan	44,137,113	22.02
Madhya Pradesh	45,618,493	22.77
Total (Yamuna Basin)	200,383,131 (16.56 per cent of India's population)	

Source: Census, 2011

2. Urban and Rural Population

About 30-35 districts of Yamuna basin comprise of industrial towns. Rural areas are dominant of agricultural community. Yamuna basin reside 62.3 percent rural and 37.6 percent urban population. This differs from the national average (71 percent rural population) mainly on account of the fact that the large population of the city of Delhi falls entirely within the basin.

3. Population Density

Population density is highest in Delhi; it has increased from 9340 persons per sq. km. in 2001 to 11320 persons per sq.km. in 2011[1] followed by Uttar Pradesh and Haryana. In Yamuna river basin cities along the river stretch are

[1] Economic survey of Delhi 2014-2015

mainly industrial and urbanized towns. Figure shows that population density is higher in the towns located on the banks of river Yamuna with maximum density in Delhi.

4. Main and Marginal Workers

"Work is defined as participation in any economically productive activity. All persons engaged in 'work' are workers. Persons who are engaged in cultivation and milk production even solely for domestic consumption are also referred as workers" (Census 2001).

"Yamuna basin has total 47,922,103 workers. These comprise 36,857,018 as main and 11,065,085 as marginal workers". Delhi shows 32.82 percent of total workers.

5. Cultivator and Agricultural Labourer

According to census "a person is classified as cultivator if he or she is engaged in cultivation of land for payment in money, kind or share. This includes effective supervision or direction in cultivation. A person who works on another person's land for wages in money or kind or share is regarded as agricultural labourers". The percentage of Delhi in Yamuna river basin is 0.20.

6. Livelihood and Employment

The most crucial need for sustainable livelihoods for an individual or household is employment, or being gainfully employed over a period of time, that ensures a level of remuneration satisfying basic needs and a quality of life. It is difficult to estimate the level of earning/ income/ inflow of money goods or services to a household that ensures such a standard are reached. The most widely used measure is income and poverty. Households existing below this level of income would be the most vulnerable and deprived households. The other measures would be employment figures, employment in different categories. Livelihoods, in many ways would then be a sum total of both the employment portfolio of a household and what it earns in monetary terms, or as services and goods, and what a household receives as entitlements being a citizen of the state, or gram panchayat. Agriculture is the main source of employment in Yamuna basin. Industrial development has increased in the basin and it is highest in Haryana and cities along river Yamuna. These areas are heavily populated because of having income generation sources.

Detailed socio-economic characteristics of the basin based on the Census report 2011 has been shown below:

Table 4.2 Socio-economic statistics of Delhi in Yamuna River basin

Indicator	Delhi
Drainage area (in per cent)	0.4
Share of population (in per cent)	11.0
Share of Urban population (in per cent)	26.85
Share of Rural population (in per cent)	1.22
Population density (/km^2)	94112
Sex Ratio	821
Population Growth rate (1991-2001)	46.31
Per cent Migration	43.42
Literacy rate	81.67
Workers (in per cent)	32.82
Cultivators (in per cent)	0.20
Birth rate	18.4
Death rate	4.7
Infant Mortality rate	37
Life	70.0
BPL per cent	8.23
HDI	0.68

Source: National River Conservation Directorate, Ministry of Environment and Forests

Agriculture

Based on crop seasons, the cropping pattern in the Yamuna basin is very diverse because of large variation in the hydro-climatic, soil and topographic conditions.

A diverse cropping system exists in Yamuna basin. Cropping pattern depends on climate, soil, overall agro-ecological setting and economic conditions. At farmer's level, potential productivity and monetary benefits act as guiding principles, while opting for a particular crop/cropping system. "These decisions with respect to choice of crops and cropping systems are further narrowed down under the influence of several other forces related to infrastructure facilities, socio-economic factors and technological development, all operating interactively at micro-level" (Rai et al, 2012).

Because of diverse soil characteristics, climatic conditions and water availability in the basin a wide range of cropping pattern seen in Yamuna basin.

In Delhi, important crops grown are gram, wheat, jowar and bajra. The important sources of irrigation are wells, tube wells, and canals. On the floodplain of Yamuna, agriculture is based on excessive use of groundwater, agrochemicals and organic manures which is not sustainable. The revival of earlier water bodies along with creation of new water bodies to 'harvest' floodwaters during the monsoon, and the accompanying change in land use from agriculture to semi intensive aquaculture and pasture greater economic returns per unit of land area can be achieved.

4.4 Implications to socio-economic status of the study area

Rivers serve as lifeline in the regional development process. Yamuna River has been a very important life line of northern India insofar as the development of agriculture and economy is concerned. However, from the previous discussions, it is evident that Yamuna River has become a bizarre for several reasons, mainly the anthropogenic activities. It is being increasingly realized that the situation has come to a break mainly on account of increasing pressure of human population (Mishra, 2014). This has laid impact on the socio-economic conditions of the region.

Delhi being the country's capital, with vivacious commerce and trade and tremendous occupation prospects, it has fascinated people from all over the nation which is highly reflective in its diverse population. Delhi truly reflects the wealth and diversity of India wherein diverse religions, languages, customs and cultures co-exist in complete plural harmony. "Delhi is among the top three States/Union Territories in terms of per capita income (Rs. 38864 in 2000-01), current prices. More than 80% of the state income is from the tertiary sector. However with the continuous inflow of labourers and unemployed persons, the number of people living in substandard areas is increasing" (Economic Survey of Delhi, 2001-2021).

This is due to migration. The both urban and rural types of migration are mostly for better standard of living. The reason for migration is mainly due to, source of income, lack of agriculture infrastructure, monsoon failure and poor standard of amenities in rural areas. On the other hand, urban areas face migration because of lack of infrastructure for development and job for survival. "Urban areas have better basic services as well as other specialist services that are not found in rural areas. There are more job opportunities and a greater variety of jobs. Health is another major factor. People, especially the elderly are often forced to move to cities where there are doctors and hospitals that can cater for their health needs" (Bhatta, 2010). It is also due to result of industrialization that farms become more mechanized, putting many labourers out of work.

According to the study by Taubenböck et al. (2008) intra-city migration from smaller to bigger cities is continuing along with the migration from rural to urban areas besides an enormous natural population pressure. Cities are facing serious shortage of power, water, sewerage, housing, transportation, and communication mixed with intense pollution, poor public health, unemployment and poverty. Thus, understanding and monitoring past and current urbanization processes is the basis for future predictions and preparedness, and thus for sustainable urban planning. Focussing on the urban growth of the cities in Yamuna basin it shows some fascinating features. It shows not only the cities adjacent to main river Yamuna, development of emerging towns has also started. Migration to urban areas is the main factor behind this. This may continue longer, which will be beneficial for metropolitan cities in reducing the population load due to migration. Lack of development and insecurity in agriculture returns is responsible for migration from rural areas to urban areas. In rural areas, often on small family farms, it is difficult to improve one's standard of living beyond basic sustenance. Farm living is dependent on unpredictable environmental conditions.

The Yamuna basin being one of the densely populated river basins in the country faces various kind of pollution load emerging from other social dynamics and activities in the region. In the basin, "due to non-existence of sanitary facilities in rural areas and urban areas, especially in slum clusters, a large section of population use either catchment area or directly to the river for open defecation. The activity contributes organic pollution and pathogens in the river water" (CPCB).

There are many other social factors that have impacted the Yamuna river basin. The unauthorized inhabitants all along the bank of Yamuna River or its tributaries produce a large portion of the solid waste that finds its way into the river. The cocktail of waste includes waste from dairies, domestic waste, flowers and other material used during worships, unauthorized slaughtering, carcases of animals etc. The dumping of human and animal dead bodies is also sometimes observed in the Yamuna River. Disposal of infant's dead bodies in the river water is practiced in the entire Yamuna stretch. Immersion of idols, especially during Durga Puja, Ganesh Puja takes place all along the bank of river. Flowers, Straw, Bamboo, Clay / Plaster of Paris, harmful chemicals used for paints, plastic bags are finds its way into the river.

These mark some of the major challenges prevailing in the region which needs to be taken care with a comprehensive planning and execution.

CHAPTER 5
ROLE OF DIFFERENT ACTORS AND POLICY AUGMENTATION

5.1 Overview

In the previous chapter, the importance of socio-economic activities was reflected with the life line of Yamuna River, how the various activities are prevalent and affecting the social and economic dimensions of the communities that live by being dependent on a river system. This chapter is basically to explore the interaction of actors, innovation networks and institutions and their influence on the development and diffusion of new technologies. Here, actors signify several entities that work together in a framework; they are active in the sense that they can follow considered strategies, institutions are somewhat passive, and i.e. they are made or evolve as a result of the conduct of actors. According to Edquist (2005), “actors may be viewed as the players and institutions as the rules of the game”.

This chapter has been divided into eight sections. After the introduction, section 2 discusses the factors that influence the Bioremediation Innovation System. Section 3 is about the role of government and different policies formulated for the Yamuna River cleaning at present. Section 4 will brief about the institutions that are actively involved in the research of the bioremediation and its implication towards the study area. Section 5 will inform about the role of private companies and consultancies. Section 6 describes the role of different NGOs participating in Yamuna cleaning movements. Section 7 will impart some light on the role of communities and people who are seemingly affected by the river contamination and policies formed about it. Lastly, in section 8 some of the implications to policy augmentation have been mentioned.

5.2 Actors Influencing the Bioremediation Innovation System (BRIS)

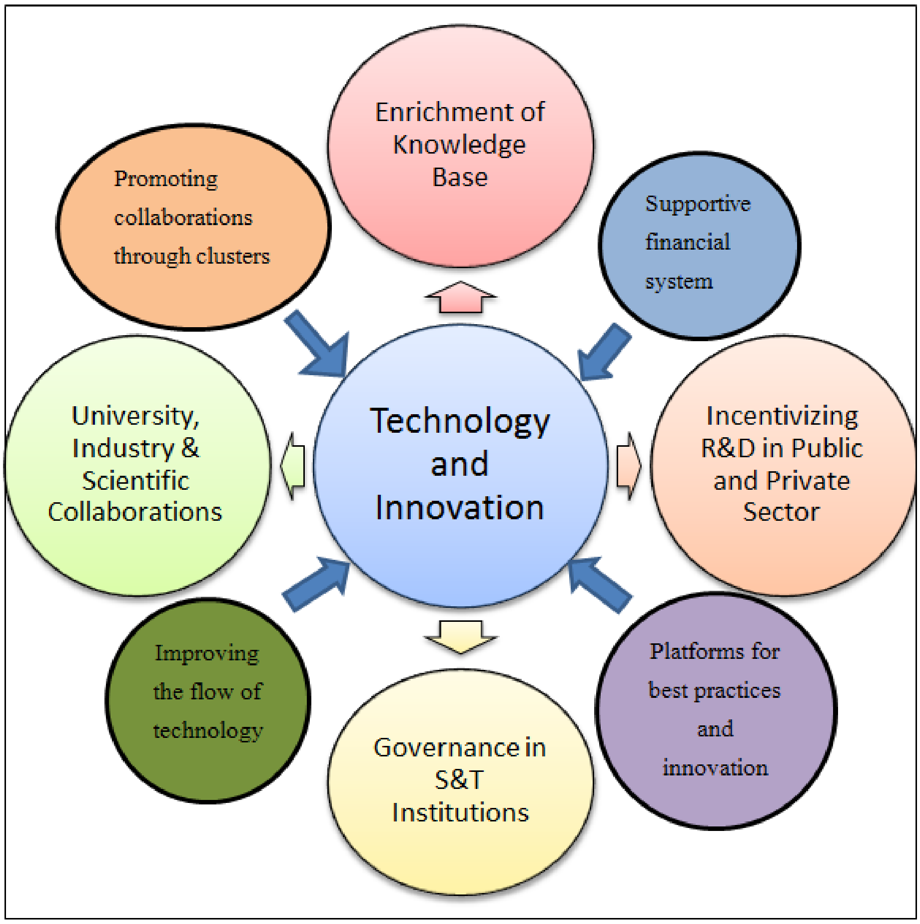
In this context, Bioremediation Innovation system is still an unexplored and evolving system where more prudent, distributed, affordable innovation is needed. In fact, Planning Commission in its 12th five year plan has led more emphasis on innovation process that is “frugal in terms of resources required and the products and services must also have a frugal impact on Earth’s resources and designed to be environmentally sustainable”. There are some excerpts below that have been derived and discussed from the 12th five year plan, and adapted according to the present study’s outlook. In the figure 5.1 it has been illustrated that how different factors impact Technology and Innovation and influence certain factors in response to it.

A holistic view of the science, technology, and innovation eco-system can ensure best points for intervention in the system. Stimulating this eco-system requires enablers in the form of policies, strategies, novel ideas, and catalysts to effectively meet the challenges in the system. There are some challenges regarding policy which is needed to address for consolidation of Bioremediation Innovation System (BRIS) the anticipated approaches for the way forward:

1) To bring enrichment of the knowledge, basic research needs to be strengthened followed by applied research which could be adopted adequately for its practical implementation. The challenge however begins to encourage the industries to promote it to the level of market.
2) Another strong factor in enhancing the technology and innovation, for its competitive growth is R&D in public and private sector. It is only the public funded institutions that lead in generating the technology that too limits itself in becoming commercial enterprises. The reason being, private sector remains unattended during fund distribution. This results into weak linkages between academia-research and industry. The challenge is to develop an active setting of Public-Private Partnership and facilitating framework to inviting investment from the industrial sector into R&D system.
3) The role of governance in S&T institutions need to analyse how to leverage the industrial infrastructure and create appropriate institutional framework and organizational mechanisms to improve upon the potential research fields. So it is important to generate a participative transformation which is multidimensional for structural changes in the existing institutions.

4) To establish a strong network among University, Industry and Scientific institutions their collaborations are much needed. A conducive research sector requires to involving these components to form a functional network with well-maintained infrastructure, generous funding and well-defined objectives. It is important to have effective collaborations so that the research output and innovations can be commercialized and transformed into marketable merchandises and services. A cluster-based approach is highly considerable these days, where a minimum critical mass of universities is identified and efforts are made to create or strengthen the innovation eco-system around them (12th five year plan).

Figure 5.1 Factors that impact Technology and Innovation in the system



Source: Author < Planninng Commission (2012)>

5) Collaborations provide a stimulating effect to innovations and fostering knowledge transfer which further foster interconnections that link intellectual, financial, human and creative capital apart from triggering under-utilized capital (12th five year plan). These enterprises could take a shape of physical or virtual clusters, which bring together research, business, risk capital, and creativity to turn ideas, into products, processes and services. The National Innovation Council (NInC) is in the process of facilitating the setting up of industry and university-based clusters to spur innovations (Planning Commission, 2012).
6) In order to emerge the technology and take it to the advanced level, a supportive financial system is desirable which provides necessary risk capital to spur innovations and enterprises. The most suitable form of finance is a Venture fund which is recognized globally for the growth of innovative technology and breakthrough ideas like Bioremediation.

Although "India is amongst the top recipients in Asia for Venture Funds and Private Equity Funds so far, these investments are not well-focused on small early stage start-ups excluding investments into relatively large and safer fields". In fact, funding should be more dedicated to innovative initiatives that focus on sustainable development.

After the basic fulfilment of requirements, it is important to have a substantial platform for best practices and innovations to make it go beyond the formal limits of R&D labs to include innovations in public service delivery such as water decontamination, restoration of land and agricultural fields etc. The dissemination of best practices must be ensured and applied on practical issues to stimulate their adoptions and adaptions on a large scale.

A strong initiative is needed to perform affordable innovations for technologies for social and public welfare. It involves the participation of multiple stakeholders and creating PPP for promoting people-centric research to address severe environmental issues with specific objectives in a given time. It has been recommended by the Planning Commission (2012), to solve the water-related issues, regarding both quality and availability.

Sustainable research solutions are essential to resolve the issue keeping in mind the consequences to the environment. The challenge, therefore, is to convert research outputs from the laboratories into revenue models based solutions in a coordinated manner among the relevant departments in both states and centre for innovative deployment under real field conditions.

5.3 Institutional Elements of Bioremediation Innovation System (BRIS)

The elements of an innovation structure identified earlier (in Chapter 3) fall into some institutional domains. An institutional representation of the innovation system is a useful tool for exploring the role of various actors in the innovation process and the way in which they may interact. There are mainly five categories of institutional participants can be identified in the given system:

(i) "Governments, which play a dual fundamental role one in constructing broad policy directions and another primary role in funding basic scientific research";

(ii) "Private enterprises and their research institutes, which contribute to development and other activities that are closer to the market than governments are";

(iii) "Universities and related institutions that provide critical knowledge and skills for further development of the technology";

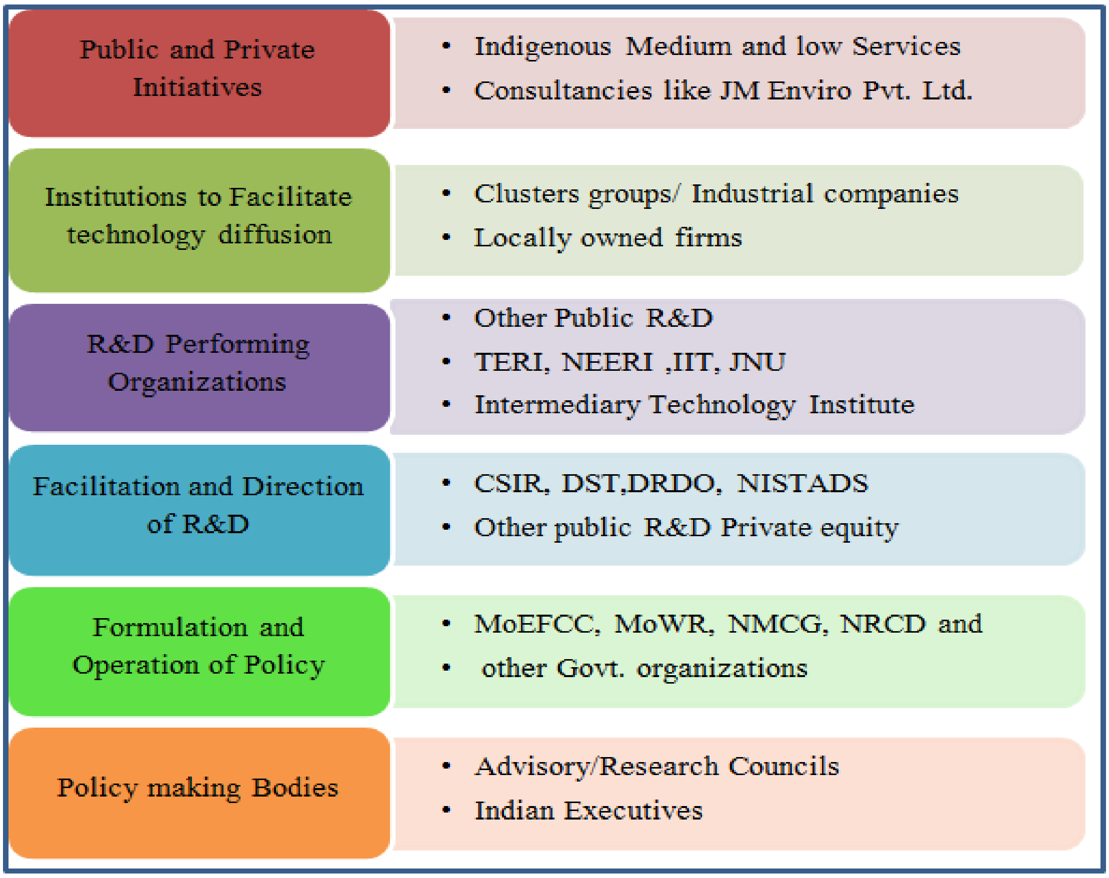
(iv) "Certain institutions acting as intermediaries under such names as 'technology centre', 'technology brokers', or 'business innovation centres', which play a significant role in bridging the gaps among the other actors and have been essential to the success of all types of research centres"; and

(v) Other public and private organizations, such as venture capital firms, federal laboratories, and training organizations.

The interaction and role of these stakeholders and institutions are demarcated and determined by certain contextual factors adequately important to the operation of innovation systems to be able to make them:

technology's demand in the market, physical infrastructure for its development, education and training and regulatory conditions applied on it.

Figure 5.2 Main Organizations shaping the BRIS



Source: Author

5.3.1 Role of Government in the Innovation System

The role of government is the crucial one among all other actors as it influences the innovation system at a large extent. Significantly, the approaches adopted by various nations in the direction of innovation systems have varied depending on the overall national economic orientation. These strategies have ranged from a 'directed or coordinated' model such as the one selected by Japan, to a much more laissez-faire model employed in the USA. Some of the other Countries such as Canada and others in the European Union (EU) region have implemented models that fall in between those of Japan and the US, nonetheless regarding strategy and sector identification for leveraging innovations. Thus, from the perspective of a national planning process, there are numerous approaches to directing and shaping the innovation-directed development processes. Even though there may be varying levels of the directed or coordinated functions of the governments in developing the innovation infrastructure, most nations have accepted the resemblance of needs for creating an innovation infrastructure (11th Five Year Plan).

There are certain modules that are being followed in an Innovation System and initiatives taken by the Government:

1) The importance of innovation for the delivery of, and access to, services that are essential for a quality of life; whether it is clean water, modern energy or affordable health care is being deployed. For India concerning an innovation policy, this may be an important and distinctive feature. The forward plan of India is towards faster and more inclusive growth. In a globally competitive market environment stress is more on a national innovation infrastructure that connects knowledge systems to wealth creation efficiently for faster growth.

2) Reinforcing Academia–Industry interface (with Public–Private Partnerships): The innovation set-up in the formal sector is thin. It requires expansion by referencing to global best practices and market demands. Such an innovation infrastructure would depend on strongly upon an active and lucrative PPP in research and development as well as commercialization of innovations.

3) New approaches and programmes are critical for allowing India's innovation potential to grow. Competitiveness innovation cluster has emerged as a successful global concept. Such innovation clusters in which academia, research and industry partner under feasible and unbiased PPP are accelerative approaches.

4) The terms of the academia and industry should be of interactive, collaborative and participative nature, realizing and respecting each other's

role and contribution. Dynamic academia– industry interaction will lead to strengthening competitiveness, promoting innovation and new technology development on the one hand and ensuring development and supply of qualified S&T manpower. To elaborate the edges, the thrust is on the development of new interface structures such as consortia, Partnership research institutions for basic and applied R&D; enhancing the mobility of S&T professionals; and promotion of technology transfer and new venture creation.

5) The central role of consortia approach should be on precompetitive partnerships involving academia to help the manufacturers develop advanced technologies and upgrade their manufacturing competitiveness. Whereas government participation could be in the form grant-in-aid to academia and provisional grant to small innovative companies, industry partners will bring with them inputs like domain knowledge, market research, and facilities for testing and validation of prototypes.

6) The role of NGOs is crucial in rural technology delivery that relates to field surveys for assessing feasibility; preparation of Detailed Project Report with inputs from potential users; networking, motivating and organizing poor rural producers, artisans, small farmers and other partners/beneficiaries. NGOs need to develop associations with technology benefactors, development agencies, and financial institutions and provide support for location specific technology adaptation and up gradation and assistance in marketing.

7) Small and medium scale enterprises (SMEs) inhabit a significant and strategic place in economic growth and equitable development of the country and act as a driving force behind a substantial number of innovations.

8) Leveraging international collaboration inputs: establishing International partnerships in S&T are indispensable mechanisms of conveying prospective plans and platforms to various countries to work together, taking mutual advantage of corresponding scientific & technological capabilities of each other. It is important to develop and flourish first-hand acquaintance

with science and technology developments and work cultures in other countries and access to sophisticated research facilities abroad. Their interaction is in a way beneficial for updating and refining the knowledge base for accelerating the pace of investigation and bridging any communication gap.

9) Steps have been taken in the area of environmental biotechnology, technologies for bioremediation of mine spoil dumps; ecological restoration of degraded ecosystems and wastelands; mangrove afforestation; biosensors for detection of organo-phosphorus pesticides; bio scrubber for removal of obnoxious odours from industrial emissions; and oil zapper technology for bioremediation of crude oil spills and treatment of oily sludge be ready for commercialization have been accomplished and still advancing (11th five year plan).

5.3.2 Schemes formed by the GoI

There a number of initiatives taken by the government to combat river pollution. The major projects have been discussed below.

5.3.2.1 Namami Gange Project

"Namami Gange Project or Namami Ganga Yojana is an ambitious Union Government Project which integrates the efforts to clean and protect the Ganga River in a comprehensive manner. It its maiden budget, the governnment announced Rs. 2037 Crore towards this mission. The project is officially known as Integrated Ganga Conservation Mission project or 'Namami Ganga Yojana'. This project aims at Ganga Rejuvenation by combining the existing on-going efforts and planning under it to create a concrete action plan for future. About Ganga Basin Salient Project features Pollution will be checked through previous approaches for Ganga cleaning Ganga Action Plan National Ganga River Basin Authority (NGRBA)".

Some crucial deliberations have been made like, expansion of coverage of sewerage infrastructure in 118 urban habitations on banks of Ganga, enforcement of Ganga specific River Regulatory Zones, development of rational agricultural practices & efficient irrigation methods and setting

Ganga Knowledge Centre. The check on Pollution will be done through treatment of waste water in drains by applying **bio-remediation** method through in-situ treatment. This would include treatment of waste water through municipal sewage & effluent treatment plants. It also involves introduction of immediate measures to arrest inflow of sewage. Introducing PPP approach for pollution control and 4-battalion of Territorial Army Ganga Eco-Task Force[1] will enhance the scope of efficiency.

There have been separate action plans for rivers- Yamuna, Damodar, Gomti & Mahananda.

5.3.2.2 Initiatives by CPCB

CPCB in collaboration with concerned SPCBs/PCCs established a nationwide network of water quality monitoring comprising 2500 stations in 28 States and 6 Union Territories. The monitoring is done on monthly or quarterly basis in surface waters and on half yearly basis in case of ground water.

Currently, “the inland water quality-monitoring network is operated under a three-tier programme i.e. Global Environment Monitoring System (GEMS), Monitoring of Indian National Aquatic Resources System (MINARS) and Yamuna Action Plan (YAP). Water samples are being analysed for 28 parameters consisting of 9 core parameters, 19 other physico-chemical and bacteriological parameters apart from the field observations”[2].

CPCB in a report called as “In-Situ Bioremediation for Treatment of Sewage Carrying Drains Joining River Ganga-Performance Evaluation of Technologies and Development of Guidelines and Protocols” has mentioned the project details.

In view of prevailing situation and considering magnitude of sewage pollution, Central Pollution Control Board (CPCB) proposes to launch “In-situ sewage treatment with **bioremediation technology**; a scheme which is

[1] http://www.gktoday.in/blog/namami-gange-project/ 25.05.16
[2] http://cpcb.nic.in/water.php# 31.05.16

relatively cost-effective and offers simpler solution for Municipalities". It is being applied by ECO- BIO block.

The relevant points are discussed below:

The Ministry of Environment and Forests on the proposal of Central Pollution Control Board has accorded Administrative Approval and Expenditure Sanction for demonstrating In-situ Bioremediation for Treatment of Sewage carrying drains. The demonstration is proposed for the drains joining river Ganga at Farrukhabad, Allahabad and Patna. The drain joining river Satluj at Ludhiana has also been taken up for demonstration.

Table 5.1 A comparison of in-situ treatment technology versus conventional treatment plants

Parameters / Features	**In-situ sewage treatment**	**Conventional STP**
Concept	In-situ bioremediation refers to using of microbes	Ex-situ bioremediation using microbes
Microbes	Microbial consortia (aerobic, anaerobic and facultative)	Microbes - Aerobic and facultative
Treatment units / Civil structure	Nil or very less	Complete unit required and need land allocation

Power consumption	Nil or very less if mechanical devices used	Electricity required all the time for aerobic treatment, pumping but, oxidation ponds may not require electricity (excluding pumping)
Operational skill	Skilled operators not required	Required
Construction cost	Nil/ insignificant	Significant
Performance efficiency	Provide pre-stabilization and helps in reducing polluting loads being directly exerted by sewage drains. Achievement may not be 100% in-terms of pollution reduction but, since	Although, percent reduction are higher but failure in power/ break down/ unskilled operations yields zero result.

	providing at least 50% reduction without much cost and hence needs to be adopted.	
Operation and maintenance	Very less and requires for microbial dosing.	Regular O & M is must and requires recurrent expenditure

Source: CPCB Report

At present, sewage treatment plants are based on conventional systems which involve high skilled operation, construction cost and maintenance. With this view, CPCB mooted a concept of “in-situ sewage treatment”. The concept is based on microbial treatment of sewage flowing in drains through various techniques. The conversion of this concept into technology is considered to be cost-effective as compared to conventional treatment and easy to handle, not requiring skilled man-power and low or no electrical power requirement to operate the treatment processes. The in-situ sewage treatment takes place while flowing in open drains without displacement of sewage thereby requiring no additional space for treatment. The technology does not involve chemical dozing and instead microbial consortia are used for dozing which are primarily of native origin and thus, not causing any hazards to environment or mankind.

The Bioremediation technology has been used in several countries and its application has been confined to lakes and reservoirs. In India, the technology has been demonstrated at Delhi, Pune and in Rajasthan. Outcome and findings of these projects were found to be encouraging.

Implementation of technologies based on the concept of in-situ bioremediation is almost new in the country. The experiments conducted elsewhere are not either commercial or bearing any R & D component in it. Without putting such technologies widely in practice, aiming for high performance and getting best results at-once, will take same time.

5.3.2.3 Extended bodies

National Mission for Clean Ganga (NMCG) is the implementation wing of National Ganga River Basin Authority (NGRBA). It is a registered society originally formed by Ministry of Environment, Forests and Climate Change (MoEFCC) on 12th August 2011. The area of operation of NMCG is the Ganga River Basin, including the states through which Ganga flows, as well as the National Capital Territory of Delhi (Yamuna River as well). The area of operation may be extended, varied or altered in future, by the Governing Council to such other states through which major tributaries of the river Ganga flow, and as the National Ganga River Basin Authority (NGRBA) may decide for the purpose of effective abatement of pollution and conservation of the river Ganga and its major tributaries(Yamuna).

"The National River Conservation Directorate (NRCD) in the Ministry of Environment, Forests and Climate Change is implementing the Centrally Sponsored Schemes of National River Conservation Plan (NRCP) and National Plan for Conservation of Aquatic Eco-systems'(NPCA) for conservation of rivers, lakes and wetlands in the country"[3].

The objective of the River Action Plans is to improve water quality of rivers through implementation of pollution abatement schemes in identified polluted stretches of rivers. NPCA aims at conserving aquatic ecosystems (lakes and wetlands) through implementation of sustainable conservation plans, and governed with application of uniform policy and guidelines.

5.3.2.4 More new projects in pipeline

The steps have been taken regarding implementation of more new projects for cleaning Yamuna. To check pollution levels in the river, "the Delhi Government in June 2014" undertook an elaborate interceptor sewer project

[3] http://www.moef.nic.in/division/national-river-conservation-directorate-nrcd?theme=moef

so that all water from the drains is treated before being thrown into the Yamuna.

Along with this, the Delhi Jal Board (DJB) has created a Sewerage Master Plan 2031, according to which, there are plans of laying sewerage systems in those locations which do not have sewer lines. It will set up a 59-km-long interceptor sewer along the three major drains of Delhi: supplementary, Shahdara and Najafgarh, which will treat sewage from around 190 subsidiary small drains and take it to the nearest sewage treatment plant (STP). This will lead to treated effluents being discharged into the drains. According to DJB officials, some new STPs are being constructed at Nilothi, Delhi Gate, Pappankalan, Chilla and Kapashera which are of high standards to treat effluents.

5.4 Role of research institutes

There are some institutes which are involved in the research work of bioremediation on contaminated sites and water treatment facilities. A few of them have been listed below:

1. Industrial Toxicology Research Centre (ITRC) is now named as Indian Institute of Toxicology Research (IITR), Lucknow, India. The institute is engaged in the field of Toxicology and one of the constituent laboratory of CSIR India, which was established in 1965 with the motto of "Safety to Environment & Health and Service to Industry".

The institute is dedicated towards research in Fundamental and Applied Toxicology. Major thrust areas include Environmental toxicology, Ground and surface water pollution, Safety assessment of food & additives, Toxicity evaluation of substances for human use, Microbial contaminations, **Bioremediation**, Hazard identification and Toxicogenomics.

2. The Department of Biotechnology at TERI University committed to the furtherance of the scientific enterprise through the establishment of a vigorous research programme, and to contribute to post-graduate level academic programmes to cater to national requirements in basic science as well as agricultural and environmental applications. Research has been

carried out in fields as varied as “microbial biotechnology, mycorrizhal biology, environmental bioremediation, plant tissue culture and biofuels”, to name a few.

3. National Environmental Engineering Research Institute (NEERI) under the Division of Environmental Biotechnology Division. This directs its scientific endeavour towards research, development and application of biotechnology based solutions for environmental problems and sustainable development. The motivation of the division is to pursue multidisciplinary R&D in fundamental and applied areas of environmental biotechnology by exploiting knowledge base from microbiology, biochemistry, chemistry, molecular biology, chemical and environmental engineering disciplines. This aims in developing eco-friendly biotechnological processes targeting societal and industrial needs to address issues related to restoration of environmental quality, bioremediation/waste treatment, waste to wealth, climate change mitigation etc.

4. Indian Institute of Technology (IIT) Delhi

In IIT Delhi, Centre for Rural Development and Technology and Department of Biochemical Engineering and Biotechnology, intensively work on the research development of bioremediation.

5. Jawaharlal Nehru University (JNU), Delhi

A number of studies related to environmental pollution, impacting biota and the ecology of fresh waters and wetlands set up the gist of this Area. Monitoring and assessment of water pollution, particularly from sewage, pesticides, and industrial effluents in rivers, reservoirs and shallow water bodies, have been investigated in detail, with the use of bioremediation.

Additional, comprehensive studies on aquatic ecosystems, including different kinds of wetlands, have covered the ecology of wetland vegetation, benthos and plankton, and their implications for wetland management. Studies on chemical speciation of heavy metals and distribution of PAH in aquatic environment have particular relevance to their effects on plants and animals.

The effects of sewage and sludge disposal, mine spoils and fly ash on soils characteristics as well as their effects on plants, and solid waste management are other major fields of concerns in this area.

5.5 Role of Private companies

Some private enterprises are emerging in the field of biotechnology, especially bioremediation which play an active role in developing and commercializing this technology. A few of them are:

1. Biotech Services in Noida perform activities that include soil bioremediation and bioaugmentation. The Company is also involved in manufacture of waste water treatment equipment.

2. JM EnviroTechnologies Pvt. Ltd. is a fast growing multidisciplinary firm and a part of an internationally famed Parent Company, GFS Trading & Contracting Co. established in Kuwait. They have developed an "innovative technology called "ABR" (Anoxic Bioremediation) giving solution to all your water problems and even to save ground water by producing Treated Effluent from sewage suitable for Horticulture activities". They have successfully completed "more than 60 water pollution control projects and certified by various Government departments related to water boards".

3. U S enviro pvt limited in Okhla Industrial Area, proposed the pilot projects on bioremediation before NMCG. The project discussed above, have been conducted by this firm only.

5.6 Role of NGOs

NGOs play a critical role among all other actors in communicating the issues to the right authority and creating awareness in the communities regarding any issue (environmental or social). The relevant NGOs have been mentioned as follows:

1. Shanti’s organization, Ganga Action was formed by Swami Chidanand Saraswatiji and launched in 2010 by His Holiness the Dalai Lama. It unites economists, scientists, environmentalists and agriculturalists with saints, scholars, and yogis to clean up the Ganges, India’s largest and most sacred river. The NGO lays emphasis on spirituality, as well as emphasis on just pure environmental awareness and education.

2. Swechha takes young people on pilgrimage-type trips from Yamuna’s source near the Himalayan Mountains back down to Delhi. Organizers hope that these tours, called Yamuna Yatra, will foster a bond to nature that will encourage environmental stewardship as the children grow into adulthood. This is how they create sensitization towards the river.

3. World Wide Fund for Nature (WWF) requests to the faith of villagers who live adjacent to protected areas. The NGO often works through the local religious leaders to spread their message of conservation. They have actively worked for Yamuna in Delhi.

4. ‘Yamuna Jiye Abhiyaan’ since early 2007 is a civil society consortium dedicated to the restoration of river Yamuna as an eco-system in its own right. The coordinator, Mr Manoj Mishra, has intensively participated and done robust programmes for the sake of Yamuna.

5. The Centre for Science and Environment (CSE) is a public interest research and advocacy organisation based in New Delhi. CSE researches into, lobbies for and communicates the urgency of development that is both sustainable and equitable. Several activities have been done by CSE for cleaning the Yamuna River.

5.7 Role of Communities

Communities are well aware of the problems and solutions but are unable to take action due to the stringent state control. Over the past fifty years, the communities living around Yamuna have seen their livelihoods get destroyed, their homes dismantled and the river becoming horrendously polluted.

In a democratic country, the political will can be significantly, even decisively, influenced by mass mobilization. And it is here that the joining hands of the environmentalists and the devotees can play a vital, even critical, role. In fact, this role is already being played, As devotional service to Yamuna River, educational programs have been launched, clean-up days have been scheduled, boatmen have been organized and enlisted in restorative work, and PILs have been filed in the courts, resulting in sewage treatment plants being built, polluting industry shut down, and minimum flows established for river health. Such work — which already exists and is enacted as affectionate service to Yamuna River herself — demonstrates the great potential for a more robust and effective alliance between environmental scientists and policy makers and members of religious communities. This work represents an initial trickle that may just turn into a mighty river of restorative action.

5.8 Implications to Policy Augmentation

Policy is the set of guiding principles directing the actions of an organization arrived at through the exercise of wisdom, foresight, prudence and sagacity. Policy formulation involves assessment of long term trends in resource availability, demand and usage pattern priorities within and without Delhi. It also involves careful identification of issues, long term objectives, evolution of a futuristic outlook and alternative scenario generation, evaluation of technological, financial, urban and social policy trends and options, legal and constitutional considerations and environmental responsibility. The long term important things which must be commenced today must get equal priority as urgent works. Visionary water sector policies, taking emerging variability and technical, social and legal options into account are required today to ensure water security for the future.

“The durable policy thus formed would lay out directions and priorities for successive governments, quarantined from political change, unaffected by preference variation resulting from leadership subjectivity or lack of institutional coordination, capable of accommodating emerging trends and technological innovations" (Water policy for Delhi, 2012). The policy thereafter becomes a guide to priorities and resource allocation.

CHAPTER 6

EMPIRICAL ANALYSIS OF THE STUDY

6.1 Overview

This study has one of the key focuses on identification of the main actors, their roles in the system, and the level of system interaction. The previous chapter covered understanding the role of different actors and institutions involved in the research and development of bioremediation and also the people who directly or indirectly are affected by the juncture of Yamuna River in Delhi. After understanding these issues, this chapter would be an attempt to analyse the data empirically, which was obtained by primary data collection through the interactions, interviews and observations.

The analysis stems from the recent theoretical thinking which has emphasised the importance of adopting a systemic approach to the study and analysing it backing up with eco-innovation drawing on three factors: regulation, process and organizational structure. An evaluation of system strength and weakness is provided in this chapter along with discussions on certain recommendations that have developed through the study.

This chapter has three sections, including the overview. In section 2, which is the main body of the chapter, a summary of the data generated is illustrated and findings have been interrogated and critically appraised. And in section 3, interpretation and implications of the findings and its relation to the context would be discussed.

6.2 Description and Analysis of the Data

The acquired information from various actors which has been discussed in the methodology chapter 3 as well has been separated into certain themes building on the objectives and research questions of the study, so that it becomes easier to cultivate a comprehensive analysis of the data.

6.2.1 Bioremediation as an Alternative Technology (Decentralization)

This is the first and foremost requirement of the study to elucidate the accountability of this technology. It is required to find out if this technology is applied at a significant level or not, or else if applied at what scale so as to evolve as a potential and sustainable alternative. It is certain, that centralized schemes have failed, it's needful to look for a decentralized scheme considering the alarming situation caused in Yamuna River, which has already been discussed in the introduction chapter.

In conversation with one of the water analyst in Delhi Jal Board (DJB) water works, Wazirabad, who is an assistant chief water analyst there, keeps check on water quality and analyse it. He gave relevant insights regarding Yamuna cleaning actions and some key points related to measures that have been taken by DJB in special.

According to him, Yamuna River is dead because of discontinuation of flow. Sewage or polluted water is directly discharged into the river, hence choking it. DJB is capable of solving water crisis not because of Yamuna, but the flow of water that is coming through Munak Nahar directed from Hathnikund and Panipat. The water is collected at Haidarpur plant which is received by Wazirabad plant through an underground channel called as "CLC" which is a Carrier Lined Channel. CLC is bifurcated, through which one line goes to the plant and another flow is directed towards Yamuna River to maintain the continuity of flow in the river in order to save the ecosystem. This is a good move for Yamuna rejuvenation.

The water quality at Wazirabad barrage is fit for drinking purposes but at downstream the case is worse. There is a no flow at all. This is because, 236 drains are discharged directly into the river, out of which Shahadra drain is too much polluted. Although STPs are working in some parts but due to lack of management and under-developed sludge management techniques are making the situation more critical, says the water analyst. The inceptors are still under process.

Mixed Liquor Suspended solids (MLSS), are used under bioremediation process as a mechanism for treating raw sewage in the primary settling tanks, which is then put into aeration chamber after settling of raw sludge, as explained by him. The use of PAC (Poly Aluminium Chloride) typical aluminium-based coagulants used in water treatment and other chemicals which is more or less harmful to the environment sooner or later.

Although the technology is not used in a substantial manner, but given the time and resources it could be enhanced to amplify its application in the water treatment. The condition of Okhla barrage marks the need for rapid transformation of the conventional operating mechanisms to resolve the dreadful pollution issues due to drains coming from industries as well as sewerages. The Engineer working at Okhla barrage gave information about how they maintain the flow but nothing is being done to treat the polluted water. The same water enters Agra Canal which after roving to Mathura becomes comparatively clean and used for irrigation purposes further, says the Engineer. When asked about centrally sponsored schemes to clean Yamuna, he replied that anything corresponding to cleaning measures have not yet initiated in this region as such, although river being at the critical and alarming stage.

In Ministry of Water Resources, a government official in Policy and Planning Department explained very well about policy related aspects handled by the ministry as such. The new technologies are being proposed to outsource from Israel in order to clean the Ganga and its major tributaries. "Making a decision about the technology transformation or adopting bioremediation as an alternative technology would be jointly reviewed by the State and Central Government", he explained. So it is not an easy venture, to be taken by the government itself.

National Mission for Clean Ganga (NMCG), an organisation under Ministry of Water Resources (MoWR), works specially for cleaning of Ganga and its major tributaries. In an interview with a Scientist in NMCG, he said that "bioremediation is being used on a pilot scale in some drains pouring into the river Ganga in Haryana, Allahabad, Kanpur, Varanasi and Patna". He added that, they have identified some of the drains and allotted work to some agencies (chosen by the Committee). The final outcome is still awaited; it is not completed so far. But they have observed improvement in some areas. Due to some administrative issues, they are not able to conclude anything further. He also mentioned that some more projects are in the pipeline. Specifically for Yamuna River, Najafgarh drain is being included under the pilot projects.

Another opinion was obtained from a Research Associate in NMCG, he was with the view that employing Bioremediation for the river is a problematic task to perform as regulating the flow of water in the river is difficult. He added further, "yet bioremediation is used for the treatment of drains going directly into the river, it is mainly used for the cascading effect. If the drains are treated, river itself gets cleaned. He further added, at present NMCG is confined to 10 Km of the buffer zone of the river controlling the surface runoff and some work on embankment of the river is being done". The control on floodplains is being done in collaboration with the other ministries like Ministry of Agriculture and Department of Land Resources. He gave some information about the floodplains of Yamuna River that "pollution is mainly because of the chemical fertilizers and for that they are motivating farmers to use organic fertilizers through some programmes".

So it could be inferred that the technology is yet to evolve and prove its potential into the mainstream.

The private consultancy firm J M Enviro Pvt. Ltd., have worked on several govt. funded projects in Delhi and other states with the use of bioremediation for the treatment of waste water, lakes and ponds. A coordinator of this firm has mentioned that "Anoxic Bioremediation (ABR) technology could be a beneficial alternative to approach with the current condition of Yamuna, as it does not require any land, in situ bioremediation could work more efficiently in this case".

It is important to take on the views of the researchers who are dynamically involved in the research and development of this technology. In an interview with a faculty from TERI University, she responded that, "if we want to talk about bioremediation, it has to be made clear that in what context. As the microbes are versatile in nature, all microbes cannot work on all type of drains as it has various different types of contaminants present in it, as it comes from, industry as well as households, so basically it depends". She added further, "it is difficult to use it in on drains that are flowing, as it requires stagnant water to work on". Also if the treatment is carried out, it requires some gestation period and some in between treatment or phase. There are huge infrastructure and facilities enrolled. At the end it is always difficult to implement any strategy or process, bioremediation is a time taking process. So it would be better if the focus goes to treatment of pollution from the source itself. But she also emphasized that this is the only technology that could help in this situation, as it does not cause any threat to environment in return. Bioremediation can become an alternative technology, but it needs to be very specific. It is the only solution for today being an environmental- friendly way to treat pollution. As a very few of bioremediation technologies are commercialized.

With these diverse views, things should be made clear before reaching at a conclusion, so more opinions were needed. For that, in conversation with a faculty of JNU from School of Environmental Sciences, a further understanding was developed on the use of bioremediation. He said, "If we talk about Bioremediation there are two concepts we should make clear of, one is ex-situ and another is in-situ treatment of contaminated sites. Treatment of waste water makes use of in-situ bioremediation. Drains can be treated by this process of treatment. But for Yamuna River it might not be feasible as it is not a site but a floating water body, yet it could be applied for the land part effectively. The term 'remediation' is used when it is stagnated and it means that 'to bring a state and affair back to its original state'. The proper use of terminology should be considered. For this, remediation term is quiet problematic." Yamuna is a receiving body which collects all the drains discharged in it. The problem has menaced with time due to decreased flow of the river and river bed has risen to the surface because of less water. Hence, it is important to sort out these issues before approaching this technology.

Nevertheless, various research works from individual laboratories have come up, which has shown tremendous outcomes from this field of research. “Biotechnology and systems biology approaches are also implicated in bioremediation and are gaining considerable importance in fostering bioremediation” (De Lorenzo, 2008; Van Aken, 2009). In a document providing a state-of-the-art report[1] on existing knowledge of this technology, “for the benefit of regulators, who evaluate the quality of environment and for practitioners, who have to implement and evaluate remediation alternatives at a given contaminated site”. This provides a complete sense of the parts and parcel of the technology for a particular site and emphasised on its prominence as an alternative technology. In an editorial by Agathos (2013), a number of papers on research and development of bioremediation technologies have been mentioned, which shows its importance in becoming a potential and remarkable technology for removing pollutants in soils, sediments and water, which has been further elucidated in subsequent section.

6.2.2 Potentials of Bioremediation

As bioremediation is an evolving technology, there are a lot of experiments being carried out in order to weave its potential. Although the techniques involved in this, have been employed since 1960s, but today it has developed many-folds with upcoming breakthroughs in Science and Technology. J M Enviro technologies in their company profile have reported the successful demonstration of ABR technology with Persnickety® 713 as a treatment for contaminated water bodies making the Total Suspended Solids (TSS) and Biochemical Oxygen Demand (BOD) levels under permissible limits of CPCB. They have synthesised the product making use of biotechnology, which is an inoculum (a small amount of substance / solution containing bacteria from a pure culture which is used to start a new culture) containing suitable niche species of microbes that best fits in the location and treats it.

[1] M. N. V. Prasad, (2011), ‘ Bioremediation, its Applications to Contaminated Sites in India’ .

In NMCG, the pilot projects on bioremediation are conducted through a Japanese technology, called as Eco-Bio Block[2] by the assigned firm. The Eco Bio Block (EBB) technology being practiced by the firm has already been demonstrated abroad (Japan and Malaysia) as well as in India (Mayur Vihar drain, Delhi). The EBB is manufactured by volcanic rock and other marine – materials and serves as houses for micro-organisms that provide supportive structure. The technology also works at minimum temperature of 100C. It is efficient in reducing the BOD, COD and TSS at permissible levels.

The potentials of this technology is not only based on research but other facilities are also associated with it. The faculty from TERI said that, a very few of bioremediation technologies are commercialized. The reason needs to be located from the source; we have to see for other timeline, if those actions or plans have been used to develop this technology. Then feasibility study should be conducted. The funds that have been provided by the govt. for its research are low; it is evident that these days' funds are very much restricted, earlier the quantum of funds used to be comparatively high. If the technology is already proved in the market, and continued for the medium scale or small scale, to prove whether it can be commercialized or not, it has to be practically implemented.

The professor from JNU, has also explained about its prospective research arena. He said that, "as treatment of waste water is highly labour-intensive work, the advancement of the technologies is an alternative approach which needs to be adopted. We require an advanced and a 3rd stage (modern) technology to enhance its application. The combination of biological entities and nanotechnology to develop 'Bio-Nano' materials will definitely surplus the potential of this technology and could bring a boom in the contemporary world".

The potential role of nano-particles in bioremediation has been widely explored these days. Baiget et al. have demonstrated the reduction of soluble

[2] "EBB is a bioremediation product that contains effective bacteria in a dormant condition until immersed in water".

uranium (VI) to insoluble uranium (IV) using an integrated biotic–abiotic system for ex situ remediation of a uranium-contaminated mining effluent. Also, Braunschweig et al. reviewed the recently recognized potential of nano-sized Iron (Fe) oxides in their various biogeochemical roles (e.g. electron acceptor for microbial respiration, electron shuttle between distinct microorganisms, scavenger for heavy metals) and extend these insights, through an examination of the biotic and abiotic factors affecting the reactivity of iron nanoparticles. Hence they have explained their emerging significance in the development of bioremediation technologies for contaminated subsurface.

In a study Bardos et al. (2015), has illustrated that dehalorespiration a key process in biological remediation has this potential stimulating effect which is believed to result from the slow corrosion of Nanoscale zero-valent iron (nZVI). It is the most commonly used nano-remediation material which reduces water forming hydroxide (OH^-) and hydrogen gas, the universal electron donor for anaerobic microbial processes in the aqueous medium. Therefore, nZVI has the potential for synergistic application with bioremediation techniques.

6.2.3 Diffusion of Bioremediation and its R&D

Undoubtedly, it is the next phase of any technology after adoption. Diffusion is the process of closing the gap between what people do not know and what they can effectively put to use. It is extremely needed to translate environmental problems and liabilities into business opportunities. According to Stoneman (1985), "if we are to gain any insight into the processes of economic growth and development, for, whatever the emphasis has been in the past in research and public policy, it is the application of innovations (diffusion) rather than the generation of innovations (invention or R & D) that leads to the realisation of benefits from technological advance".

In India, the role of technology transfer agents and other channels of communications including organisations such as Indian Space Research

Organisation (ISRO), Atomic Energy (AE), Defence Research and Development Organisation (DRDO), Council of Scientific and Industrial Research (CSIR) have set up their own mechanisms to diffuse their innovations and technologies. The attempts are made to diffuse inventions, innovations and technologies generated in national or publicly funded R&D organisations and academic institutions through these channels.

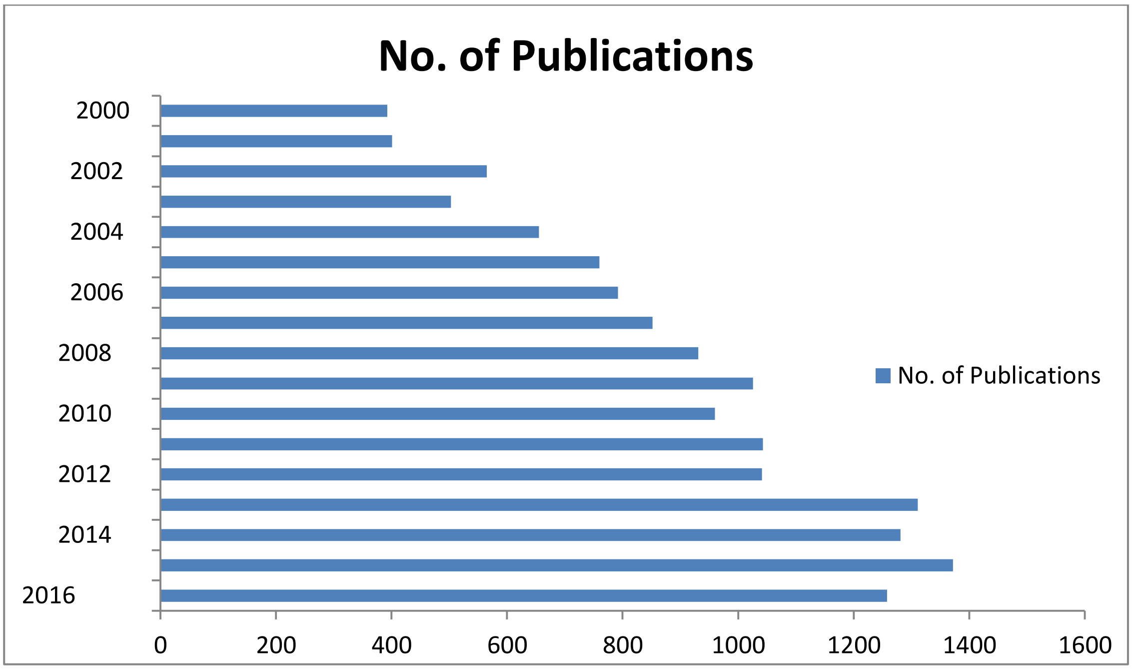
In context of this study, bioremediation is yet to be diffused into the mainstream, which is a leading challenge. In view of JNU Professor, "the communication gap of the research institutes, lack of coordination and less funding are the major challenges in development and diffusion of this technology".

According to TERI faculty, "it takes 7-8 years of intensive research which requires at least 2-3 phases of funding. Only few of the scientists are dedicated, because most of them focus on publications, they forget their main target, rather target should be to develop the technology and take it to the implementation level. Private companies are also working but because of these few scientist who are not dedicated this spoils the whole scenario. So it is recommended that policy should be stronger. This is a challenge in its diffusion. If we talk about its cost-effectiveness, it is probable to say that at a long run, when technology is developed, it is very much cost-effective. It needs to be followed stage wise, first it is at the budding stage, medium scale then pilot-scale, at this point it is cost-effective but again, the gestation period is high. To make it more cost-effective we need further explorations, for that we require funding".

In fact, it has been found that this technology is highly cost-effective compared to other technologies pertaining to decontamination of polluted sites. The Senior Manager of J M Enviro firm, emphasised that, the diffusion of the technology might not be due to the personal benefits of engineers as one STP construction costs approx. Rs. 3000 Cr. It doesn't require any land, any civil construction and power; hence it is also beneficial to treat waste water with a technology that involves natural process of degradation.

In recent years publication of bioremediation has emerged rapidly. The number of publication titles on water research is 455 now, but it is highest on Journal of Hazardous Materials i.e. 1095. The topic of water covered is 306 and for soil it is 1861.

Fig.6.1 Articles published on bioremediation (Global)

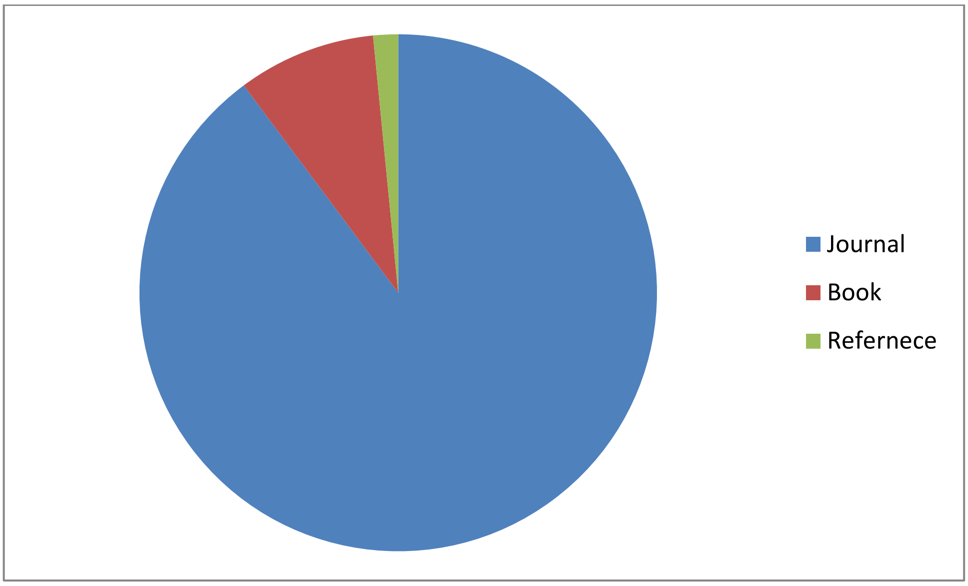


Source: Author; www.sciencedirect.com<D.O.A May, 2016

Out of total 19189 publications, the number of journal is 17235, book is 1656 and the reference work is 298, shown in Figure 6.2.

In the study conducted by Saraswat (2014), “among top five countries, United States (US) was the forerunner sharing 61.85% patents in bioremediation technologies followed by China (7.9%), Japan (6.77%), Korea (4.51%) and India (2.93%)”. The recent report suggested that “the counties with largest R&D expenditure are US>UK>France>Germany>Japan>China>Korea”. The study concluded that number of patent applications in bioremediation domain is very less.

Fig.6.2 Total contribution of published work on bioremediation



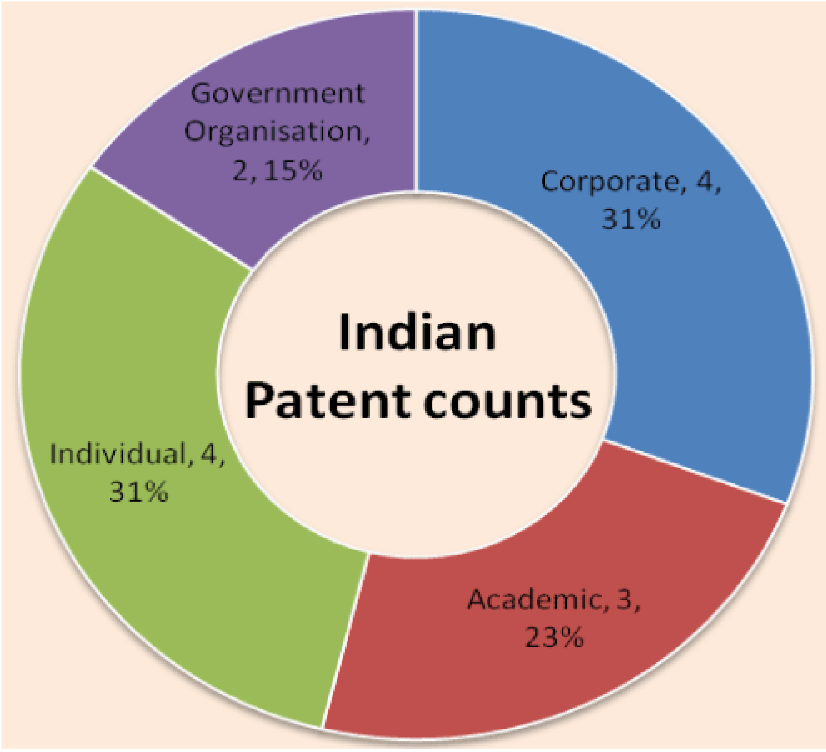
Source: www.sciencedirect.com

Most of the patents were directed towards processes for reclamation of contaminated soils using micro-organisms or enzymes. Comparatively, technologies for biological treatment of wastewater are less. These identified research gaps in the field of bioremediation bring out a scope for generating intellectual property rights in a wider sense (Saraswat, 2014).

As individuals have more number of patents as shown in Fig. 6.3. they are indicative of progressive hub of the nation. Therefore, government should promote such individuals and groups for developing eco-innovative pollution remediation technologies to leverage environmental protection.

Environmental pollution is a global issue disregarding political boundaries. Therefore, it is important for both developing and developed countries to emphasise in finding sustainable solution for pollution control. The transfer of bioremediation technologies and international diffusion in order to reduce their toxic wastes is necessary to contribute in global environmental protection. Hence, promoting eco-innovative bioremediation technologies would provide better environmental protection.

Fig. 6.3 Distribution of bioremediation patents in India



Source: Saraswat (2014)

6.2.4 Role of Actors in Positioning of Bioremediation Innovation System (BRIS)

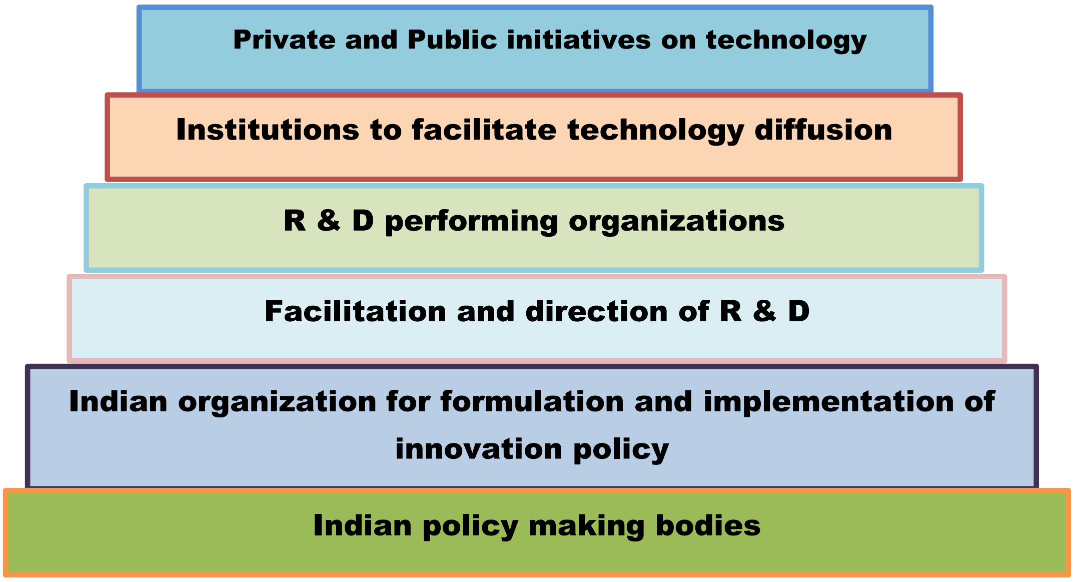
The various actors, agents, institutions and public/private companies are adjoining a common platform with an approach to sustainable solutions to the environmental degradation caused by human interventions through various channels. In NMCG, with the help of private firms the work on cleaning the drains is being conducted. The government agencies pertaining to water related issues, are welcoming private entrepreneurs to conduct pilot projects on Bioremediation that is itself an initiative to reach the sustainability goals. This in a way is creating or opening doors for an Organizational innovation as it is indicative of new forms of management being established in the organizations itself.

Also, the private firms are carrying out innovations in developing technology to meet the requirements demanded by the Government agencies in order to reduce contamination on sites and making them as cost-effective as possible.

However, it has been observed that it is an interesting but quiet neglected field till now. The BRIS is relatively in an evolving stage of the accounting profession in view of the fast changing social and economic landscapes. So the importance of a kind of hybridisation of actor's roles and tasks are required. Indeed the upcoming roles of researchers in the current economy, and to actively cooperate with other professional groups with different dominion and from diverse backgrounds, towards the achievement of common aims is remarkable.

Thus the provision of formal and informal tools and practices to foster this process deserves more attention. As it has been mentioned earlier also, the communication gap among the researchers and stakeholders for an issue relating to their ability to embrace different views and to interact with other groups of professional need to be seriously taken into consideration. So, to better depict the main implications of such a complexity, it is useful to refer to the issues relating to the management of the organizing bodies pertaining to the problem-solving or solution-seeking part of the matter, as illustrated in Figure 6.4. This provides an overview of the main organisations influencing the BRIS, with organisations depicting their main function. In addition, it is important to recognise the influence of national policy making and innovation support organisations in propelling the system. If the figure is seen from bottom to top, each box contemplates a specific function i.e. Indian policy making envisage policy making and there are separate organizations for Innovation policy formulation and implementation. The facilitation and direction of R&D function to Support and direct R&D. Also R&D performing organizations work to undertake R&D. On the other hand, institutions play an important role in facilitating and conducting knowledge diffusion. And at the top of all, private and public initiatives display the critical function of knowledge exploitation.

Fig.6.4 Organizational functions within the BRIS



Source: Author

In view of TERI faculty, the solution should be sought in a collaborative manner, like holding meeting with Ganga cleaning organizations (NMCG) and those industries which are polluting the river, and talk about the issue. She also added that "it has been observed that even if the industries are controlled, they do not allow collection of water sample on follow-up visits, claiming that they treat the water". There is no check or monitoring being done. They give incentives to the faculties or staffs who are engaged with treatment. So there should be some policy, and online monitoring system. The govt. should keep it under their control and check the regulation.

She emphasised that constraints should be looked up critically and solutions also have to be provided accordingly. It requires funding from the concerned industries for successful experiments. Now govt. is taking initiatives in developing the public-private partnerships. And policy has a crucial and central role to play.

It is interesting to note that the Indian regulation has altered with the present regime which has increased over the years by progressively enriching the number of measures and their applicability. It has highlighted the importance of the use of confiscated resources for social purposes. Such a process culminated with alteration in organisational structure, initiatives aimed at providing a systematic and revision of the existing norms towards more effective actions to distinct the organised polluting bodies that remain under-assessed most of the times.

According to Rathoure (2015), greater effectiveness of the prevention measures is widely accepted, not only for the presence of a specialized court that administers the check, control and regulation of a particular policy but also for their more rapid and broad applicability.

From this perspective, and in the light of the above mentioned difficulties struggling with a multidisciplinary and multifaceted knowledge that are required to acquire in short times call for a more systematic regulative action that are even more acceptable and reasonable.

Conferring from the views of professors/researchers from the universities/ laboratories and private firms, if the problems related to interaction between the professional groups are re-called on a particular issue it could be managed effectively. It will be possible to realize a fully successful interaction between them and the innovative biotech networks, in the battle against environmental contamination and leading towards sustainability.

6.2.5 Socio-Economic Dimensions of the Technology

In contemporary world, a significant contribution by scientific and technological research has always facilitated to seek solutions for sustainability and development challenges. It is important to understand human and social dimensions of science and technology as an important complement to this research. To ensure that new scientific ideas are applied appropriately in diverse cultural contexts, and support improvements that is rational among and within nations. Therefore, it is essential to integrate relationships between science, technology, and society into the broader sustainability and development research curriculum.

In view of the present environmental scenario, it is undoubted that environmental complexities are affecting people as forces such as demographic change, urbanization, competition for scarce resources, migration and diversity are inadequately managed, and they may also give rise to major challenges such as intolerance and conflict. The situation demands for a systemic approach to solutions and shift to a combination of approaches that comes in the form of eco-innovation.

According to Government officials, "if we try to find out the indicators of the innovation performance that leads to growth and economic prosperity, it is difficult to give insights into social aspects of these developments."

For any technology to be accepted by the society, it has to be inclusive, and sustainably viable. "In case of bioremediation technology, it requires people's perceptions, knowledge, and attitudes towards it", pointed by the JNU professor (respondent). The influence of people may differ from country to country on the use of bioremediation but can be critical to the continued and expanded use on contaminated land or water.

Taking on the view of researchers, it can be inferred that bioremediation is an evolving research field although its prominence is increasing with time, but the gap still lies in its acceptance as an alternative technology. Proclamation of future consequences of the use of technology is difficult at this stage. So there emerge two trends: one of these is favourable for bioremediation technology and other is unfavourable. The relative importance would vary in a particular context.

Apparently, technologies are influencing the global communities at a faster rate. Thus, considerations imbibing thought and meaning are crucial that aims technology use reflecting the shared needs and values of society. An understanding of dynamics between society and technology is vital to improve utilization of resources for the world's future prosperity.

However, in order to analyse such challenges, to make sense of their implications and to respond to them adequately, the resources of the social and human sciences are indispensable. Similarly, "humanities studies, which have a crucial role in promoting critical thinking, have a major contribution to make to global, regional and national responses to contemporary social and ethical challenges faced by major steps of scientific and technological advancements", supplemented by faculty of Teri University.

So it could be inferred from the above discussions that the role of technology and its socio-economic dimensions are yet to be explored well. The mixed views are insufficient to clarify on which way bioremediation technology would lead to.

6.3 Implications of the findings

The study was aimed to seek responses of a number of research question related to bioremediation, its evolution and potential as an alternative technology. Also, it aimed in particular to examine its process, practice and organizational structure along with its knowledge mobilization (diffusion). It was based on the framework of eco-innovation drawing on three factors regulation, process and organizational structure of the respective components, the analysis attempted to elaborate more on these aspects. It has definitely fetched us certain implications that have been jotted down keeping in mind the context of this study.

1. An important inference that came out was that there is a lack in knowledge mobilization when operating at a national level. This might be due to less concern on facilitation of R&D on this research area. A special attention towards the practice and execution is also needed in undertaking R&D, with deliberations and communication among researchers.
2. The empirical data aids to major practical contribution which is needed on the activities surrounding the mundane adoption and diffusion of bioremediation. Its importance depends on, if it has not been explored well earlier.
3. Another important implication of the study arises from the finding on the uniqueness of the knowledge and information work carried out by NMCG as part of cleaning of rivers. The finding points to a specific set of capabilities, information source, decision styles and strategies, attitudes towards knowledge and evidence that may set apart the work of this organization from the other existing bodies.

Although analysing the data with a view to identifying and codifying these skills and behaviours goes beyond the concern of the current study. But contacts have already been established with appropriate institutions to explore how this can be achieved collaboratively in the near future.

4. A third implication stems from the framework of the study which could differ on the notion of individual's choice. The finding suggest that knowledge mobilization, understood as a series of practices and tools that support, foster or hamper the continually evolving technology, is possible, when organizational capability be learned and refined as one's perceived context and tasks change over time.
5. Accordingly, the research suggests that we need to abandon the simplistic instrumental view that simply asks 'what' type of inquiries. Instead, the issue of how to nurture and support the knowledgeability of technology may need to be addressed in terms of how such a capability could be sought, developed and improved through a reflective and continual monitoring of individual's (private and public) initiatives in developing the bioremediation technology.
6. In this sense, although this research falls short of developing a fully formed diagnostic tool given its exploratory nature, it clearly indicates the main dimensions of a framework for reflecting on the trend regarding bioremediation.

7. The study being of exploratory and interpretative nature raises a number of opportunities for future research, both in terms of theory development and concept validation. More research would be necessary to refine and further elaborate the novel findings. The study could also be extended in longitudinal and comparative ways.

CHAPTER 7
CONCLUSION

The main objective of the thesis is to understand and analyse the emerging approaches in Bioremediation Innovation System in India, taking Yamuna River in Delhi as a case study. This system being an evolving system, needed to penetrate deep into its knowledge generation and diffusion process, involving several actors and institutions associated with it. This study is grounded on the idea that the problems relating to environmental degradation and pollution as the consequence of uncontrolled development and population growth, represents issues that still deserve further investigation, above all in relation to sustainable development. The issues pertaining to water, is flaming these days, in this view, restoration of the natural resources especially water is highly considerable in the present sustainability regimes. With this view, Yamuna River in Delhi is facing a detrimental condition which requires an ultimate attention and measures for its revival.

The present study is exploratory in nature and has followed a systemic approach taking Eco- Innovation as a theoretical framework to address the research questions, where it looked into the regulation, process and organizational structure of the technology in a system. The study has documented the socio-economic characteristics (demography, urban and rural population, agriculture etc.) of the study area through observations and literatures. To elaborate more on the roles of actors, it has been provided with a distinct part to each of the actors and tried to justify one of the objectives of the study. The collected data and information were analysed empirically, drawing on literatures, discussions and observations.

Conventionally, the techniques used to treat the contaminated water became a failure as centrally sponsored schemes are not able to reach at full tilt to meet increasing demands of water and clean river and adjoining floodplains, although spending a huge amount of money. This pushes to make a shift to decentralized mechanisms, which could be acquired by bioremediation technology. If the river gets revived again by bioremediation after treating the drains being discharged directly into the river, the socio-economic conditions that got affected by the river pollution would be addressed. It might generate other sources of income again which has been shattered by the pollution.

It has been found through literatures that the motivation of cost savings triggers eco-innovation. The role of regulation strongly influences eco-innovation. Organizational innovations such as environmental management systems seem to be an especially important tool for triggering these cleaner cost-effective technologies such as Bioremediation.

The innovation processes are progressively central to research in biotechnologies that have gained in particular plenty of trust and recognition by public opinion and governments worldwide, over the lasts years. The change in technology or adopting a new technology takes time to get positioned in the existing technological diversities. As the potentials of bioremediation are explored and still evolving with time, its acceptance at a commercial level is a challenging concern. It fairly depends on its prospective as an alternative technology and also decisions made by government assisted by societal support and coordinated policies that favours innovation which simultaneously seeks environmental sustainability. Therefore, a global and holistic view encompassing economic, social and ecological aspects of bioremediation becomes critical.

In fact, sustainable development involves the consideration of many diverse, multidimensional and sometimes contrasting fundamental problems, as well as broad range of stakeholders at local, regional and global levels.

The study tries to seek solution that, it may be enriched and reinforced by the activation of cooperation dynamics and the stakeholder's interactions among various actors, especially taking into account the industry and the research institutes, have cultural and social impacts. The social implications and open concerns, both in relation to the linkages within innovative networks and between institutional professional's actors, allowing the identification of any grey areas and limitations. The present work also emphasised on the framework useful to find out what are the factors that encourage effective systems interactions and an enhancement of knowledge production and knowledge diffusion, towards a value-added sustainability. In this regard, it is worth stipulating that the above-cited systemic view adopted in the study allowed us to provide evidence that looks at the issues relating to the commercial social/ environmental sustainability and also to the crucial questions of the systems social/environmental sustainability.

Further, the study proves the importance of institutions in growth and development of the Bioremediation Innovation System. The various actors, agents, institutions and public/private companies are adjoining a common platform with an approach to sustainable solutions to the environmental degradation caused by human interventions through various channels. The government agencies pertaining to water-related issues are welcoming private entrepreneurs to conduct the pilot projects on Bioremediation that is itself an initiative to reach the sustainability goals. This in a way is creating or opening doors for an Organizational innovation as it is indicative of new forms of management being established in the organizations itself.

The shift to private companies might be due to the cost-effectiveness as positive environmental effects can be explicit goals or side-effects of innovations, depending on the use of product or services.

The study reveals that the governance taking care of environmental issues at the national, regional and global levels is crucial for the attainment of environmental sustainability and eventually sustainable development through technologies like bioremediation. However, despite the surprising and undeniable ability of bioremediation to producing radical innovations and improving environmental conditions, it is quite clear that there is still a lack of valuable components to envisage a full expression of its potential. For this new reforms and new policy regimes are crucial to making the interplay happen in a favourable manner.

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9. APPENDICES

9.1 ANNEXURE-I: QUESTIONNAIRE

1. The recent issue of Yamuna River is prevalent in today's policy agenda, what are your view points on this?
2. What kind of technologies are employed or proposed to be employed for cleaning of the river?
3. Why are the centralized schemes failing or failed?
4. Why the alternative technologies like bioremediation are not employed for the treatment of polluted rivers?
5. Why do you think, the collaborations are not maintained so strongly or following the common approach?
6. What could be the reasons that R&D is not very much directed towards the applied research like bioremediation?
7. How do the centre and the state government coordinate in the clean Ganga/Yamuna Mission?
8. Are the efforts appropriate or sufficient?
9. What do you think if bioremediation can be used as an alternative technology for the cleaning of Yamuna River?
10. Does this technology have a potential to remediate the river pollution?
11. At what scale this technology is being employed?
12. Do you have any collaboration with research institutes?
13. Do you offer any services to the Government bodies for treatment of contaminated sites?
14. Do you get any help from the R&D departments like CSIR, DST etc.?

15. In what ways we can apply bioremediation to the contaminated sites?
16. What challenges are being faced by the researchers in order to develop this technology and its diffusion?
17. How innovations are being carried out to enhance the potentials of bioremediation technology?
18. How much cost-effective this technology is compared to other technologies?
19. How can we facilitate the diffusion of bioremediation technology?
20. What could be the factors that affect the socio-economic dimensions of the technology?