1

Introduction

1.1 Theme and rationale of the study

It is an established fact that out of all the available natural resources, freshwater is undoubtedly the most important for the living world. Rivers of various length and size serve as major source of freshwater on the earth. Natural flow patterns are the basic pre-requisites for a river system. Flow regime components ranging from low flow to seasonal floods play a crucial role in shaping a river ecosystem and livelihoods of river-dependent riparian communities.

Despite the huge availability of water, it is not evenly distributed all over the globe. However, the Northeastern region of India is endowed with a bounty of accessible freshwater sources in the form of various streams, rivers, lakes, wetlands, marshes etc. with the mighty river Brahmaputra flowing across the middle of the area. These rivers supporting the social, ecological, cultural and overall environmental setup of the region act as arteries in human body. Additionally, these rivers alongwith numerous floodplain wetlands sustained by them serve as shelter to a variety of organisms and sub-ecosystems.

The socio-economic, political and cultural well-being of a particular region is directly proportional to the availability and distribution of freshwater riverine systems. In the last few decades, in order to meet the needs of the swelling population there is a worldwide degradation of the freshwater ecosystems. We are now faced with the harsh reality that many of our rivers are in a very bad shape and a few of them already on the verge of extinction. Studies reflecting the negative impacts of land use on riverine environment within rural, urban and industrial areas are being conducted globally by different authors [1, 2, 3 and 4].

Until recently, the rivers of North-East India were in pristine free-flowing and undisturbed state. However, during the last few decades in order to meet the growing demands of the increasing population, our freshwater resources are being exploited and degraded at an alarming rate. Out of numerous irresponsible anthropogenic acts being perpetrated on our rivers that require special mention are of water pollution from various point and non-point sources, damming (both for flood control as well as hydroelectricity generation), over abstraction and human encroachment in the river beds and floodplain areas. Human interference in the form of embankments have regulated and fragmented the flows of our rivers – often irreplaceably, hence, forcing the rivers towards their hydrological and ecological death. The Bharalu river of Guwahati, Kolong river of Nagaon, Bhugdoi river of Jorhat, Umiam river of Shillong, Wangjing river of Manipur etc. are examples of few hydrologically and ecologically degraded river systems of northeast India. A degraded river system subsequently leads to huge loss in bio-diversity, agricultural productivity as well as socio-economic and aesthetic values.

In the present milieu, it is high time to recognize and facilitate the concept of sustainable river restoration plan based on state-of-the-art knowledge and scientific expertise currently available on the subject. River restoration is an approach utilized to reverse past degradation of freshwater ecosystems and to mitigate the anticipated damage to freshwaters from future activities [5]. The concept of sustainable river restoration has gained substantial momentum in the last few decades. A considerable amount of river restoration works has been conducted in many countries around the world including India. Although in some more advanced countries like USA, Japan, China, Russia and also in some parts of India, river restoration is no longer a new concept, however it is still at its infancy in Northeast India despite widespread degradation of our river systems.

Few notable national level river improvement examples are discussed below:

Many Indian rivers, including the Ganga in several stretches, particularly during lean flows, have become unfit even for bathing because of huge pollution load contributed by point and non-point sources. Realizing that the rivers of the country were in a serious state of degradation, a beginning towards their restoration was made with the launching of the Ganga Action Plan (GAP) in 1985. The principle thrust of the GAP was to intercept and deflect the wastes from urban settlements away from the Ganga River. Although initially the GAP was focused on restoring the water quality of the Ganga River, its focus has now been evolved to cover all other major national river basins in India, including a few lakes under the aegis of the National Rivers Conservation plan.

Other examples of few national-level restoration works that can be cited here include the one in Gujarat where the Aga Khan Rural Support Programme (AKRSP) has restored the Meghal River. Similarly, in Alwar District of Rajasthan, Tarun Bharat Sangh revived a system of five rivers primarily based on the traditional knowledge and indigenous know-how of the local people. Over a period of 25 years, the NGO has worked with villagers to revive the Arvari and Nanduwali River by restoring the traditional social processes of water management. Sankat Mochan Foundation of Uttar Pradesh is currently working on the restoration activities for the River Ganga and to mobilize community interest and participation.

The National Green Tribunal (NGT) in a landmark judgment pronounced on 13th January 2015 has set an ambitious route map and principles for a rejuvenated Yamuna River by the end of 2017. It has undertaken a project entitled '*Maily se Nirmal Yamuna rejuvenation project, 2017'* encompassing various measures of preventing and controlling of pollution of the river for reviving it into its former self. Similarly in Northeast India, Manipur has recently started working on restoration of River Wangjing in collaboration with Global Water Partnership.

Successful restoration projects begin with careful investigation of the stream system, including the historical meteorological patterns, stream hydraulics, sediment transport patterns and various other related conditions. Unfortunately, most of the river rejuvenation projects in India are found to focus mainly on the water quality aspect thus neglecting the natural flow requirement options. The minimum flow required in any fluvial system and its connecting ecosystems to execute their ecological and evolutionary functions is broadly termed as *Environmental flow* (e-flow). Globally, extensive progress has been made in implementing policies and laws to identify environmental flow needs of various rivers. Recently, several Cumulative Impact Assessment (CIA) techniques of Indian Rivers like Lohit, Alakananda-Bhagirathi, Bichom etc. have also introduced the e-flow estimation techniques [6].

Water flowing through our rivers is a precious natural resource and at the same time very complex to manage. Humans have manipulated this precious gift of nature as per their requirements since time immemorial. Exploiting and taming of water bodies for hydroelectricity generation, flood control and solid waste disposal are among few instances of extensive and deliberate destruction. No doubt, development and human benefits are the prime objectives of today's world; however, it should never be attained at the expense of our environment. So, there is a thrust towards the concept of sustainable watershed management in the present world.

1.2 Statement of the problem

The Kolong River of Assam, once a free-flowing and flourishing off-shoot stream (*Suti* in local language) of the mighty river Brahmaputra, was known for its active navigability, rich biodiversity and high agricultural productivity. The river and its adjoining wetlands have had a considerable influence on the riparian communities who have settled on its banks over the centuries. During the colonial era, the Kolong River and the smaller streams feeding it were the primary source of potable water for the people of the region and hence most of the human settlements were found concentrated along their banks. Notably, in those times, there was substantial scope for drinking, washing, bathing, swimming, fishing, irrigation, navigation etc. Besides, the flood waves during the flood season used to deposit fertile alluvium in the adjoining floodplains thus aiding natural fertilization.

The Kolong River also facilitated the development of a significantly rich natural ecosystem where large variety of fishes and other aquatic flora and fauna including river dolphins flourished. In addition, an array of biologically prosperous, economically resourceful and hydrologically important wetlands were created by the meandering course of the Kolong River and found scattered all over the floodplain. The present day ***Samaguri beel*** and ***Mori-Kolong beel*** are few notable examples of such creation which are ox-bow lakes developed on portion of abandoned river channels. Apart from these, the river also served as an important business link between lower and upper Assam during those days. Tea leaves and other vegetables grown in parts of the Kolong basin were transported to other parts of the state via steam boats which once used to ply on the Kolong River.

However, it is an irony that such a socio-economically dynamic and ecologically significant river is currently suffering persistent deterioration mainly caused due to an unscientific human intervention as an ad-hoc flood control measure during the year 1964. It is noteworthy that, as an aftermath of the great Assam earthquake of 1950 (measuring 8.7 on the Richter scale), the magnitude and frequency of flood episodes in the low lying riparian tracts, including the Kolong basin, had assumed serious proportions primarily as a result of aggradation of the river beds due to increased sedimentation [7].

In order to tackle the escalating flood menace and to safeguard the district head quarter town of Nagaon in particular, the entry of water into the Kolong River was blocked by putting up an earthen embankment across its take off point from the Brahmaputra at Hatimura during the year 1964. This massive alteration done on the river has left the channel incised and mostly detached from its former floodplain thus shattering the delicate agro-economic base of the Kolong basin.

Although, the flood risks has reduced to some extent by the embankment, but the undesirable environmental, social, ecological and cultural impacts it caused all along the river, essentially in the up-stream portion, are absolutely unwanted and destructive. In the subsequent years that followed, the river bed started getting filled in with waste materials, sediments, and invaded by water hyacinth (*Eichornia sp*) and other weeds like *Ipomoea* etc. Due to lack of enough flow, especially during the non-monsoon months, the river dries up almost completely leaving only fetid pools of water here and there. Consequently, the unique freshwater habitats that existed in the pools and riffles present along the meandering course of the river are highly disturbed, and thus, the rich aquatic and riparian biodiversity which used to flourish earlier in this region is now almost missing or in highly jeopardized state with river bed being encroached by illegal settlers. There is reportedly a sizeable decline in agricultural productivity particularly in the upstream floodplain regions due to the lack of sufficient water in addition to lowered groundwater table.

Besides, degradation of river Kolong has dealt an ecological disaster to numerous water bodies which used to be nourished by an overflowing Kolong in flood season. The Samaguri Beel, an ecologically important wetland famous for its bird diversity and aesthetic beauty is an example of such a degeneration of an excellent water body. Water level of Samaguri beel has fallen over the years because water has ceased to flow into the wetland from the drying Kolong. Moreover the feeder channel with which the wetland was linked to the river Kolong has also degraded considerably. Water hyacinths have made their insidious presence visible in many parts of the beel. Fish population has dwindled significantly in recent years putting the survival of the local fisher folks and fish dealers at risk.

Moreover, the release of untreated solid wastes by the major urban agglomerations present along the river stretch in addition to the lack of self-purification capacity of the river due to insufficient flow has left the river in nearly moribund condition. On one hand, the municipal corporation at-large is inept to treat the increasing load of municipal sewage flowing into the river, while on the other hand the receiving water body does not have sufficient water for their dilution. Consequently, the Kolong River is listed among the 275 most polluted rivers of India by the Central Pollution Control Board [8].

In a nut-shell, the Kolong River and its floodplain are seriously being degraded as a consequence of the post-dam effects thus diminishing their potential to perform various riverine functions. Among all the environmental changes brought about by the dyke construction, the alteration of natural flow regimes has the most persistent and detrimental effects on the fluvial system. River restoration/rejuvenation which is the science and art of working with a degraded river system with an aim to revive it in every possible manner is the only viable option for ensuring an ecologically healthy Kolong River system which in turn will act as an integral part of sustainable watershed management. Thus, in the present context an environmentally sustainable, economically feasible and socially acceptable river restoration plan based on state-of-the-art technologies and scientific know-how presently available on the subject, is the need of the hour.

1.3 Significance of the study

In the present study, the Kolong River is selected for an elaborate river restoration work as it is a preeminent example of a degraded river of Northeast India. Despite certain reach scale restoration plans with minimal scientific validity are being attempted on the Kolong River in the recent past, the lack of large-scale spatio-temporal and scientific considerations has led these efforts to fail miserably. The spoon feeding of water from Brahmaputra to the artificial channel of Kolong River at the takeoff point under the scheme of integrated lift irrigation system is an appropriate example of such a failure. Thus a comprehensive river restoration plan that reestablishes watershed-scale connections encompassing the entire Kolong river system is an essential need of the hour and hence this maiden attempt has been made. Accordingly, in the present context, a holistic scientific, technical and geo-environmental study is conducted and a regulated river flow regime harmonized with a carefully intended control mechanism at the take-off point is finalized so that the minimum flow necessary for sustaining freshwater ecosystem and human livelihood and well being is attained.

Moreover, unlike rivers of some developed nations, lack of available hydrological and physical databases is a major constraint for any scientific study and planning in case of the Kolong River. Therefore, in the present research an effort has been made to develop a methodical knowledge-base for the Kolong River system in order to attain a significant enhancement on current and future river rehabilitation projects.

1.4 Historical account of the Kolong River

The Kolong River basin is a major watershed of middle Assam. The river had great influence on the masses dwelling on its both banks over the centuries. A number of battles were fought on the banks of the river. The presence of the river became so intertwined with the region itself that the region and the river became synonymous. There are numerous manuscripts like imperial gazetteers, historical accounts of British expeditions and various books on history of Assam by different British writers with wealth of information regarding the socio-political-economic history of the Kolong River and its floodplain wetlands. The information and data used for analyzing the history of the river and floods were collected from both primary and secondary sources. The secondary sources included the imperial gazetteers, notes on the Kolong River, historical accounts and field notes of British officers on duty. As a primary source, unstructured interviews and conversations were conducted with some of the informed sections of the public in order to gather relevant historical account of the river.

The riverine history interested the British who were keen to know about the riverine systems of Assam. E.A. Gait, W.W. Hunter, F. Hamilton and B.C. Allen were the pioneers in this regard. Their accounts of the river valleys and its people yield valuable information about the interest and perceptions of the colonial administration.

Hunter (1879) [9] had depicted a meticulous history about the river and its neighborhood. To quote Hunter, "*The next principal river is the Kalang, which issues from the Brahmaputra in the north-east of the District, flows a southwest course through the estates of Kaliabar and Nowgong, then turns more to the west, flowing through the estates of Raha and Chapari, and finally rejoins the Brahmaputra at a* *place called Kajalimukh, about fifteen miles above Gauhati. During the rainy season the Kalang has a depth of upwards of twenty-six feet of water; but in the cold weather it is only navigable from its confluence with the Brahmaputra in the extreme east of the District for a distance of twenty-one miles. It is, however, navigable for large boats during about six months of the year".*

The morphology of the river is well described by Sir Edward Gait [10], according to whom there was a single stream named Dikhu flowing from Majuli upto Kajalimukh, parts of which still survives at Majuli and at Nagaon with the name Tuni river and Kolong river respectively. Allen et al (1905) [11] in the Imperial Gazetteer of the Bengal province provides a wealth of information about the river, the topography, the vegetation and the people of these areas. He opined that the great Brahmaputra throws out large branches on either side, which rejoin the main channel after divergence of many miles. Kolong River is one such large divergent channel, which is an offshoot of the Brahmaputra. They further inferred that the Kolong River in the past served as a pivotal transportation and commercial link between Nagaon and Guwahati.

There is frequent reference to the island between the Brahmaputra and Kolong River in the book *'An Account of Assam'* by Hamilton (1940) [12]. He used Wood's survey, to ascertain that about 104 miles upstream of Guwahati, the Brahmaputra divided into two branches; of which the northern is by far the greatest, and preserves the name, while the southern was presumed to be the *Kolong*.

The above discussions give us a fairly good idea about the size of the river in the past; hence, demonstrates an epigrammatic outline about Kolong River.

1.5 Review of relevant literature

Although the concept of river restoration is not very old but presently large number of works in this field are being carried out globally. The dynamics of river restoration and associated problems are comprehensively studied by scholars all over the world. Some of the relevant works are mentioned below:

1.5.1 Research work done abroad

The River Thames in Britain is one of the first well documented cases of successful river restoration. The Thames had become critically polluted by the early 1800s. Restoration began in the 1960s and chiefly through the construction of sewage treatment plants the fish fauna of the river exhibited a fantastic recovery [13].

Hill et al (1993) [14] focused on the fact that biodiversity of a river can be increased tremendously by restoring its natural flow regime through dam removal. They cited the example of the removal of the Dead lake dam on Florida's Chipola River, following which flow fluctuation increased alongwith diversity of fish species, which expanded from 34 to 61.

Iversen et al (1993) [15] stated that Denmark alone has removed numerous small dams from its highly impacted river systems and resultantly has succeeded in improving habitat and fish passage on many of its rivers. A similar review concerning the environmental and socio-economic effects of dam removal was also addressed by Shuman (1995) [16].

Auer (1996) [17] represented the modified operating criteria suggested for relicensing of over 450 FERC-licensed dams of United States between 1999 and 2001. Through the relicensing process new dam operating conditions were set for meeting environmental concerns, including increased minimum flows, added or enhanced fish ladders, periodic high flows, and protection actions for riparian lands.

An overview of the detrimental ecological impacts of the Edwards Dam over Kennebec River leading to serious decline in numerous fish species by blocking migration and diminishing suitable spawning habitat was mentioned by Dadswell (1996) [18]. Based on the quantum of ecological and socio-economic impacts, the Edwards dam was removed in July 1999.

Another example of dam removal as a solution to ecological river restoration was cited by Arnould (1997) [19]. He mentioned about the removal of two large dams in the Loire valley of France as an effort to restore Atlantic Solomon on the European Atlantic Coast.

Kondolf (1997) [20] studied the negative effects of damming on sediment regime of riverine systems. He found that obstruction of rivers by dams disrupt the movement of sediment in them and causes changes in river’s structural habitat. The study reveals that retention of sediment by any reservoir can cause sediment-deficit water to be released downstream of the dam, thus limiting the sediment and nutrients availability for the native organisms. Whereas, with a river no longer having the power to transport sediments downstream, often results in aggradation of stream bed by silt deposition upstream of the dam [21].

Poff et al (1997) [22], in a research paper entitled ‘The Natural Flow Regime’ surveyed the role of spatial and temporal variations in magnitude, frequency, duration and regularity of flow as a driver for habitat stability, sediment transport and broader connectivity of river floodplain ecosystem. They stated that by physically blocking a river, storing excess runoff, or releasing water according to human needs, dams leads to alterations of natural flow regimes thus ecosystem imbalance.

Sparks et al (1998) [23]assessed the degree of change in the flow regimes of two ecologically and commercially important rivers viz. the Illinois and the upper Mississippi river and described ongoing efforts to restore or naturalize the altered flow and sediment regimes.

Bednarek (2001) [24] in his paper entitled ‘Undamming Rivers: A review of the Ecological Impacts of Dam Removal’ discussed elaborately the ecological benefits and cost effectiveness of dam removal as an option towards river restoration. The paper reviews various case studies regarding the possible ecological impacts of dam removal. According to this paper, dam removal although controversial, is an important alternative for river restoration.

Wohl et al (2005) [25] in their paper on ‘River restoration’ described the necessity of a sound scientific basis for attaining successful river restoration results. Believing natural variability as an inherent attribute of all river systems, they hypothesized that restoration of process is more likely to progress successfully than restoration aimed at fixed end point. Moreover, they encouraged watershed scale undertakings to achieve restoration objectives.

Bernhardt and Palmer (2011) [5] had summarized elaborately a wide array of recent river restoration approaches and the limitations being faced during their successful implementation. They emphasized on protecting and promoting healthy riparian vegetations and reinstating the reduced hydrological connectivity between rivers and their floodplains in addition to structural enhancement of the stream channels for achieving restoration goals.

Lehner et al (2011) [26] carried out an elaborate study on the existing reservoirs dams on the rivers around the world and developed a global database describing their characteristics and geographical distributions. They concluded that smaller reservoirs pose considerably more eco-hydrological and socio-economic impacts on the riverine systems due to flow alterations than in comparison to larger dams.

A lot of research has been devoted highlighting floodplain connectivity as an inseparable component of river restoration. Ward and Stanford (1995) [27] had conducted a detailed study on hydrological connectivity in alluvial river ecosystems and its disruption due to long-term flow regulation. They remarked lateral and in-stream connectivity as an important component of almost all aspects of a functioning river system, together with the maintenance of water quality, flow, temperature and sediment transport. Winter (1990) [28], Drinkwater and Frank (1994) [29] and Wik (1995) [30] studied the enhancement of fish movement and improved habitat quality augmented by re-establishing connectivity of river-floodplain systems. Further, Heiler et al (1995) [31] regarded hydrological connectivity and flood pulses as the key aspects for the integrity of a river-floodplain system.

Preety et al (2003) [32] reported a systematic assessment of the effects of river rehabilitation efforts on the ecology of the river especially on target organisms like certain fish species. They assessed fish population of 13 rehabilitated rivers using point abundance measures and depletion electro-fishing. They concluded that, in general, rehabilitation strategies increased depth and flow heterogeneity of the concerned rivers, and fish species richness and diversity appeared to respond positively to increased flow velocity in the restored reaches.

Poff et al (2003) [33] established the fact that restoration of flow regimes below existing water control structures presents fabulous opportunities to gather knowledge about system specific responses that can act as a guiding tool for future restoration actions. Experimental flood release for instance those on the Colorado River in Grand Canyon [34] or the Murray River in Australia [35] deliver opportunities to establish and test hypotheses regarding the ecosystem effects of these floods. These experimental flow releases provide important knowledge about river response to restoration efforts.

Palmer et al (2005) [36] and Giller (2005) [37] recently put forward some standards for ecologically successful river restoration plans. They attempted to develop a consensus describing the important parameters needed to be considered for examining a successful river restoration outcome. They established a set of criteria or standards against which the restoration projects can be evaluated.

Rohde et al (2005) [38] had examined an integrative search strategy for floodplain level restoration. During their study they prepared restoration suitability maps based on a list of criteria and indicators that emphasizes the ecological key factors like hydrology, connectivity, bed load, water quality and sediment load etc. that drive floodplain restoration. The study was based on the application of GIS with multiple criteria decision analysis (MCDA) system for generating the restoration maps. Lastly, the practical applicability of the search strategy in accomplishing floodplain restoration was illustrated through a case study from the Rhone-Thur Project in Switzerland.

Nakamura et al (2006) [39] presented a well-documented overview of the various ongoing and completed river restoration works in Japan and discussed in detail the lessons that can be learned from those restoration case studies.

Brooks and Lake (2007) [40] assembled and combined data on restoration projects in Victoria, Australia. A total of 2,247 projects were with the main focus on riparian management including fencing, native plant revegetation, weed management and willow removal. Bank stabilization, habitat improvement and channel reconfiguration were also considered in the research.

Few case studies depicting the ecological success stories of river restoration was analyzed by Alexander and Allan (2007) [41]. As part of the National River Restoration Science Synthesis, they interviewed 39 project contacts from a database of 1,345 restoration projects in Michigan, Wisconsin, and Ohio to (1) validate project information; (2) collect data on project design, execution, and coordination; (3) evaluate the extent of monitoring; and (4) estimate success and the factors that may influence it.

Richter and Thomas (2007) [42] found that for restoring biodiversity and ecological function in rivers which have been subjected to flow diversion or are dammed, it is necessary to reestablish historical flow regime, levees removal for recovering floodplain functionality, scheduling of water releases from impoundments etc. Furthermore, in some cases even removing flow blockage or reconnecting river reaches were recommended.

Rosgen (1997) [43] reported the importance of stable channel configuration for a successful river restoration plan. He developed a system for clustering all rivers into a few categories based on eight fundamental characteristics, including the channel width, depth, slope, and sediment load. Land managers easily classify a river based on this system and then predict how it might respond to changes, such as increased sediment.

The simultaneous consideration of both physical as well as biological components in a successful river restoration technique is being pointed out by Schiff et al (2006) [44]. Shields et al (2003) [45] described the application of hydraulic engineering tools for the assessment of watershed geomorphology, channel-forming discharge analysis, and hydraulic analysis of flow and sediment transport.

The applicability of the relationship between rates of change of channel physical dimensions with change in discharge in formulating a proper river restoration design was discussed elaborately by Copeland, 1994 [46]. Thus, the 'hydraulic geometry' relationships which provide a basic framework for operational river restoration came into limelight. Leopold and Maddock (1953) [47] were the pioneer workers on the field of hydraulic geometry and they described the rate of change of width, depth and velocity as power functions of discharge.

The importance of public participation in successful accomplishment of river restoration demands widespread attention. Adequate studies focusing public attitude as an important ingredient of restoration work are available nowadays. Tunstall et al

(2000) [48] in their paper entitled 'River restoration: Public attitudes and expectations' carried out a study focusing on the public attributes towards restoration in three rivers using questionnaires and in-depth interviews between local public and restoration managers. Based on their study, conclusions are drawn that consultation and involvement of local residents yields better results.

Once a restoration project is implemented, it is necessary to regularly quantify its success or failure rate. Downs and Kondolf (2002) [49] presented an overview on post-project appraisals in implementation and management of river channel restoration. They emphasized the applicability of post-project appraisals in better understanding the short-term and long-term performance of river restoration projects thus providing the basis for communicating the outcomes of one restoration scheme to another, thereby improvising future restoration initiatives.

1.5.2 Research Work done in India

Unlike most of the developed nations, the river restoration perspective with a scientific modulator is a new concept in India. Although, the tradition of treating rivers as sacred entities is prevalent since time immemorial, however, extensive anthropogenic pressure, with intense landuse and indiscriminate resource extraction has left our rivers extremely stressed and flow starved.

The Ganga Action Plan (GAP) under the aegis of Central government is perhaps the oldest river rehabilitation strategy undertaken in any Indian River based on scientific inputs. GAP was initiated during 1986 with the view to rejuvenate the Ganga River which has been facing the detrimental effects of water pollution for the past few decades. The main thrust of the GAP was to intercept and divert the municipal and domestic garbage and sewage generated from urban settlements away from the Ganga River. The GAP has further evolved to cover all the other major national river basins in India, including few lakes under the banner of National Rivers Conservation Plan.

Helmer and Hespanhol (1997) [50] had carried out a case study on the pollution status of the Ganga River and mentioned the initiatives being undertaken under the GAP and discussed about their success in accomplishing the set goals.

Yamuna, the largest tributary of the Ganga, is also facing severe consequences of flow regulation due to damming and barrages for domestic water supply and irrigation. Besides increased flow regulation, water quality deterioration is also prevalent due to unprecedented point and non-point pollution load. Gopal and Sah (1993) [51] published a research paper discussing about a conservation and management scheme for the Yamuna River. They emphasized that the Yamuna River must be treated as an eco-complex and that there is a need for watershed scale sustainable river management plan for rejuvenating it. Sharan (2015) [52] examined the presence of the Yamuna River in Delhi city and the interrelationships between user interface and the prevailing river conditions. His study mainly focused on the pollution related issues of the river and the existing river restoration initiatives been acted upon it. He proposed that the present restoration initiatives are limited, anti-poor and far from sustainable.

Sarkar et al (2007) [53] carried out a water quality management study for the Hugli River of Kolkata. The study revealed that socio-economic development and anthropogenic pressures of the Kolkata city is responsible for the deplorable water quality of the Hugli River. They suggested few measures for restoring the ecological stability and economic vitality of the river. Lastly, the authors urged that environmental education should be used as helpful tool for water resource management dealing with intricate and complex problems in the interaction between nature, technology and human beings.

Central Water Commission (CWC) is an organization dealing exclusively with the water quality related issues of almost all the major rivers of India. CWC is monitoring water quality at 390 key locations covering all the major river basins of India. It is regularly maintaining a three tire laboratory system for analysis of physico-chemical as well as bacteriological parameters [54]

The merits of using GIS based technologies in attaining watershed management goals was highlighted by Chowdary et al (2008) [55]. They generated an integrated water resource development plan for sustainable management of Mayurakshi River basin of Dumka and Deogarh districts of Jharkhand, India, using remote sensing and GIS technologies.

Further, a GIS based sustainable management plan for the Thorli watershed from Ratnagiri District of Maharashtra was presented in a research paper by Shirke et al (2012) [56]. They pointed out that topographic and geomorphic features of the area motivate the planning for the greater sustainable management scheme of the watershed. They further emphasized the applicability of GIS and RS technologies in deriving geomorphic parameters which is otherwise a tedious and cumbersome task if done manually.

Implications of drought and water regulations in the multi-state Krishna River Basin of peninsular India were assessed by Gaur et al (2007) [57]. They stated that over-exploitation in the basin has lead to an increase in hydrological droughts and water conflicts in the recent past. They urged that the over-exploited basin demands integrated basin management, together with a proper evaluation of water allocation criterion. River linkage and its impact on Krishna river of Maharashtra was carried out by Gophane (2013) [58] and he observed widespread negative impacts outweighing the positives on the Krishna watershed.

Chattopadhyay and Chattopadhyay (2014) [59] in their research paper entitled 'Rejuvenation of Kerala Rivers: Geoenvironmental Setting, Potentials, Problems and Recent Initiatives' reported an extensive watershed level study on the polluted rivers of Kerala. They suggested that river restoration warrants catchment scale approach considering all parameters, consisting local initiatives like river bank mapping and involvement of all stakeholders.

The book entitled 'Living Rivers, Dying Rivers' by Iyer (2015) [60]examined the present situation of several Indian Rivers, their various deplorable states or deteriorated health or other relevant issues affecting their overall well being. He collected works of several workers thus conducting radical re-examination of what constitutes true development. This compilation is important as an exhaustive river-wise account of the situation, and serves as an aid to understand what has gone wrong (or right in a certain cases) and what needs to be done in order to restore our rivers to their vibrant health.

Chattopadhyay et al (2005) [61] had conducted a water quality based case study of Chalakudy River Basin, Kerala. They established the relationships between landuse pattern and water quality variations thus emphasizing the fact that change in landuse practices particularly urbanization and intensive agriculture have detrimental effects on water quality of the Chalakudy River.

Paranjpye (2002) [62] had discussed about a sustainable restoration plan which had been used in the Bhima River basin. He emphasized the onset of new and advanced fields of management like Integrated Water Resource Management (IWRM) which aims to strike a balance between utilization of resources for livelihood and conservation of resources for the future generations.

Dandekar and Thakkar (2012) [63] provided an elaborate road map on ecological based river management strategy for Indian rivers. They discussed about the existing river related issues and the challenges in achieving successful river management in long run. According to them river management task should take into account not only the ecological aspects but also the social and cultural aspects related with the watershed.

The India Water Portal (IWP), India's largest resource and platform focused on water related issues is dealing with various river degradation case studies and management schemes all over India since its onset on 2005. Detailed report on water quality of three major rivers namely Tungabhadra, Cauvery and Kabini of Karnataka state was presented in an article of IWP (2007) [64]. IWP (2013) [65], under the title 'From worshipped and revered to looted and diseased-Karamana in Kerala' it discussed about the degraded condition of Karamana River, which once used to be the pride of Thiruvananthapuram and served as an important source of drinking water, but now is degraded and diseased. The portal further enlighten the integrated river basin management plan adhered by the Kerala State Biodiversity Board.

Moreover, the main thrust of the first ever India Rivers Week – 2014 was on restoration of the degraded rivers of India [66]. The IRW, a conclave to facilitate learning and encourage river restoration skills and actions from sharing and exchange of ideas, experiences and practices was held between November 24th and 27th, 2014, at New Delhi. Over 125 river specialist, planners, researchers, artists, enthusiasts and activists from different parts of the country congregated and discussed about the restoration issues.

1.5.3 Research works done in North-East India

Despite being endowed with splendid water resources, North-eastern India possesses few extremely filthy and flow starved rivers of India thus causing serious apprehension and concerns in the region. Rivers like the Bharalu, the Kolong and the Bhugdoi River of Assam, the Nambul River of Manipur, The Chite River of Mizoram, the Umkra and Umshyrpi Rivers of Meghalaya etc are few illustrations of extremely degraded river systems. Although some studies regarding the deteriorated conditions of these rivers had been conducted from time to time, however, a holistic approach for their restoration is largely lacking and demands paramount attention.

Sharma (2006) [67] compiled an elaborate dataset comprising the gifts and woes of the rivers of North-East India. He emphasized the need to come out with an out-of-the-box thinking by strengthening or installing new institutional facilities and equipping them with required resources so as to bring sustainable and acceptable river management outcomes. Similarly, an article was published on IWP (2011) [68] based on a lecture given by Prof. Chandan Mahanta of IIT Guwahati, citing the necessity of improvising the existing technological and organizational facilities currently available in north-east India for maintaining the health of the rivers of the region.

Goswami (2008) [69] carried out an elaborate study describing the wealth and woes of the Brahmaputra River of Assam. He has given a hint in the title of the article itself that Brahmaputra contains both wealth as well as woes. He makes an attempt in his article to consider how the wealth and the woes of river Brahmaputra should be judiciously managed. He further illustrates the negative impacts on the downstream as a result of the construction of mega-dams over the river.

Jacob et al (2009) [70] conducted a detailed survey on the pollution status of the Chite River of Aizawl, the capital city of Mizoram. They compiled the works undertaken by the Zoram Research Foundation (ZORF) which is a grassroots organization functioning with local communities on livelihood and traditional water management in Mizoram. They identified the specific threats to the Chite River ecosystem due to various water abstraction and pollution activities. Finally they set up certain strategies for re-establishing a sustainable management scheme for the river.

Sharma et al (2011) [71] had carried out a study evaluating overall characteristics of individual components of Umtrew River basin of Meghalaya with a goal to obtain a sustainable watershed management plan. It involved the evaluation of morphometric analysis of the sub watersheds of Umtrew River as well as the changing pattern of land use/land cover for the past three decades of the said watershed using Remote Sensing and GIS techniques so that the data generated from the study will help in environmental management of the said watershed.

A holistic solid waste management plan for reducing their quantity and thus the hazardous impacts on the Nambul River of Manipur was discussed by Yadav and Devi, 2016 [72]. They urges that the existing municipal solid waste management (MSWM) system of Manipur is having lots of shortcomings and is unable to cope up with the huge solid waste generated by the Imphal town. They further suggested that immediate and successful implementation of the newly proposed strategies and action plans by the Imphal Municipal Corporation to combat the shortcomings of the existing MSWM system will give good feasible results.

Kurse (2016) [73] carried out a morphometric analysis of the Diyung watershed of Arunachal Pradesh with an aim to accomplish flood management. He used GIS techniques for carrying out the analysis and based on the obtained results, structural and non-structural measures were proposed to mitigate the impacts of flood events.

Few research works describing the water quality and watershed level geomorphic and vegetative analysis on Kolong River and its basin are done during the last few years. Bora and Goswami (2014) [74] in their paper on 'Study for restoration using field survey and Geoinformatics of the Kolong River, Assam, India' discussed about the prevailing deplorable state of the said river and set forward few restoration strategies with a view to revive it. Khan and Hazarika (2012) [75] and Bora and Goswami (2015) [76] studied the deteriorated water quality of the Kolong River of Assam and provided few suggestions to rejuvenate the river. Moreover, Bora and Goswami (2016) [77] collated extensive water quality parameters and estimated Water Quality Index (WQI) values for the river water. The WQI will help in better understanding of the status of the river water and its applicability for various utilities.

This study will help in developing a water quality monitoring plan for the Kolong River Basin.

Furthermore, Bora and Goswami (2016) [78] and Bora and Goswami (2016) [79] carried out few watershed level research works highlighting the inter-relationships between the Kolong river's health and the existing watershed components viz. vegetation health and landuse landcover activities. These watershed level studies will help in developing a holistic restoration plan for one of the most polluted rivers of India.

Additionally, few doctoral level research works describing watershed management have been conducted. Gogoi (2013) [80] had carried out an in-depth study on environmental geomorphology and natural hazards of the lower Subansiri Basin of Assam. She had formulated an intricate sustainable development plan for the Subansiri basin. Barman (2015) [81] on the other-hand had carried out an exhaustive geo-environmental study of the Dhansiri (South) River basin of Assam.