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Environmental Management of River Basin Ecosystems

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Preface

Rivers have been the prime sources of sustenance for mankind. Man has continued to reap the benefits provided by the rivers for centuries, largely without understanding much of how the river ecosystem functions and maintains its vitality. Rivers play a significant role in the biogeochemical cycle and in the provision of water for domestic, agricultural, recreational, navigational, and industrial purposes and sediment and nutrients for the sustenance of natural ecosystems. A river basin is a basic geographic and climatological unit within which the vagaries of natural processes act and manifest at different spatiotemporal scales. The channels, the water, and the sediment transported and distributed within the river basin act as a unified system connected to each other through a delicate environmental equilibrium. This equilibrium is influenced by the vagaries of nature including climate, lithology, slope, etc. Left undisturbed, the river system has its own dynamism of maintaining its natural health and equilibrium. Any change in the factors that affect the equilibrium would result in recognizable changes in the system, often to the detriment of the natural dynamism of the rivers and thus the sustenance of mankind.

Given cognizance to the importance of holistic study, integrated management practices, and sustenance of environmental flow of river systems for nourishment of river basin ecosystems, there are a number of international efforts in terms of the Stockholm conference on the Human Environment (1972), United Nations conference on Environment and Development (1992), International Geosphere-Biosphere Program, International Human Dimension Program, and more recently, the EU water framework directive, and flood directive. There are many other programs that provide a comprehensive guideline for environmental management of river basins. As a corollary to these efforts, this volume presents specific thematic papers covering the various facets of river basin ecosystems, methods of study, myriad varieties of influences on natural environmental processes, anthropogenic interventions and resultant impacts, methods of reclamation, remediation, management, and nourishment. Though the interconnectedness of river basins as a unified system and its delicate balance between litho-bio-hydro-atmospheric processes are known to the scientific community, the importance of sustenance of this delicate equilibrium is exemplified through various case studies and methodology papers in this volume.

The publication of this volume is intended to enlighten academicians, researchers, administrators, and planners. This intention would be served if the readers spread awareness among the common people and those concerned for the wellness of the Earth and sustainability of its resources.

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The seeds for compiling a special volume emphasizing the multifaceted nature of river basin ecosystems were sown by the discussions held between the editors of this volume during the national seminar on River Basins organized under the aegis of SAP—DRS Phase-I sanctioned to the Department of Geography, School of Geosciences, Bharathidasan University, Tiruchirapalli, India. The grant sanctioned by the University Grants Commission, New Delhi is gratefully acknowledged. A casual pep-talk that originated at tea-break during the seminar among the editors has culminated in the publication of this special volume.

We profusely thank Dr. Johanna Schwarz and her editorial team of Earth Sciences, Springer-Verlag GmbH, Heidelberg, Germany, for agreeing to publish this special volume of papers, and for the professional support extended to us. We thank those academicians and researchers who have actively involved in reviewing the articles and helped the authors to present the data in a better way. Ms. Radhika Sree and her team at production unit have done excellent work and are thanked for their professional and flawless handling.

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Above all, we submit our thankfulness to The Lord Shree Ranganatha, who by His choice and design chose to reside on a river island (Srirangam), for his boundless mercy showered on us.

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Contents

Land Use Dynamics and Environmental Management of River Basins with Emphasis on Deltaic Ecosystems: Need for Integrated Study Based Development and Nourishment Programs and Institutionalizing the Management Strategies

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Abstract The deltaic systems maintain a delicate equilibrium with the litho, hydro, bio and atmospheric processes and provide sustenance to the biosphere. Located at the receptive end, the lower reaches of the river basins *a la* deltas are fragile ecosystems and are susceptible to the changes in the upstream regions. These ecosystems survive at the mercy of processes not only in their vicinity, but also the processes that act at the catchments of the river systems. With the growing population and economic development, they are under multiple pressures emanating from anthropogenic activities. Unlike the natural processes, the anthropogenic interventions with the deltaic ecosystems are highly complex and varied. These range from modification of physical surface characteristics, introduction of physical, chemical and biological pollutants from point and non-point sources, in the name of developmental activities including but not limited to urbanization, commercial, industrial, recreational and agricultural endeavors, culture, geopolitics, racism, quality of life, economic might, and mismanagement and unsustainable rates of exploitation of natural resources. All these could be comprehensively

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termed into conversion of natural land cover into land use. In this paper, an attempt is made to enlist the human endeavors that convert the natural land cover into anthropogenic land use and resultant adverse impacts and irreversible reactions. These are then summed up into a scheme of comprehensive study for integrated management. A plea is also made to institutionalize the management practices for effective implementation and sustainable development.

Keywords River basin management · Deltaic ecosystem · Integrated model study · Strategies

1 Introduction

The rivers have been the prime sources of sustenance for the mankind since the advent of civilization. Rivers play significant roles in the provision of water for domestic, agricultural and industrial activities (Ayivor and Gordon 2012), and generate sediments and nutrients for the sustenance of the natural ecosystem. Humans continue reaping the benefits provided by rivers for centuries, without understanding much on how the river ecosystem functions and maintains its vitality (Naiman and Bilby 1998). The bludgeoning population and its ever-increasing dependence on the natural resources for agriculture, transport, water and land for domestic, commercial and industrial activities, make nourishing the river systems an all the more important and urgent task.

Within a river basin, the deltaic regime, being a receiving basin acts as an interface between fluvial, oceanographic, atmospheric and anthropogenic dynamics. These traits make this important macrogeomorphic unit ecologically fragile and susceptible to environmental deterioration very easily, even by changes in the catchment (pollution, siltation, flooding, etc.), and ocean (inundation, erosion, accretion, etc.,) and atmospheric equilibrium. For this reason, understanding the deltaic processes has been the endeavor of researchers of various disciplines. Deltas are one of the most frequently and intensively studied natural ecosystems as they host a wide variety of depositional, geomorphic and oceanographic settings. These ecosystems support a wide variety of economic, agricultural and transport avenues.

In this paper, we reviewed the current trends of research on the river basins, particularly the lower reaches (deltas of river basins) with specific emphasis on the land use dynamics and land use-land cover-human interactions, and present a multidisciplinary schematic procedure as an idealistic methodology for understanding the deltaic systems for better management and ecosystem nourishment.

2 A Review on the State of the Art

2.1 Nature of the River Basins

In a classic review, Barrow (1998) stated that except for the most arid and cold regimes, the World's landscape can be divided into distinctly mappable river basins of various scales (large, medium and small) and the river basins themselves can be sub-divided into upper, middle and lower basin, based on the hydrologic and geomorphic characteristics. Since each river basin acts as a holistic system in tune with the climatic, geological and anthropogenic interactions, any study on the river system should understand the dynamics of the river basin as a whole. A river basin is a basic geographic and climatological unit within which the vagaries of natural processes act and manifest at different spatio-temporal scales. However, even if juxtaposed, no two river basins respond to natural processes in a similar way and thus, each river basin is unique. Hence, any developmental activity or conservation effort has to be uniquely designed and implemented for each river basin.

The actions of the rivers include transport of water and fertile soil/sediment from their catchment areas and distributing them in the lower reaches that form the basis for cultivation, settlements, etc. The channels, the water and the sediment transported and distributed within the river basin act as a unified system connected to each other through a delicate environmental equilibrium. This equilibrium is influenced by the vagaries of nature including climate, lithology, slope, etc. Left undisturbed, the river system has its own dynamism of maintaining its equilibrium. Any change in the factors that influence the equilibrium results in recognizable changes in the system, including adverse impacts such as flooding, erosion (Walling 1999), and desertification, which in turn, may cause loss of critical resources that provide sustenance to human race such as land, agricultural produce and other commercial activities. In addition, it also alters the nutrient availability in the deltaic region and contributes to the proliferation of exotic species in coastal regions, that adversely affect the people who depend on the normal natural processes at downstream regions (*for example*, Wu et al. 2008). Hence, a proper understanding on the natural processes, human endeavors and interactions between litho-hydro-eco-atmospheric processes at various scales in a basin-wide ambit is necessary for sustainable future. However, the existing pattern of research, either theoretical, laboratory and or field based studies are segmented. In order to understand the basin-scale processes, transcending subject barriers and conducting interdisciplinary studies are necessary.

Though, for thousands of years, the human beings have been modifying land for food, shelter and other essentials of life, the current rates, extents and intensities of such modifications are far greater than ever in the history (Efiong 2011). In view of the prevailing favorable conditions for habitation, cultivation and industry, explosive growth of human population and resultant pressure on natural environment is high in river basins (Zarea and Ionus 2012). Traditionally, the river basins are treated as treasure troves for natural resources, but the human needs have taken precedence over environmental concerns (Triedman 2012). Nevertheless, the land use dynamics continue to impact on the river catchments (Wu et al. 2008) which have negative repercussions for river health. The impacts of change of natural land cover, particularly the urban expansion is detriment to the local and regional hydrology, and water quality (Li et al. 2008; Koch et al. 2011) and increases the non-point sources of pollution (Tang et al. 2005). The impacts of the human activities translate into catchment erosion (Walling 1999), sedimentation within river channel, surface and ground water pollution, increased levels of turbidity, acidity, mean dissolved oxygen and nutrient loads (Ayivor and Gordon 2012; Memarian et al. 2013). Catchments of many river basins are subjected to irreversible damages particularly by mining and hydro-electric projects. In addition to landscape modifications, such developmental projects cause acid mine drainage, metal pollution and excess sedimentation in the river basin and invigorate a chain of secondary detrimental effects.

2.2 Land Use Dynamics and Their Impacts on the Deltaic Ecosystems

When compared with other ecosystems, the deltaic regions support a high population density and provide sustenance to fauna and flora. Johannes et al. stated that rapid population growth in deltaic regions inevitably brings in recreational, commercial and industrial use of these lands and waters, causing environmental deterioration. To assess the impacts of these activities, baseline information is a prerequisite, with which the ongoing and future trends of sustainability of ecosystems could be adjudicated to strategize the management programs for wellness of the human community and economic prosperity. The availability of a variety of floodplain environments in large lowland river valleys provides opportunities and constraints for a host of human activities (Hudson et al. 2006). One of the visible signs of pressure on the natural environment is the change in land use/land cover which often if not most probably results as a function of population growth (Qi and Luo 2006). Being riparian, the deltaic regimes are subjected to ecological deterioration and experience geohazards not only due to the changes in the immediate vicinity, but also under the vagaries of changes in the catchment regimes, such as rainfall, land use, deforestation, etc. (*for example*, Jessel and Jacobs 2005; Bathurst et al. 2011). Brush demonstrated that the water quality, climatic changes, land use dynamics, imprints of forest fire, cultivation, human settlement and industrialization are all recorded in deltaic sediments. Deterioration of water quality due to conversion of forest land cover into urban and agricultural land use on a basin scale has been documented by Li et al. (2008), Kim et al. (2011) and Koch et al. (2011). Hesslerova et al. (2012) are of the opinion that the higher human activity, particularly the conversion of natural land cover into land use increases the surface temperature that results in water loss on a basin scale.

Murty et al. attempted linking land use patterns along river systems and the quality of the environment. Mutie et al. (2006) are of the opinion based on the study of land use patterns of Mara River basin that, the conversion of natural land cover into mining, agricultural, pastoral and game parks has resulted in severe constraints on the long-term sustainability of environmental health of the river system and dependent wildlife and human society. Similar conclusions were drawn by Siahaya and Hermana (2013) based on their study of land use changes and resultant water resource potential in urban watershed. Wijesekara et al. (2010) observed that conversion of 5 % of watershed area into urban lands resulted in 2.6 % increase of overland flow, 2.3 % reduction of evapotranspiration and 11 % increase of combined overland and base flow into Elbow River, southern Alberta, signifying the exponential nature of flooding of rivers due to the growth of urban sprawl. Coulthard and Macklin (2001) observed that the British river systems have been sensitive to short term (ca. 102 years) climate fluctuations, land-use change and sediment supply. They further stated that this observation has important implications for forecasting river response to future climate and land-use changes.

Li et al. (2008), Tong and Chen (2002), Koch et al. (2011) and Yaakub et al. (2012) demonstrated the existences of significant positive relationship between physico-chemical properties of river water quality and the land use/land cover patterns. According to Zwolsman (1994), there has been much concern about the effects of increasing nutrient inputs into natural environments as the rivers draining densely populated and industrialized areas are being loaded with very high concentrations of phosphate, nitrate and ammonium. Enhanced nutrient inputs to the river basin ecosystems often bring in exotic biota that destruct the native species and eventually create ecological imbalance. Increase of nutrient inputs, especially nitrogen in river water as a result of changing of forest land cover to agricultural land use in riparian areas of various watersheds in Hokkaido, Japan was reported by Okazava et al. (2010). Based on their study, these authors have suggested a management strategy to curtail the detrimental effects of nitrogen pollution. According to them, when cropland covers much of the catchment region and increases the nitrogen concentration in the river water, the elevated levels can be reduced significantly through conversion of much of the riparian region with forest cover. Kroeze and Seitzinger (2002) analyzed the nitrogen loading in rivers and estuaries in relation with changing land use scenarios and concluded that significant reduction of these nutrient-pollutants could be achieved by reducing the use of fertilizers and NO_2 emissions.

Ramkumar (2003a, b) emphasized the link between land use dynamics with that of coastal environments, particularly the mangrove swamps. The coastal deltaic lands serve as repositories of rich biodiversity and as nurseries to endemic avian, aquatic and other species, including mangroves. It was Balls who had established a firm link between nutrient accumulation in natural sedimentary environments, particularly in estuary and adjoining regions and transport of nutrients to coastal marine regions, as a function of land use change based on data from nine rivers located along the east coast of Scotland. Padma and Periyakali analyzed physico-chemical and geochemical characteristics of the coastal lakebed sediments and reported the impact of industrial contaminants over sediment textural and geochemical properties. As the coastal environments are homes to a vast array of primary producers, and act as nurseries, which in turn are dependent on the physical and chemical characteristics of the bed-sediments, significant alteration of these traits by industrial contaminants affects the fundamental units of the food-chain and primary producers. A similar study by Solaraj et al. (2010) in the deltaic regions of the Cauvery River basin, Southern India, reported high concentrations of dissolved salts, organic pollutants and phosphate exceeding the permissible levels at certain sampling stations as a result of agricultural runoff from the vicinity, sewage, and industrial effluents.

Employing geochemical analyses and dating of core samples, agricultural and other land use records collected from governmental records, Heathwaite was able to accurately document the link between land use changes and geochemistry of ensued sediments. Based on geochemical data of the overbank deposits of the English and Welsh flood plains, Macklin stated that geochemical profiles show apparent changes across records of the industrial revolution, forest fire, agriculture and human settlements. Supplemented with carbon, pollen and thermoluminescence dating, it was made possible by their study to assess the impacts of anthropogenic activities over the natural ecosystems. Passmore and Macklin recognized coeval shifts in geochemical profiles of ancient sediments coinciding with the periods of conversion of natural vegetation into agriculture, industrialization, and mining land uses.

Qi and Luo (2006) observed the land use changes on a basin scale in the Heihe River basin and found that the observed changes caused severe environmental problems in terms of surface water runoff change, decline of groundwater table and degeneration of surface water and groundwater quality), land desertification and salinization (Zhang and Zhao 2010), and vegetation degeneracy. Glendenning and Vervoort (2010) evaluated the effect of rain water harvesting structures on a catchment-basin scale in terms of water balance models, intensity of surface run off, water variability in storage capacity, etc., to suggest suitable eco-friendly developmental activities. The nexus between agricultural land use, effluent disposal and the quality of river water have been examined by Tafangenyasha and Dzinomwa (2005) and the results have shown that the land use change imposes beneficial as well as detrimental effect on the natural environment and biodiversity.

The abilities of the estuaries and adjacently located microenvironments the deltas to receive, assimilate and disperse nutrient and contaminant inputs from natural and anthropogenic sources is well known. Throughout the World, this capacity of the deltaic systems has been exploited as a means of disposing such waste materials. However, this capacity is finite and if exceeded, environmental quality may be unacceptably compromised (Balls et al. 1996). As the estuaries and coastal environments are valuable ecosystems characterized by high primary productivity and large stocks of juvenile fish (Robertson and Duke 1987), assessing the status of natural environments in these regions is important in terms of academic, economic and ecological points of view (Zwolsman 1994; Ramkumar et al. 1999; Ramkumar 2007; Ramkumar and Neelakantan 2007). Estuaries are characterized by naturally derived organic matter that originates from the autochthonous production, the open sea, surrounding salt marsh and mangroves and river drainage (Cifuentes et al. 1990). In addition to these natural sources, the rivers are also recipients of the organic matter from anthropogenic activities and hence, the documentation of the source, quantum, and the nature of interaction of organic matter in estuarine waters is essential.

The tendency of organic matter to attract heavy metals, available from natural sources in trace amounts but mostly released from the industrial and urban wastes, aggravates the ecological vulnerability as the organic matter in coastal regions form the basic units of energy source and is actively consumed by lowermost link of food web, through which, the toxic metals reach top of the food pyramid often to the detrimental effects on humans (Rajaram and Devendran 2013). The very nature of mushrooming industrialization, urban sprawl, commercial and recreational activities along river channels, deltaic and coastal plains generates newer domestic, exotic and toxic wastes and nutrients and stresses further the already fragile ecosystems leading to environmental deterioration (Rao 1998). This observation is affirmed by the study of Hampson et al. (2010) that has documented the microbial pollution of river systems of UK due to land use change.

2.3 Geohazards Associated with the Deltas

Geohazards occur everywhere and no region of this earth is safe. With the opening of global economy and consequent expansion of domestic, industrial, commercial, recreational and aesthetic land use in every available piece of land by the human race result into intervention of natural geological processes leading to the potential loss of life and property. Owing to their vast expanses of monotonously low altitude topography, the lower reaches of the river basins are home to many geohazards. However, the unscientific anthropogenic developmental activities in the deltaic regions often aggravate the intensities of geohazards in terms of susceptibility to flooding (Hickey and Salas 1995), coastal inundation, river and coastal erosion and sedimentation, tsunami, storms, cyclones and quick sand (Ramkumar 2009). As these areas are thickly populated, the resultant damages often reach catastrophic levels even during slightest change in existing equilibrium of coastal geological processes (Jayanthi 2009).

While the developmental activities could not be contained for the sake of non-intervention with geological processes, a well thought-out planning and developmental activities with minimal intervention with geological processes would thwart many a potential hazardous events. However, the very nature of the geohazards being unpredictable, it would be advisable to classify the land and water regions that are being and/or planned to be utilized, according to vulnerability levels to various potential geohazards, and not to engage in potential catalytic activities. In addition, should there be any eventuality, being ready with contingent plans for relief and rescue operations would minimize the potential loss. Ramkumar and Neelakantan (2007) have evolved an idealistic model for geohazard mitigation,

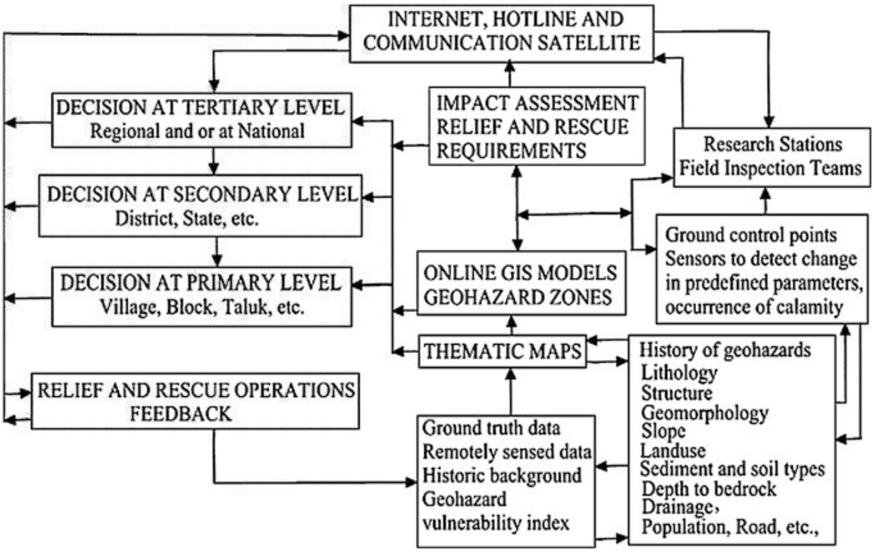

Fig. 1 Scheme for geohazard mitigation, information dissemination and coordination

information dissemination and coordination of rescue and reclamation efforts (Fig. 1).

Among all the geohazards, flooding is more typical and recurrent in the lower reaches of the delta. It occurs from riverine and marine sources and is also influenced by other geohazards such as storm surges, cyclones, etc. Although flooding is a natural phenomena that plays a major role in replenishing wetlands, recharging groundwater and supports agriculture, extreme demands on the natural resources due to the population growth people and their property move closer to water bodies, which in turn increases the risk of life and property loss due to flooding (World Meteorological Organization 2005). Land use change in the catchment regions in terms of deforestation, may cause severe flooding in the riparian regions, in terms of increase of peak discharge and shorter return period of flood events, especially when deforestation exceeded 20–30 % (Bathurst et al. 2011). Studies on fluvial geomorphology of various river basins including Yellow River, Sacramento River, Strickland River, and Brahmaputra River indicate that rivers maintain valley-scale controls on channel alignment, conveyance of flood waters and transport and deposition of sediments (Rogers et al. 1989; Gupta 1988, 1995; Shu and Finlayson 1993; Fischer 1994; Jain and Sinha 2003; Singer et al. 2008; Sacramento River Flood Control Project 2012). Hence, valley-scale documentation of these characteristics and designing flood control measures with site and measure specifics is necessary.

2.4 Sand Mining and Their Impacts on the Deltaic Ecosystems

With the bludgeoning population, economic liberalization, integration of national economy with global systems, and increase in the purchasing capacity of people of the fast growing economic countries such as Brazil, Russia, India and China, construction activity is fast apace not only for the human dwellings but also for commercial activities. The fast pace of economic developments, rise in foreign remittances and liberalized housing schemes for building constructions, mainly from banking sector are some of the causative factors responsible for unabated sand mining from river beds (Padmalal et al. 2008; Sreebha and Padmalal 2011). The environmental impact of river sand extraction becomes increasingly well understood and linked with the globalization in developing countries such as China and India (De Leeuw et al. 2010). There were arguments in favor of linking sand mining with globalization and resultant global environmental change (Sonak et al. 2006). The rivers in which sand is harvested at rates in excess of natural replenishments often undergo channel degradation, causing incision of the entire river system including its tributaries (Ashraf et al. 2011). Striking cases of excessive removal of river sediment removal are summarized by many researchers (Bull and Scott 1974; Sandecki 1989; Kondolf and Swanson 1993; Kondolf 1997; Macfarlane and Mitchell 2003; Hemalatha et al. 2005; Ramkumar et al. this volume). Though mining of building stones and limestone create permanent scars in the vicinity of mining that are located in a variety of geomorphic settings, the impacts are felt only in a geographically restricted region. However, the very nature of unified system on a valley-scale (Singer et al. 2008) and quick reaction time of fluvial system (Kale et al. 2010), mining of river sands from channels advocates a cause of serious concern. Though such generalizations are in the common knowledge, the environmental and geomorphic consequences are not fully understood due to the paucity of requisite data (Macfarlane and Mitchell 2003; Kale 2005; Ashraf et al. 2011; De Leeuw et al. 2010). Ramkumar et al. (this volume) attempted documenting the effects of sand mining on geomorphology, sediment texture and long-term sustainability of the natural fluvial system.

2.5 Socio-economic-Cultural-Racial-Geopolitical Impediments in Managing the Land Use Dynamics

Soini (2005, 2006) examined the interactions between the land use change and the livelihood, environment, socio-economic conditions and biodiversity in the context of population pressure, cultural and regional historical factors, and climate change in selected regions of East Africa for improving the existing understanding on their dynamics and to design better management strategies. The results have emphasized the intricate and complex nature of land use change. Not only the culture, but race and socio-economic conditions were also found to have influenced the land use planning and river basin environmental management and the tendency was termed as "environmental racism" by Miller (1993). Verbatim, the statement of this author reads—"*this essay traces the political and economic framework of New York City's land use and planning processes for North River, discusses how issues of race and socio-economic status are integral elements in this process, and examines one community's actions against environmental racism*". Although not exactly similar, but related issue was documented by Wu et al. (2008) who have recorded the environmental and socio-political pressures from upper reaches of the Yangtse River, China and traced their impacts on the dynamics of land use/land cover changes. In an exhaustive study covering many countries and continents, Englund et al. (2011), assessed the impacts of land use change from agriculture to cultivation of feedstock for biofuels on air and water quality and biodiversity. This is one of the test cases where the overriding influence of land use on environmental, social, economic and livelihoods of people was demonstrated unequivocally by scientific data, leaving no room for subjectivity. In recent years, there are attempts such as that of Costello (2010) that exhibited the link between consumption pattern of agricultural products and the land use dynamics.

The study of Weng (2000) is a classic work that documented the origin and propagation of agriculture in relation with the climate and sea level changes during the Holocene era, and the development and widespread practice of rice cultivation, horticulture and dyke-pond system of human-environment interaction. Based on these data, the study has also exemplified the adverse effect of imprudent use of technology over natural environment that manifested through increased incidents of flooding and increase in flood intensity, which in turn were found to be detrimental to the economic advancements obtained from agricultural innovations.

In one of the pioneering integrated spatial and statistical study of land use, land management practices, soil, geomorphic and hydrological parameters and their relationship with river water quality data of more than hundred basins of Ontario, Ongley and Broekhoven (1978) concluded that the land use exhibited close relationship with water quality and the relationship was found to be more influential than the hydrological parameters! Wolanski et al. observed that the floodplains of Mekong River delta are extensively utilized for rice cultivation and aquaculture while the mangrove swamp regions supply wood and fish stocks providing sustenance to millions of people. These economic benefits are increasingly being curtailed by rising sea level, resultant salt-water intrusion into the river channel and deposition of sediments within estuarine channel itself and hinter inland water transport and felt that it is necessary to understand the depositional dynamics to plan for developmental activities.

2.6 Other Impediments for Effective Management Programs

Despite endowed with vast expanses of coastal lands, many of the developing countries lack accurate information on comprehensive scientific data on the coastal land use, their areal extent, and condition and utilization status of them in the form of maps and statistical data for use in policy decisions on effective coastal zone management plan. These authors have also commented that data may be available in few cases, but there seem to be a long time-gap between data collection and publication that render the data not suitable for effective management plan. While reviewing the river basin-scale environmental management programs world over, Coppola (2011) observed that the failure to achieve many of the plans was mainly due to the fragmentary approach, instead of employing a comprehensive and integrated multi-disciplinary approach. Seto et al. (2002), Tong and Chen (2002), Moss (2004), Qi and Luo (2006), Ranade (2007), Li et al. (2008), Zhang and Zhao (2010), Yueqing et al. (2011), Sharma et al. (2011), and Kotoky et al. (2012) suggested the use of remote sensing and GIS for monitoring and mapping land use/ land cover changes for environmental management planning. Applying Spatial Auto Regression model on salinization, environmental quality, and land use pattern etc., Zhang et al. (2011) demonstrated a methodology for strategizing deltaic environmental management plans.

The fallacy of one dimensional modeling of effluent dispersal in estuaries and adjacent coastal waters has been explained by the studies of Ramkumar (2000a, 2001, 2003a, b, 2004a, b, 2007), and Ramkumar et al. (2001a, b). These studies, together with Rajani Kumari et al. (2000), Ramkumar (2000b), Ramkumar and Pattabhi Ramayya (1999), Ramkumar and Gandhi (2000), Ramkumar and Vivekananda Murty (2000), Ramkumar and Neelakantan (2007) and Ramkumar et al. (1999, 2000a, b, c), have demonstrated the methods to discriminate the natural and anthropogenic processes prevalent in the deltaic ecosystems and integrate spatio-temporal variations of geomorphology, land use, sediment textural, geochemical and remotely sensed data through conventional methods and geostatistical and GIS analyses for modeling deltaic systems for designing better management plans.

3 Strategizing and Institutionalizing the Management Programs

It was during the year 1972 at the Stockholm conference on the Human Environment, a clarion call was made to study the land use changes. Similar calls were made at the United Nations Conference on Environment and Development (UNCED), International Geosphere and Biosphere Program (IGBP) and International Human Dimension Program (IHDP) to foster research on land use—land cover changes and to integrate other environmental parameters for establishing developmental planning (Gajbhiye and Sharma 2012). Koch et al. (2011) advocated that since land-use change strongly affects the water quantity and quality as well as biodiversity and ecosystem functioning, analyzing the land-use change scenarios should form an essential part of these regional development scenarios. According to Crawford (2005) and Ganf and Oliver (2005), owing to the conversion of flood plains and river courses into urban, commercial, agricultural and recreational land uses, the consumption of water from rivers and adjoining regions multiplies and as a result of which the estuarine regions and dependent ecosystems are affected severely. Hence, determination of environmental water flow for the sustenance of riparian regimes and acting accordingly is an essential task in any river management plan.

In recent years, a term "environmental flow" (*sensu* Cottingham et al. 2003; Scoccimarro and Collins 2005; Speed et al. 2012; Morrison 2013) and "environmental water requirement" (Robson et al. 2005; McNeil and Fredberg 2011) are being emphasized for planning river basin management planning. It refers to the minimum water and sediment transport by a river system at various points of its traverse, so that the natural ecosystem on a basin scale (Ganf and Oliver 2005) is sustained without any adverse impact either on its own and/or on the developmental activity that is being made in the basin. Accordingly, planners and administrators are increasingly becoming aware of the economic and ecological benefits of the environmental flow and take it into consideration while strategizing developmental *vis-a-vis* environmental management plans. Assessment of environmental flow is unique to each river basin (Speed et al. 2012) depending on its climate, land use, soil, geomorphic, demographic and many other traits.

Faced with pressures from the population, urban, aquaculture, recreational, commercial and other utilities on coastal environments, the Tasmanian government has evolved a policy of sustainable development following the International practices (Anutha and Johnson 1996 and references cited therein) of conservation and management. The policy states that "*sustainable developmental plan means managing the use, development and protection of natural resources in a way, or at a rate, which enables people and communities to provide for their social, economic and cultural well-being and for their health and safety while sustaining the potential of natural resources to meet the reasonably foreseeable needs of future generations, safeguarding the life-supporting capacity of air, water, soil and ecosystems and avoiding, remedying or mitigating any adverse effects on the environment*". According to this policy, a holistic environmental management system has to be established through an integrated study of status of the ecosystem based on which, remedial and conservation efforts have to be taken up and effectiveness of the system has to be monitored periodically through measurable attributes. Leggett et al. (2003) and Memarian et al. (2013) are of the opinion that different strategies and methods of natural resource management themselves need to be evaluated for their effectiveness and implemented accordingly. A combination of mathematical and GIS tools for effective monitoring mechanisms and assessment of effectiveness of environmental management strategies has been suggested by these authors. Jessel and Jacobs demonstrated a method to evaluate the effectiveness of management programs based on stakeholder responses. Collection of socio-economic and environmental data from stakeholder interviews has led Albinus et al. (2008) to interpret the importance of understanding land use changes over the community lives and ecological balance. The study has also evinced the importance of understanding the cause-effect processes on a basin scale.

To preserve the coastal environment and to regulate the use of land near the Indian coastline, Coastal Regulation Zone (CRZ) was introduced in 1991 in India and amended periodically. The main aim of the CRZ is to ensure the developmental activities along the Indian coast in a sustainable manner based on scientific principles taking into account the dangers of natural hazards in the coastal areas and sea level rise due to global warming (http://moef.nic.in/downloads/public-information/CRZ-Notification-2011.pdf).

In order to judicially utilize the natural resources and to reduce the developmental pressure on land use change, based on the land use reform practices of Hudson River valley, Knudson (2011), suggested involving non-profit organizations for regional and local planning and for implementing the management strategies. Fallon and Neistadt (2006) suggested practical measures for planning, implementing and monitoring the physical, mental and social well-being of the society by involving the local boards. In his review, Barrow (1998) stated that the river basins have been used for developmental planning since the 1930s, but the results have been disappointing. According to Moss (2004), despite the involvement of many factors, including paucity of data, lacuna in scientific understanding of natural and anthropogenic processes that are in operation at various scales, the lack of appreciation for integrated study and institutionalizing the efforts are the reasons for these disappointments. Realizing the importance of protection of fluvial environments, soils, water, and landscape contained in them, EU water framework directive (Moss 2004) and flood directive that include establishment of baseline database through holistic study have been designed and are being implemented in many parts of the World (*for example*, Fleta et al. 2008; Clapcott et al. 2011; Appiah-Opoku 2012 and the papers contained in the edited volume) and these directives caused a paradigm shift towards the integrated management practices (Hampson et al. 2010).

4 Conclusions

From the foregoing review, a broad consensus as concluding remarks can be made.

- The rivers act as a holistic system wherein any change at any part of the basin has repercussions in other parts of the basin and wellness of the system. Hence, any management or nourishment program should take into account the basin scale processes and basin-wide responses of the river system for effective management.

- The rivers have a self-healing ability to the anthropogenic interventions. However, this ability is limited and if exceeded, the resultant damage would be irreversible. Hence, the reclamation, management and nourishment programs of river basins should also include objectives based on these "critical/threshold limits" of the river systems. These limits have to be assessed with more realistic, recent and comprehensive data.
- The growing population and resultant anthropogenic interventions in the name of "developmental activities" translate into conversion of natural land cover into anthropogenic land use. The land use in turn, is influenced by a variety of factors, including geopolitics, racism, culture, etc., which are beyond the realm of any reasonable scientific study. Hence, it is suggested that in addition to setting objectives based on "limits" of the river systems, these factors should also be taken into account for effective management programs.
- As observed by many of the publications cited in this paper and references cited therein, paucity of baseline information about the river basins and their deltaic systems hampers the understanding of scientific community, leave alone the planners and administrators. If at all databases exist, they were found to be fragmentary and also that there is a big gap between acquiring the data and their availability for stakeholders and users including the academics and researchers. This is a serious impediment that hampers proper understanding, designing effective management program and strategizing implementation of the programs.
- Owing to the large quantum and varied types of data involved in the study of basin scale processes, many studies use temporal remotely sensed data and apply a combination of spatial, statistical and mathematic modeling, together with conventional analyses for better understanding. From the review, it is also revealed that there is an improved awareness among the planners, administrators and political class about the complex interactions of land use dynamics and tenuous nature of the deltaic ecosystems.
- An idealistic methodology for integrated study of river basin and deltaic ecosystems (Fig. 2) is presented in this paper. In order to circumvent the racial, geopolitical and cultural and other factors that hamper effective implementation of management programs and monitoring the nourishment efforts, institutionalizing the programs is suggested. It may include policy guidelines and framework for implementation and monitoring, such as those of EU Water Framework directive.

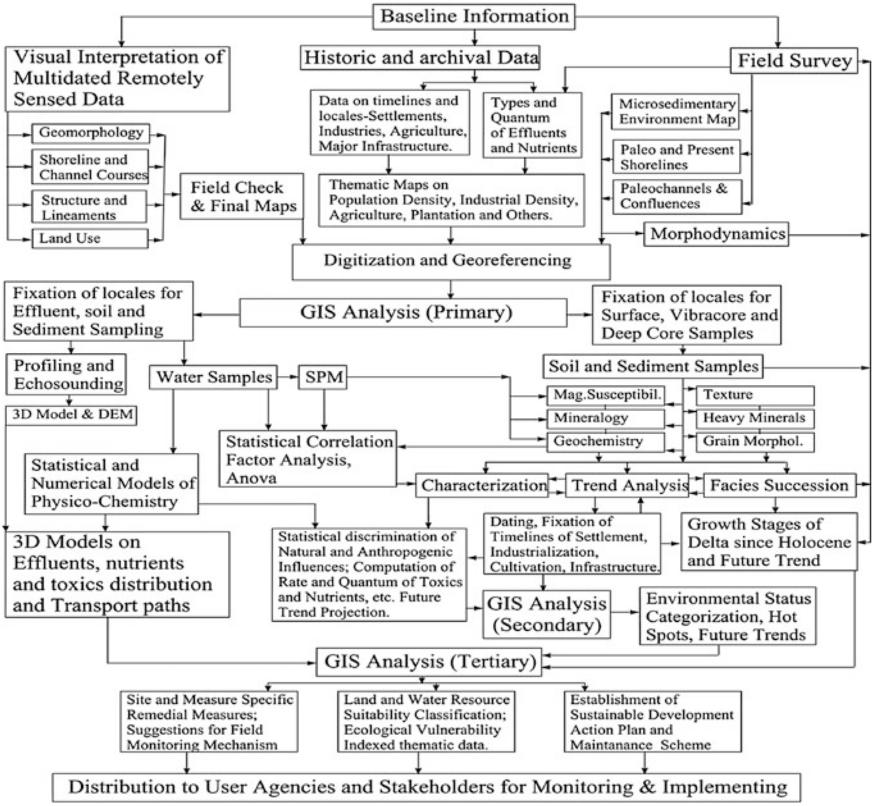

Fig. 2 Model scheme for integrated study of river basin ecosystem in regard to land use

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