Chapter 5
Climate Change and Sustainable Management of the Rivers System with Special Reference to the Brahmaputra River

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Abstract Climate change is one of the biggest challenges and likely to have significant impact on the hydrology. Due to the increase in urbanization, industrialization and climate change, availability and requirement scenario of freshwater have been changing. Water availability and water security are becoming more uncertain through changes in temperature and precipitation, shifts in the timing and intensity of the monsoon, increased frequency of extreme events such as droughts and floods and accelerated melting of the Himalayan glaciers resulting in changes in short- and long-term runoff, snow cover and melting. The Brahmaputra River basin is one of the most vulnerable areas in the world as it is subject to the combined effects of glacier melt, extreme monsoon rainfall and sea level rise. For years, the river has been serving as one of the most important freshwater resources for agriculture, irrigation, transportation and electricity and habitat for aquatic organisms in the north-eastern India. People residing along its banks are heavily dependent on the river for their livelihood, thus making them a highly vulnerable riverine community. As climate change is a major concern, we should reduce both greenhouse gas emissions and develop effective management strategy for freshwater resource. Climate change adds uncertainty in controlling core issues of water management due to lack of capacity to address climate change. Therefore to address this problem, we need resilient institutions. At the same time, we need political process, involvement of diverse array of actors and foreign policies of riparian countries for transboundary water management.

Keywords Climate change · Sustainable management · Brahmaputra River

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5.1   Introduction

Climate change is one of the biggest challenges having significant impact on the hydrology. Due to increase in urbanization, industrialization and climate change, availability and requirement scenario of freshwater have been changing. According to the IPCC's 2007 report, rising temperature and increase in carbon dioxide concentration that contributed to the climate change would have direct impacts on river system. This would subsequently cause melting of glaciers, change in rainfall pattern and loss of biodiversity (Bates et al. 2008). Change in temperature and rainfall pattern led to shift in the timing and intensity of the monsoon, increase in the extreme event frequency such as droughts and floods and accelerated melting of the Himalayan glaciers, causing changes in the short- and long-term runoff, snow cover and melting (Rasul 2015; Eriksson et al. 2009; Shrestha and Aryal 2011). Climate change causes increase in temperature of the river system and affects aquatic organisms. The higher temperatures and lower rainfall has impact on riverine flow, which in turn affects the water quality of the river. Reduce flow causes higher concentrations of pollution due to less dilution. Higher rainfall intensity could lead to sediment deposition and other contaminants entering rivers leading to more silt deposition.

   All of these, melting of glaciers, extreme rainfall during monsoon season and rise in sea level along with geographical location, have combined impact on the Brahmaputra River. Hence this river basin is considered as one of the most vulnerable areas in the world. In the north-eastern region of India, the Brahmaputra River is one of the most important resources for freshwater. For years the river water has been used for agriculture, irrigation, transportation and electricity besides serving as the natural habitat for the aquatic organisms. People residing along its banks are heavily dependent on the river for their livelihood and thus making them a highly vulnerable riverine community. As climate change is a major concern, we should reduce both greenhouse gas emissions and develop effective management strategy for freshwater resources. This chapter highlights the impact of climate change on the river system with special emphasis on sustainable management of the Brahmaputra River. The study also made an attempt to correlate weathering and CO_2 consumption rate with the extent of heavy metal pollution in the environment.

5.2   Materials and Method

The river water samples (n = 54) were collected in three different seasons during 2011 and 2014, and nine surface sediment samples (n = 27) were collected during 2011, 2012 and 2013 from upstream to downstream of the Brahmaputra River. The collection areas which covered nine sites starting from upstream to downstream of the Brahmaputra River, i.e. Guijan, Romeria, Dibrugarh, Jorhat, Dhansiri Mukh, Tezpur, Guwahati, Jogighopa and Dhubri, are shown in Fig. 5.1. Water samples were analyzed for major ions as per standard methods prescribed by the American
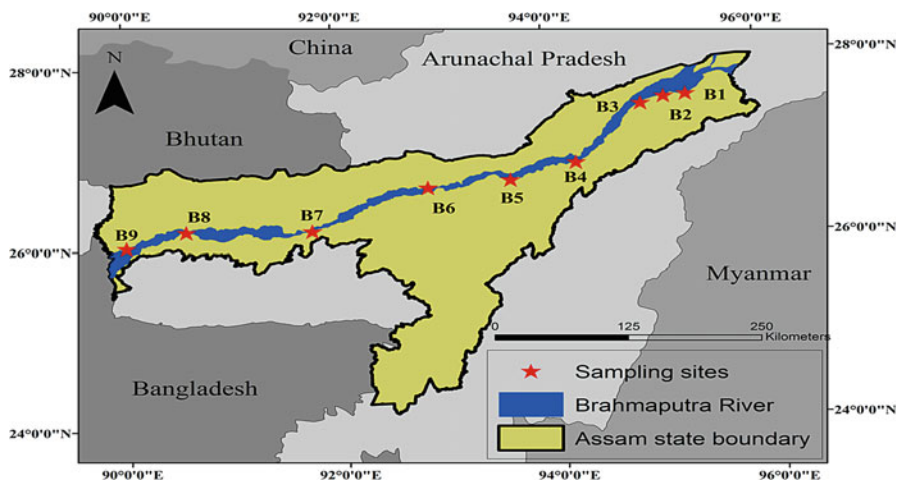
Fig. 5.1 Map of the study area illustrating the Brahmaputra River with sampling locations. Guijan to Dhubri (upstream to downstream) is assigned sample ID B1 to B9 serially

Public Health Association: {calcium (Ca^{2+}) and magnesium (Mg^{2+}) ICP-OES}; {sodium (Na^+) and potassium (K^+), flame photometer};{phosphate (PO_4^{3-})}, {dissolved silica (H_4SiO_4), sulphate (SO_4^{2-}), nitrate (NO_3^-), UV spectrophotometer}; and {chloride (Cl^-), titration method}. Heavy metals (Sr, Ti, Fe, Mn, Cu, Zn, Pb, Ni, Co, Cr) were analysed in ICP-OES (2100 DV Perkin Elmer). A statistical analysis (PCA) was performed using SPSS Version 22.0.

5.3 CO$_2$ Consumption Rates of the Brahmaputra River

Chemical weathering of rock involves consumption of CO_2, a greenhouse gas that exerts strong influence on climate (Berner et al. 1983; Das et al. 2005). Weathering of silicates and carbonates represents an important carbon sink at various scales. The carbon dioxide in the atmosphere dissolves in rainwater forming carbonic acid, which, once in contact with rocks, slowly dissolves them. The CO_2 consumption rate due to silicate weathering (W_{Sil}-CO_2) and carbonate weathering (W_{Carb}-CO_2) of the Brahmaputra River for 2011–2012 and 2013–2014 is shown in Table 5.1 and compared with the world's major rivers. From the value of TDS flux and CO_2 consumption of the world's major rivers (Table 5.1), it was observed that TDS flux of the Brahmaputra River was found to be higher than the Indus River (Himalayan River), the Yellow River (Tibetan River) and the Amazon River (global river). The present result showed that TDS yield was lower than that of the major Indian rivers (Ganga, Godavari, Krishna) and other non-Indian rivers like Mekong and the Amazon but higher than that of the Indus and the Yellow Rivers. As compared with the world's major rivers, the CO_2 consumption rate due to carbonate weathering of the Brahmaputra River was found to be higher than that of the Ganga, Indus,

Table 5.1 TDS flux and CO_2 consumption of the Brahmaputra River and other major rivers of the world

Rivers	TDS flux (tkm^2yr^{-1})	W Sil-CO_2	WCarb-CO_2	References
Brahmaputra	57	0.52	0.57	**Present study**
Brahmaputra	26	0.55	0.58	
Ganges	171	0.45	0. 24	Gaillardet et al. (1999)
Indus	10	0.06	0.09	
Godavari	102	0.29	NA	Jha et al. (2009)
Krishna	28	0.36	NA	Das et al. (2005)
Huang He	NA	0.09	0.27	Wu et al. (2008)
Amazon	147	0.05	0. 11	Gaillardet et al. (1999)
Mekong	56	0.28	0. 58	
Ganga	72	0.38	NA	Singh et al. (2005)
Indus	42	0.06	NA	
Mekong	72	0.24	NA	
Yellow	25	0.08	NA	
Amazon	35	0.05	NA	
World avg	36	0.09	NA	

WCarb-CO_2 - (carbonate weathering x10^6 mol Km^{-2} yr^{-1}). Source: Das et al. (2016)
WSil-CO_2 - (silicate weathering x10^6 mol Km^{-2} yr^{-1})
NA Not available

Amazon and Huang He Rivers and lower than the Mekong River. Our result shows that high CO_2 consumption rate was associated with carbonate weathering.

5.4 Heavy Metal Distribution in Surface Sediment

Heavy metals (Sr, Ti, Fe, Mn Cu, Zn, Ni, Pb, Co and Cr) in distribution in surface sediments of the Brahmaputra River are shown in Fig. 5.2. Figure 5.2 shows that there was considerable variation in heavy metal distribution among the nine sampling stations of the Brahmaputra River. Distribution of Fe, Mn, Sr, Ti, Cr and Co in surface sediments shows decreasing trend from upstream to downstream, whereas spatial distribution of Cu, Zn, Ni and Pb shows increasing trend from upstream to downstream. In some sites metal content was exceptionally high, which may be due to several anthropogenic activities such as urbanization, dumping of solid waste, industrial effluents, etc., and taking place in the catchment area. At site 7 (Guwahati) concentrations of Cu, Zn, Ni and Pb were comparatively higher. Site 7 is an important river port which receives high volume of industrial effluent and urban runoff. All the drainage outlets in the Guwahati city discharge into the Brahmaputra, thereby polluting the river. Moreover, extensive agricultural practices and high dependence on chemical fertilizers and pesticides are possible anthropogenic sources that contribute to the increase in metal concentration in the river.
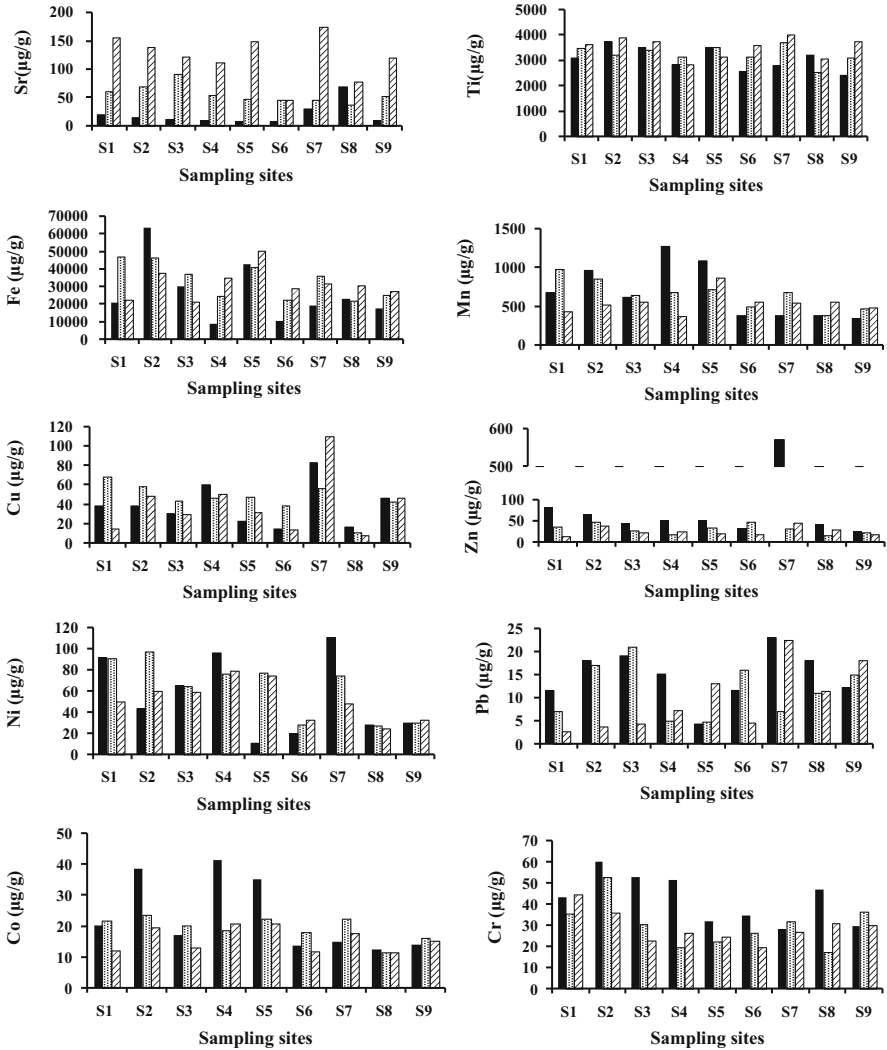
Fig. 5.2 Spatial and temporal variation of heavy metal (Sr, Ti, Fe, Mn, Cu, Zn, Ni, Pb, Co, Cr) in surface sediment of the Brahmaputra River

5.5 Statistical Analysis

Principal Component Analysis (PCA) in Surface Sediment

PCA was performed on heavy metal content in surface sediment samples in order to identify the major process that affects the water chemistry of the river and possible source of different variables. PCA for 13 variables was performed, and 4 components were extracted with eigenvalue >1.

Table 5.2 Factor loading of principal component analysis (PCA) of heavy metal, pH and organic matter in surface sediment samples

	Component			
	F1	F2	F3	F4
Fe	**0.578**	**0.504**	0.002	0.113
Sr	−0.214	**0.774**	0.177	−0.254
Ti	0.249	**0.810**	−0.007	0.115
Mn	**0.900**	0.050	0.037	0.072
Cu	0.143	0.177	**0.849**	0.089
Zn	−0.198	−0.339	**0.713**	0.175
Ni	0.292	0.060	**0.742**	−0.073
Pb	−0.161	−0.120	0.423	**0.712**
Co	**0.935**	−0.162	0.127	0.124
Cr	0.437	−0.080	−0.064	**0.749**
pH	−0.188	**0.772**	−0.129	−0.094
OM	**0.636**	−0.184	0.326	−0.451
Eigenvalue	2.93	2.34	2.13	1.43
% of variance	24.4	19.5	17.8	12.0
Cumulative %	24.4	44.0	61.7	73.6

The results of PCA for heavy metal concentrations, pH and organic matter in surface sediment samples are shown in Table 5.2. The first factor (F1) accounts for 24.4% variance with Fe, Mn, Co and OM as dominant variables. These elements mainly originate from lithogenic sources such as rock weathering and soil erosion. High positive loading of Mn and Co with OM indicates complexation of organic matter with lithophile elements or participation in biological activity with the mobility of these metals being controlled by organic colloids. Association of Fe with Co and Mn indicates that during weathering, Co and Mn are released as Co^{2+} and Mn^{2+}, respectively, from ferromagnesium minerals. It was reported that Co^{2+} and Mn^{2+} were retained in sediments in association with silicate layers and organic colloids and mostly in oxides of Mn (Alloway 2010).

The second factor (F2) accounts for 19.5% variance. In factor 2 high loading of Ti, Sr and pH indicates that pH controls the distribution of Sr and Ti. pH is a vital factor that regulates concentration of heavy metal in sediment. With decrease in pH, sorption of heavy metal decreases, and at high pH, sorption of heavy metal in sediment increases (Christensen 1989). The third factor (F3) accounts for 17.8% variance. The dominant variables were Cu, Zn and Ni indicating metal released from similar anthropogenic source. Industrial waste and sewage in urban areas also add to ubiquitous distribution of Cu and Zn (Kumar et al. 2013a, b). The use of anti-corrosion paints on fishing boats may add to the occurrence of Zn in sediment (Aris et al. 2009). Agricultural runoff containing chemical fertilizers is another important source of these metals in the river basin. The fourth factor (F4) accounts for 12.0% variance with dominant variables, Pb and Cr, indicating strong association with vehicular emission. Common sources of Pb are sewage sludge, vehicle exhaust, lead arsenate pesticide and pesticides (Lei et al. 2008).

5.6   Assessment Imprints of Climate Change on Weathering Rate and Subsequent Metal Release

Table 5.3 shows the effect of climate change on weathering. It shows that factors like temperature, rainfall, runoff, partial pressure of CO_2 (P_{CO2}) and increase in sea level lead to an increase in chemical weathering rate. The carbon dioxide in the atmosphere dissolves in rainwater forming carbonic acid, which, once in contact with rocks, slowly dissolves them. Eventually CO_2 that was present in the atmosphere gets introduced to the river through wet precipitation and then transported into the oceans, where it is trapped for several thousand years, before returning to the atmosphere again or alternatively being stored in river sediment.

In the present study partial pressure of CO_2 (log PCO_2) was calculated from CO_2 concentration recorded in IPCC reports from 2000 to 2010 using the following equations:

$$\log (PCO_2) = -\log KH + \log (H_2CO_3^-) \tag{5.1}$$

Table 5.3 Effect of climate change on weathering

| Effects of climate change	Impacts on weathering	Verdict
Increase in temperature	High levels of CO_2 cause high temperatures through the greenhouse effect. Increase of temperature speeds up chemical weathering. Silicate weathers faster at high temperature, consuming larger quantities of CO_2. This causes CO_2 levels and global temperature to drop. At low temperatures, silicate weathering and CO_2 consumption are minimal, causing CO_2 to accumulate in the atmosphere	Favours weathering Positive
Increase in rainfall	When CO_2 dissolves in rainwater, carbonic acid is produced. As the rainwater moves through soil, the carbonic acid dissolves calcite	High rainfall favours weathering Positive
Increase in runoff	Climate change will lead to increased runoff. High runoff increases chemical weathering rate. Runoff – warmer = more precipitation = > weathering increases	Increased runoff favours weathering Positive
Increase in partial pressure of CO_2	Increased partial pressure of CO_2 near the surface of Earth results in increase in CO_2 dissolution in water	Increase partial pressure, CO_2 consumption increases. Positive
Glacier melt and rising of sea level	Increase in sea level leads to increase in runoff. As a result the amount of suspended solids, sediment load and associated contaminant metal flux increases	Positive
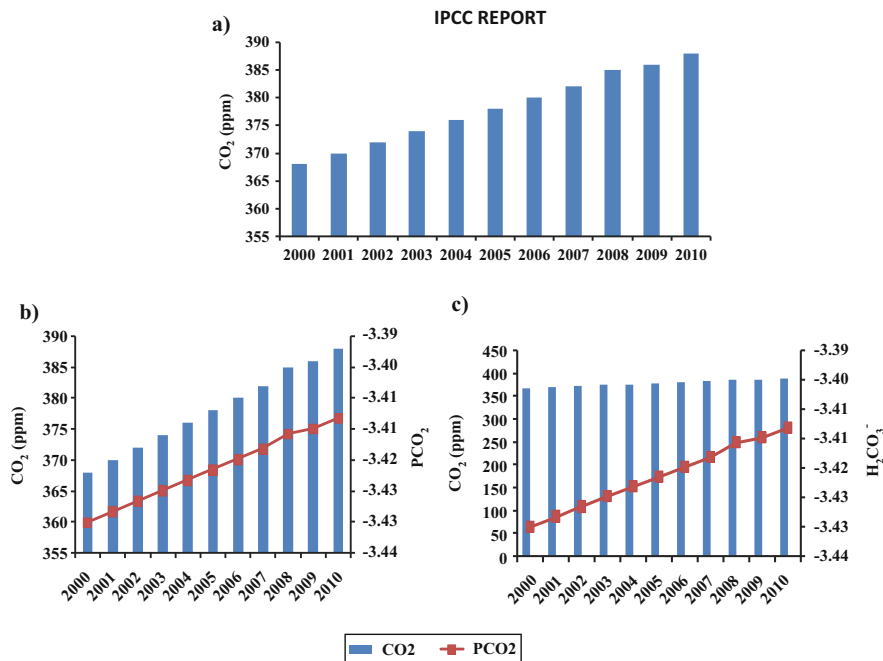
Fig. 5.3 (**a**) Atmospheric CO_2 concentration of IPCC report from 2000 to 2010. (**b**) Partial pressure of CO_2 (log PCO_2) calculated from atmospheric $CO_{2.}$ (**c**) Carbonic acid (H_2CO_3) calculated from log PCO_2

$$\log\left(H_2CO_3{}^-\right) = -\log K1 - pH + \log\left(HCO_3{}^-\right) \qquad (5.2)$$

River alkalinity is an indicator of climate change. For every 1 mole of mineral reacting with carbonated water, there is proportional release of dissolved silica and bicarbonate (alkalinity). The exact amount will depend on the type of minerals being degraded by water, the atmospheric CO_2 concentration and temperature conditions. Figure 5.3 shows that with increase of CO_2 concentration in the atmosphere, partial pressure of CO_2 (logPCO_2) in the atmosphere will increase. In turn $H_2CO_3{}^-$ and $HCO_3{}^-$ concentration will increase.

Figure 5.4 (a) shows variations of CWR and CO_2 consumption rate. As silicate weathering gives net sink of CO_2, significant correlation between SWR and CO_2 consumption was drawn, (b) indicating that with increase of weathering rate, CO_2 consumption rate increases.

Weathering is a key natural process that releases most of the metals. Overall findings in the present study suggest that input of heavy metals was mainly through geogenic source. Multivariate statistical analyses suggest that metals were mostly released from terrigenous source. Therefore chemical weathering is one of the key
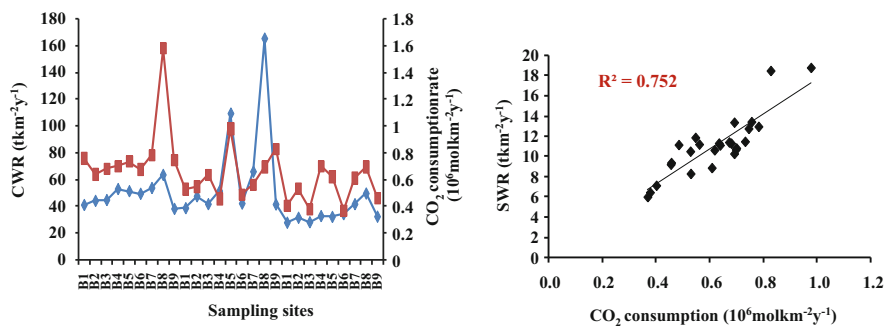
Fig. 5.4 (**a**) Variation of chemical weathering rate (CWR) and CO_2 consumption rate. (**b**) Plot of CO_2 consumption v/s SWR indicate significant correlation between SWR and CO_2

processes that control the concentrations of metals in the bed sediment of the Brahmaputra River. As the weathering rate increases, concentration of metal release through geogenic source increases. Hence metal behaviour is indirectly related with climate change.

5.7   Sustainable Management of the River System

The Brahmaputra River is a major Asian river cutting across international boundaries as it traverses four very distinct regions: the Tibetan Plateau, the Eastern Himalayan Mountains, the Assam plains and the delta in Bangladesh (Singh et al. 2005). The Brahmaputra River is characterized by frequent channel pattern change and shift, due to which it has high seasonal discharge and sediment load and regarded as one of the largest sandbar braided rivers in the world (Thorne et al. 1993). Geologically the Brahmaputra River is the youngest among major rivers of the world.

The Brahmaputra River is known to be the lifeline of Assam, but at the same time it creates havoc through flood and erosion. In India, among the eight north-eastern states, Assam faces the most severe brunt of flood and erosion. Both flood and erosion have severely impacted the economy as well as the political, social and cultural life of the people in Assam.

In order to reduce the hazard of flood and bank erosion, we need proper planning, community participation and application of contemporary technologies for identification of needs and opportunities and for understanding the governing cause-effect relationships and the related management options. Climate change and sustainable development maintain dual relationship (Cohen and Waddell 2009), and not only does climate change affect development, but development affects climate too.

Sustainable Development Policies

1. Application of alternative development pathways: Alternative development pathways such as modification in building infrastructure can save biodiversity loss and degradation of ecosystem services. Managing water resources.
2. Sectoral environmental/economic policies: Economic policies should include economic analyses of regulatory policy instruments such as emission trading, estimating greenhouse gas reduction, benefitting the role of uncertainty and modelling the economic impacts.
3. Institutional/managerial changes: Institution should involve in planning and implementation of water resource management. Promote hazard and risk mapping, disaster management.
4. Innovation/technological changes and their application: Spread the benefits of industrialization worldwide and without unsustainable impacts on water and other natural resources.

Climate Change Policies

1. Avoid climate change damage: Implementing adaptation strategies, risk reduction, financial insurance, micro-insurance, microfinance and risk-pooling transfer are some of the policies that can minimize the risk of loss and damage and financial burden of adapting to climate change.
2. Secondary benefits/costs: Policies to reduce emissions of greenhouse gases also have impacts on other policy goals, especially health.
3. Spill over/trade effects management: Impact of mitigation actions by the industrialized countries on the level of greenhouse gas emissions in the developing countries.
4. Encourage innovation/technological change: Innovation technology like low-carbon technologies can increase welfare.
5. Direct national/sectoral costs.

5.8   Transboundary Water Management

Figure 5.5 shows the interrelation of different factors and parties in transboundary water management. The Brahmaputra River is a transboundary river shared by different countries and managed differently based on the interest of the respective countries. Due to this, conflict arises between states in India and neighbouring countries, and also lack of consistent cohesive cooperation among the countries to address the core issues of water management and climate change adds further uncertainties in controlling the same. A resilient cohesive workable institutional framework is required to drive and resolve the issues. At the same time, we need political initiative and process, state policies, foreign policies and active and efficient actors in governing the system.
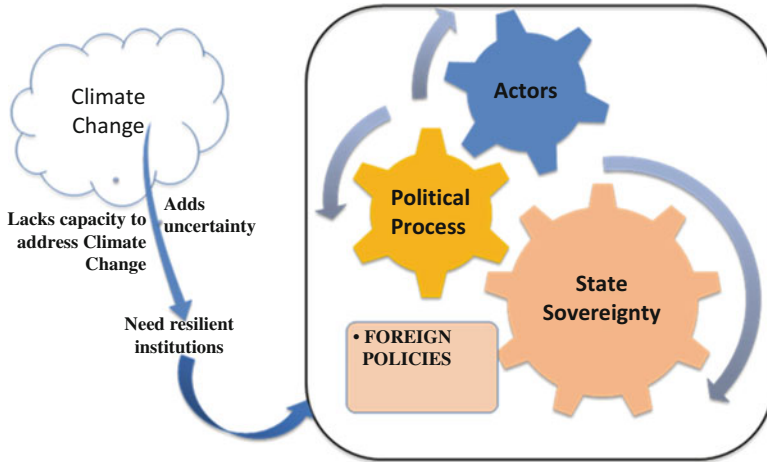
Fig. 5.5 Transboundary water management

5.9 Conclusion

Overall result shows that input of heavy metals is mainly through geogenic sources. Statistical analyses show that metals were mostly released from terrigenous source. As weathering rates increased, concentration of metal release through geogenic source also increased. Hence, metal behaviour is indirectly related with climate change. Significant positive correlation between weathering rate and CO_2 consumption rate signifies increase of CO_2 concentration in the atmosphere which induces weathering rate, thus causing metal release. Therefore, release of metals from natural sources is indirectly affected by the extent of weathering and CO_2 increase due to greenhouse gas emissions. This further indicates that major river systems do respond to the increases of CO_2 concentration in the atmosphere by establishing a new equilibrium at the interface of water-air. This is a result of increased CO_2 dissolution and bicarbonate acid formation inducing weathering and resultant release of metals locked in silicate structures of clay minerals and metal carbonate.

The study of metal quantification with respect to weathering rate will provide understanding of anthropogenic and natural contribution of heavy metal in the sediments. The present study will probably be the first attempt to relate metal behaviour with weathering and carbon dioxide consumption rate in the Brahmaputra River, the fifth largest river in the world. The study of natural and anthropogenic contribution of heavy metal will provide better understanding of metal behaviour under different environmental condition. The study will contribute effective management strategy for freshwater resource with the potential to extrapolate the present case of the Brahmaputra River with major rivers in the world and their possible future scenarios. The integrated results as a whole will also contribute to the development of sustainable freshwater resource management and thus will be helpful to solve one out of the two most vital challenges the world is facing today, i.e. lack of freshwater and need for sustainable energy production.

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