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A framework to analyze the complex dynamic delta system for adaptive decision making in Bangladesh

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Abstract

Adaptive Delta Management as a promising policy making approach has been embarked in many deltas to deal with future uncertainty. Bangladesh is on her way to develop scenario based water-centric adaptive delta plan. So, analysis of relevant uncertainties of the complex dynamic delta system is essential and it requires a framework. We applied XLRM framework to analyze dynamic interactions in southwest Bangladesh. The different components of XLRM are identified and relationships are described in this study. The study contributes to scientific knowledge on dynamic interactions of complex delta system assisting in policy area of water centric adaptive delta management.

Keywords: Adaptive Delta Management, XLRM framework, Complex dynamics in delta, Bangladesh.

Introduction

Public policy making in many delta system of the world are embarking on adaptive delta management as a promising approach to deal with the intrinsic dynamics and uncertainty that characterizes these systems. Bangladesh is on her way to develop scenario based water-centric adaptive delta plan taking into account future uncertainty in physical and socio-economic developments. Informed decision making on a deeply uncertain future demands for a context specific framework to structure the relevant information of the system and their dynamic relationships. This study applies the XLRM framework (Lempert et al., 2003) to structure the dynamic relationships.

Our objective is to address two key questions: 1) How to analyze the complex dynamic delta system for adaptive decision making under deep uncertainty? and 2) What are the key system components and their dynamic relations for water resource management in southwest coastal Bangladesh? For this purpose, we adopted the XLRM framework of Lempert et al. (2003). The exogenous uncertainties (Xs), Policy Levers (Ls), Relationships (Rs) and Measures (Ms) were identified from extensive literature review and stakeholder interaction. Based on the information, the key components and their inter-relationships are developed in causal diagram and analyzed.

Study Area

The study area for this research is the South west region of Bangladesh. The region is an ecologically and economically important zone because of its agriculture, energy and marine resources (Kabir, Cramb et al. 2016). The region represents 16% of total land area of Bangladesh (~25,000 sq km) and 14 million people (BBS 2011). Figure 1 shows the location and major rivers in the region. The area represents an agro-ecological landscape of the Ganges tidal floodplains. The area is lower part of the highly active Ganges-Brahmaputra-Meghna Delta. The tidal dynamics in the area is heavily influencing the overall situation.

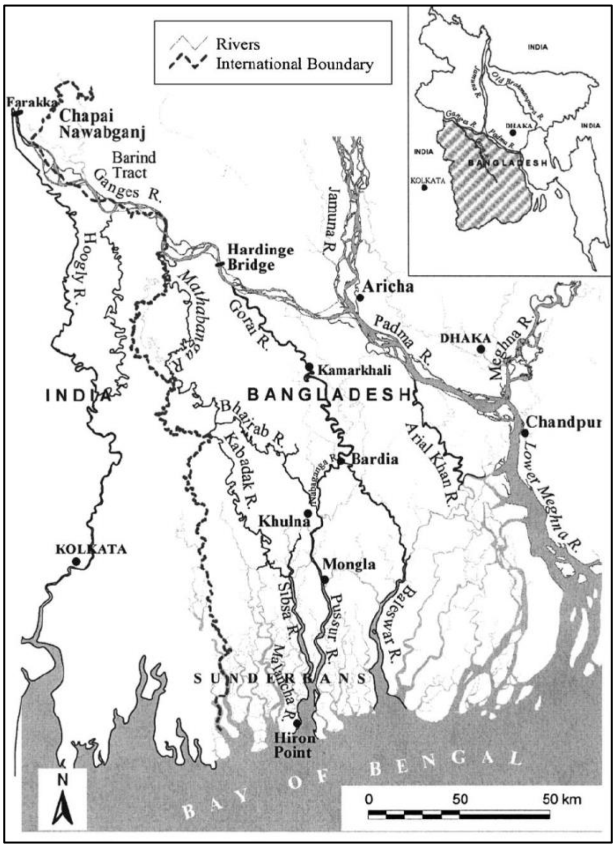

Figure 1: South-West region of Bangladesh

Source: Figure used from Mirza & Sarker (2004)

The coastal community's livelihoods in this region are dependent on agriculture (~40%), fishery (~20%), forestry (~25%) and the remainder (~15%) includes laborers and professionals (e.g. teachers, government officials and businessman) (Hossain, Eigenbrod et al. 2016). A larger share of poor income group relies on rice production for food and labor income. The region has around 80% share of the total shrimp production in Bangladesh (Haider, 2012). Paralleling the expansion of shrimp farming, extensive salinity intrusion has been observed in freshwater and soil in many coastal districts in Bangladesh. The shrimp cultivation is dominated by large farmers and land owners. Moreover majority, around 43%, of the shrimp cultivated land is owned by distant land owners using rented land and hired labour (Alauddin and Hamid, 1999). According to the Salinity Survey Report 2010 of Bangladesh, about 2.13 million acres of cultivated land is affected by soil salinity in varying degree, accounting for 70% of the total cultivable area in the coastal and offshore regions (SRDI, 2010). Major percent of that affected area is located in South west region. Number of environmental factors and climate change such as reduction of upstream water flow, change in rainfall pattern and temperature and tidal flooding are contributing to the phenomenon of salinization in the coastal region (Kabir, Cramb et al. 2016). In the southwest region, the mean cultivated area per households has decreased from 1.3 ha in 2000 to 0.92 ha in 2010. The annual decrease rate is 0.038 ha/hh (Hossain, Eigenbrod et al. 2016). Population pressure remains as the central force controlling the level of consumption production and cropping strategies involved (Ali 2006). The pressure on net agricultural land/ production is increasing mainly due to environmental factors as more lands became unsuitable due to hazards and socio-economic development demanding the land use for other economic purposes. In response to the pressure on net agricultural land, the traditional smallholders adapt intensification of agricultural yield via frequent cultivation employing more labor input, and using improved techno-managerial strategies and high yielding variety (Ali 2006).

But the socio-ecological system of this region is rapidly changing in recent decades because of sea level rise, land-use change, water scarcity, migration and urbanization (Hossain, Eigenbrod et al. 2016). All these have made the overall situation very complex and dynamic from both physical and socio-economic systems aspects.

Methodology

The study methodology focuses on the critical problem of long term policy planning. In order to take decisions, decision makers often evaluate the performance of policy strategies over an ensemble of deeply uncertain trajectories of the future. For this, decision makers select plausible ranges for each uncertain factor, often employs statistical algorithm to discover scenarios. The scenarios show ranges of the exogenous factors and their impacts on system variables. A policy strategy over a long time period might cause poor performance due to the changing nature of exogenous factors and consequent system responses. Therefore, a framework of key decision components in combination with Robust Decision Making (Lempert, 2003), Dynamic Adaptive Policy Pathways (DAPP) (Haasnoot et al., 2013) etc. can support decision makers to determine how changes in their assumptions about exogenous factors affect the performance of their planning strategies. For complex environmental systems, this is especially useful because it can help planners to identify in which condition their current strategy will be ineffective and an adaptation of their strategy will be required.

To identify and structure the relevant information of the policy problem in water management in coastal region of Bangladesh, we adapted the XLRM framework of Lempert et al.(2003). The XLRM framework has been widely used in policy problem formulation to organize relevant factors into four distinct but interconnected components of a decision centric analysis

(Kasprzyk, Nataraj, Reed, & Lempert, 2013). As described in Lempert et al. (2013), the letters X, L, R, and M refers to four categories of factors:

Exogenous uncertainties (X) are factors like climate change that are outside the control of decision makers but that may affect the ability of near-term actions to achieve decision makers' goals;

Policy levers (L) are near-term actions that decision makers want to consider, in this case as part of the integrated flood risk management strategy, e.g. investments in polder or tide gates that could reduce flooding, and implementation of land use policies that could reduce exposure to any flooding that does occur;

Outcome Metrics (M) are the performance standards used to evaluate whether or not a choice of policy levers achieves decision makers' goals, e.g. risk to various segments of the population or to the economy; and

Relationships (R), are the internal and external relations among the system variables, exogenous factors, policy levers etc. and are generally represented by simulation models, describe how the policy levers perform, as measured by the metrics, under the various uncertainties.

Based on the available literature and insights from stakeholder interaction, the exogenous uncertainties, policy levers, outcome metrics have been identified for the coastal Bangladesh. The major issue for the region is to sustain and enhance economic outcome under adverse natural and socio-economic situations. For representing the system relationships, a causal diagram has been developed in Vensim pro. The causal tracing has been performed with 'Causes Tree Tool' to identify the variables that 'cause' the selected variables to change up to two connections distance. The uses tree diagram resulting from 'Uses Tree Tool' shows the uses of the selected variable. The relationships derived on the basis of the causes and uses analysis are explained in result section.

Results

a. *Developed XLRM framework:*

The framework development is mainly based on the XLRM components. In order to understand the complex dynamic delta system in the SW Bangladesh and the system response characteristics, the major uncertainties, strategies, relations and performance metrics have been identified. Table 1 shows the XLRM components for the complex delta system in SW Bangladesh.

Table 1: XLRM components for SW Bangladesh

Exogenous Uncertainties (X)	Policy Levers/ Strategies (L)
▪ Global Environmental Change − Different RCPs & local socio-economic scenarios − Effects of pollution on environment − Sea level rise and salinity intrusion ▪ Developments in Upstream Catchments of transboundary rivers − Water withdrawal ▪ Socio-economic development/ changes − Changes in societal needs − Changes due to economic development ▪ Changes in land use dynamics ▪ Population dynamics and distribution ▪ Future values and cultures ▪ Innovation of new technology	▪ Policies for efficient use/ management of water resources ▪ Policies for disaster risk reduction/ management ▪ Policies promoting River basin level water management approach for sustainable water sharing among the riparian countries of trans-boundary rivers. ▪ Policies promoting diversification in agriculture/ livelihood actions ▪ Policies on environmental protection ▪ Policies on value chain management ▪ Land use Regulations ▪ Research on Innovation of new technology
Relationships (R)	Outcome metrics (M)
System dynamics relations of physical, social and economic system	▪ GDP growth ▪ Environmental quality ▪ Water use efficiency ▪ Food security ▪ Poverty level ▪ Inequality in economy, society, damages

The first component in the XLRM, is the *exogenous uncertainties (X)*. For the study area the major exogenous uncertainties include Global climate change, Developments in upstream catchments of trans-boundary rivers outside Bangladesh, Changes in socio economic setting, changes in land use dynamics, population dynamics, future values and culture in society and new technology.

The climate change uncertainties focus on changing climatic conditions and related socio-economic changes. This uncertainties can be explored by the IPCC developed representative concentration pathways (RCPs) and combining additional local socio-economic scenarios. Besides the scenarios, the effect of pollution on the environment and its resilience to adapt with increasing pollution is of important concern for future planning.

Due to the physical location of Bangladesh as a lower riparian country of major river basins travelling through India, China, Nepal and Bhutan, the developments in upstream catchments of these trans-boundary rivers are major uncertainty for the SW Bangladesh. The developments in upstream catchments include construction of dams, barrages etc. for hydropower generation, irrigation and diversion of water to other areas via artificial canals.

The change in the local socio-economic setting is of great influence to future policies and decision makers. These changes include the changing requirements of society and economy with respect to level of protection from disaster, needs for facility and infrastructure, water use etc.

The changes in land use and population dynamics are one of the major factors influencing long term planning. As the country has a very high population density, the land use and population dynamics can substantially affect decisions. So, these dynamics can play major roles in policy formulation and decision making.

The future values and culture plays important role from social point of view in policy planning. The decision maker of future might have a completely different viewpoint based on their values and culture compared to the present generation.

Innovation of new technology can play important role in policies also. It can make decisions feasible that cannot be thought of today. So, this can generate some uncertainty for the future policies.

The *policy levers (L)* or the strategies to handle the aforementioned uncertainties include several near term actions which can be suggested from current decision making understanding. These are: Policies for efficient use/ management of water resources to increase water use efficiency and capacity development on it, Policies for disaster risk reduction/ management targeting on minimum damage caused by any disaster, Policies promoting River basin level water management approach for sustainable water sharing among the riparian countries of trans-boundary rivers which is necessary to create win-win scenarios and ensure water availability during crisis periods, Policies promoting diversification in agriculture/ livelihood actions to make economy more resilient in the face of any uncertainty, Policies on environmental protection to ensure a reasonable environmental condition for future generation and also economic development, Policies on value chain management to identify and promote products, goods and services to be marketed at a fair price and boost economy, Land use regulations to manage a balance between demands for residence, economic activity, food production and environmental needs and Research on innovation of new technology to enable society and economy to sustain progress under uncertain futures.

The *relationships (R)* are the most vital element of the overall framework. This includes the dynamic relations among the physical, social and economic systems. In this study the relationships have been explained by the cause effect analysis. The details of these are presented in the following section.

The *outcome metrics (M)* are the evaluation methods for the analysis of the effectiveness and applicability of the policy levers. This metrics can vary depending on decision makers views and perspectives. Here the metrics are selected to evaluate GDP growth, Environmental quality, Water use efficiency, Food security, Poverty level and Inequality in economy, society and disaster damages distribution. These metrics will enable decision maker to evaluate a policy and its effectiveness.

b. Dynamic relationships

The main element of the XLRM framework developed is the relationships among the system variables. Figure 2 shows the relationship in the form of a causal diagram generated using Vensim.

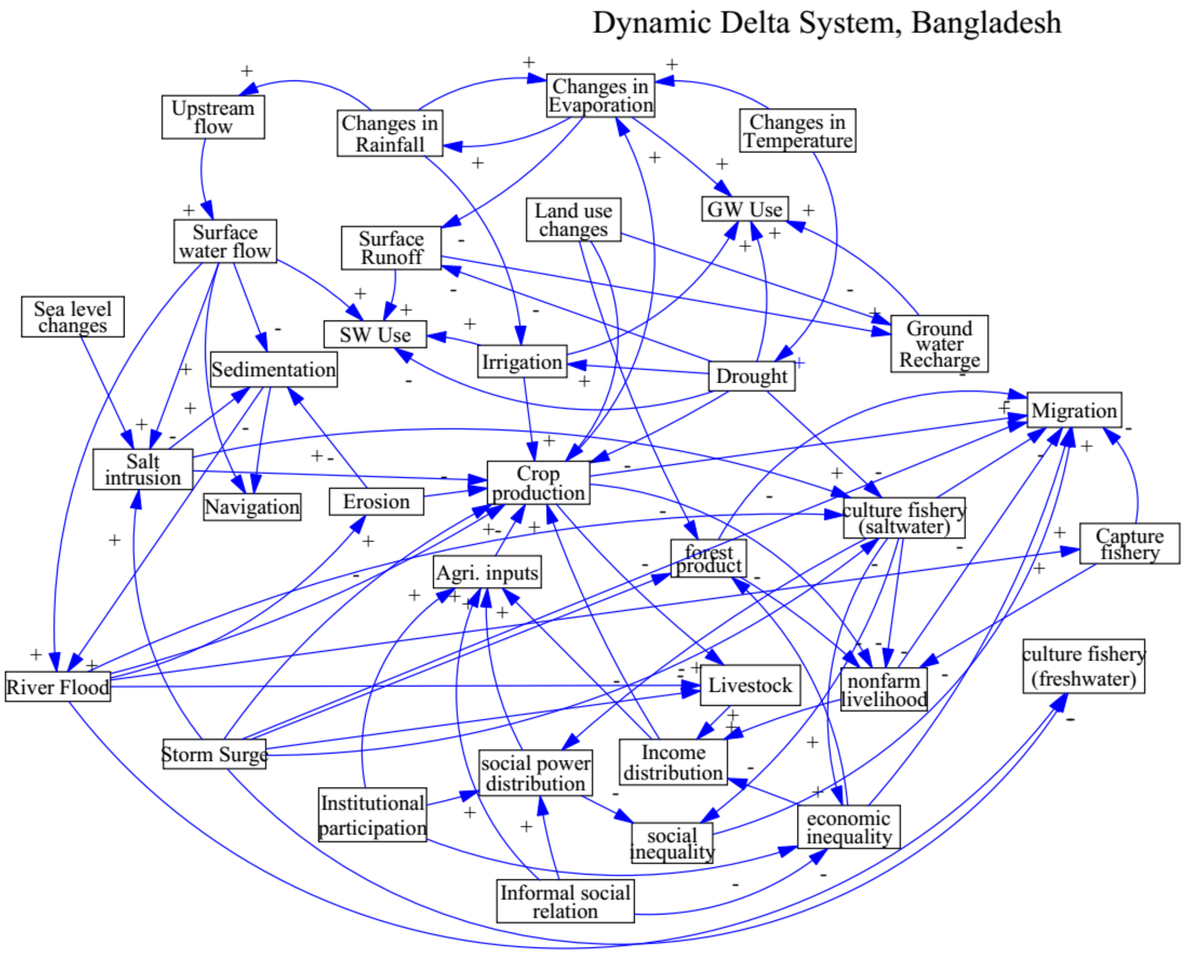

Figure 2: Causal diagram explaining the relationship in the dynamic delta of Bangladesh

The dynamic relationships are formed based on literature review, stakeholder interaction and expert opinions. The overall diagram can be divided in several blocks like climate parameters, river flow from upstream cathcments, seal level changes and salinity, water resources system, land use, disasters (Flood, drought, storm surge, erosion), production and livelihood system (crop, livestock, forest product, culture/ capture fishery, non-farm livelihoods) and socio-economic parameters (income distribution, economic/ social inequality, social power distribution, informal social relations, institutional participation). Of these, climate, upstream flow and socio-economic parameters are mostly controlled exogenous uncertainty. Through their relationships with the physical and socio-economic system, the influences are transferred.

The climate parameters include changes in temperature, rainfall and evaporation. These are linked with each other also. Increase in temperature and rainfall increases evaporation also. Increased evaporation can result in rainfall increase as a feedback. Figure 3 shows the linkages of climate parameters to others. Rainfall influence water availability in surface and ground water sources and can facilitate irrigation and crop production. Upstream flow from transboundary river catchments has a major role in water availability. It is controlled by climatic parametrs and also water diversion/ withdrawal in the upstream countries. Increase in flow can increase flood, sedimentation, water availability, facilitate navigation and decrease salt intrusion by reducing tidal influence inland.

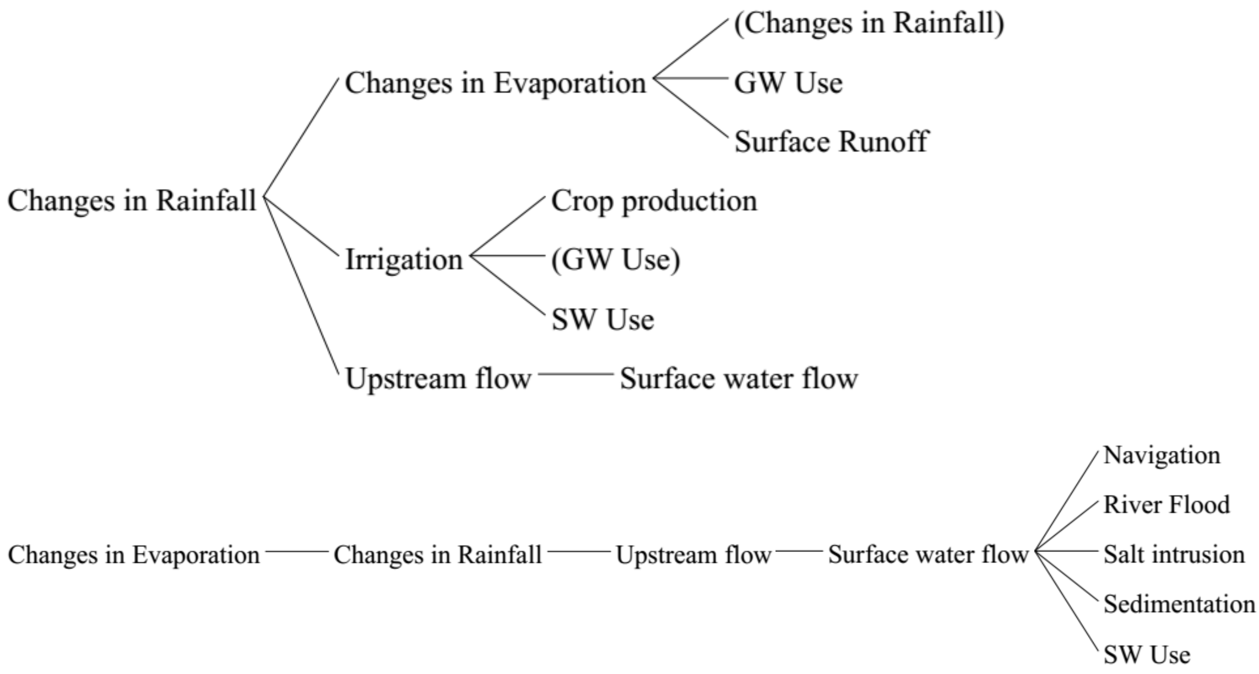

Figure 3: Cause-effect relation for changes in climatic factors and upstream flow

Changing land use pattern is another important parameter. With economic development and population increase more houses and industries/ commercial areas are required. These results in more urbanization and increased surface runoff from rainfall while reducing groundwater recharge. This also negatively impacts crop production and forest product by encroaching of land from agriculture and forest areas.

Figure 4 shows the cause-effect chain of flood and drought. Flood is mainly influenced by rainfall and upstream flow and to a lesser extent by sedimentation. Flood can negatively impact all production and livelihood sectors, can increase inequality and migration. Erosion is also increased as an effect of flood. This further damages livelihoods. Drought is a consequence of increased temperature, lesser rainfall and less flow from upstream areas. Land use changes can also intensify it. It affects mainly water availability and water use by crops, population and industrial activities. So, the negative effects are on livelihood options and results in socio-economic consequences.

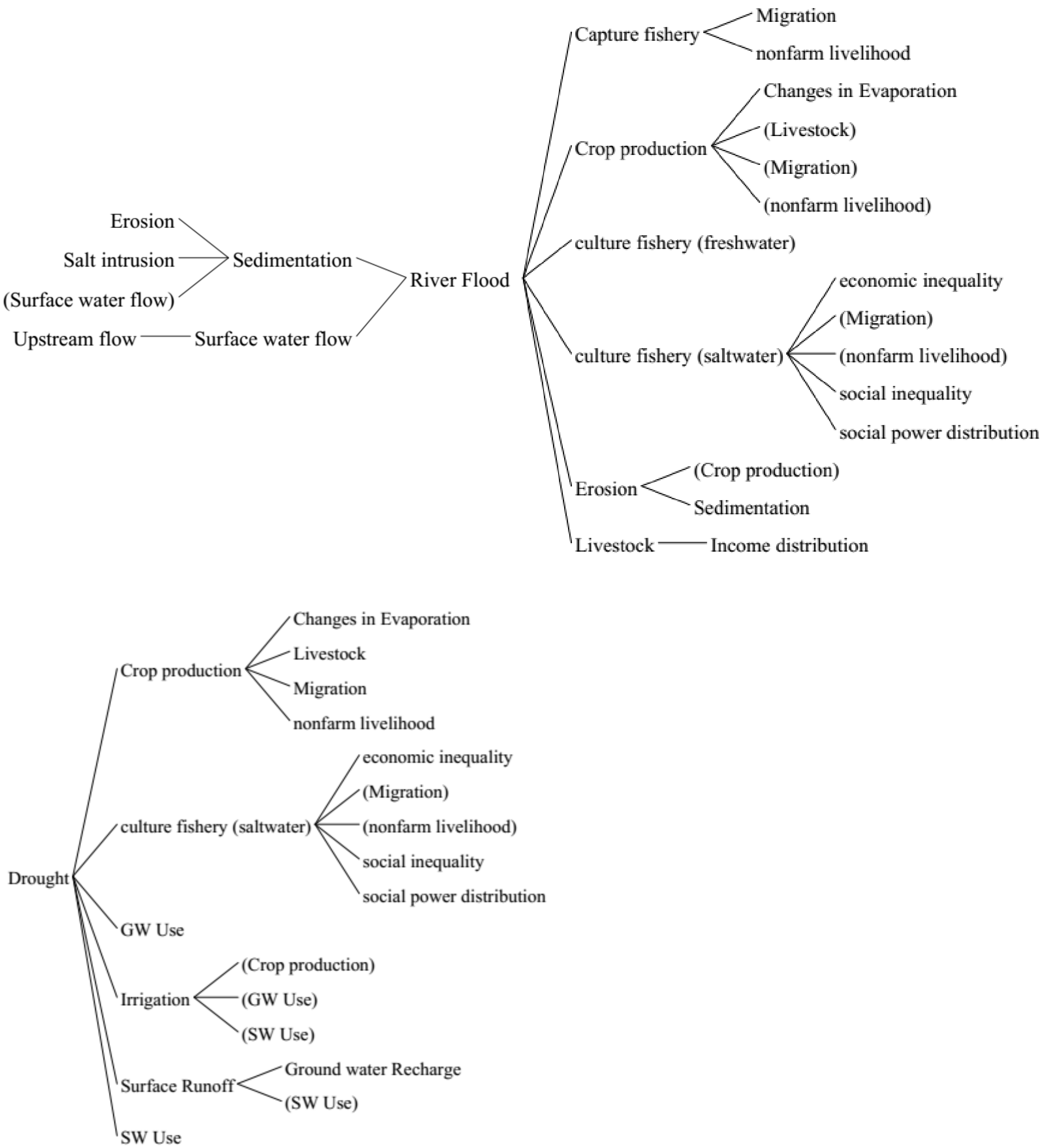

Figure 4: Cause-effect relation for river flood and drought

Sedimentation can be caused by flood, erosion and storm surges (Figure 5). It can be increased by salinity. Sedimentation can cause damage to navigation, crop production and other livelihood activities through water logging.

Salt intrusion is mainly caused by sea level and storm surges (figure 5). It increases with reduced flow in rivers due to less flow from upstream or lesser rainfall. As major part of production and livelihood depends on freshwater, salt intrusion damages them. It can destroy the crop production completely after threshold salinity values. Salt intrusion helps saltwater fisheries which can increase inequality also.

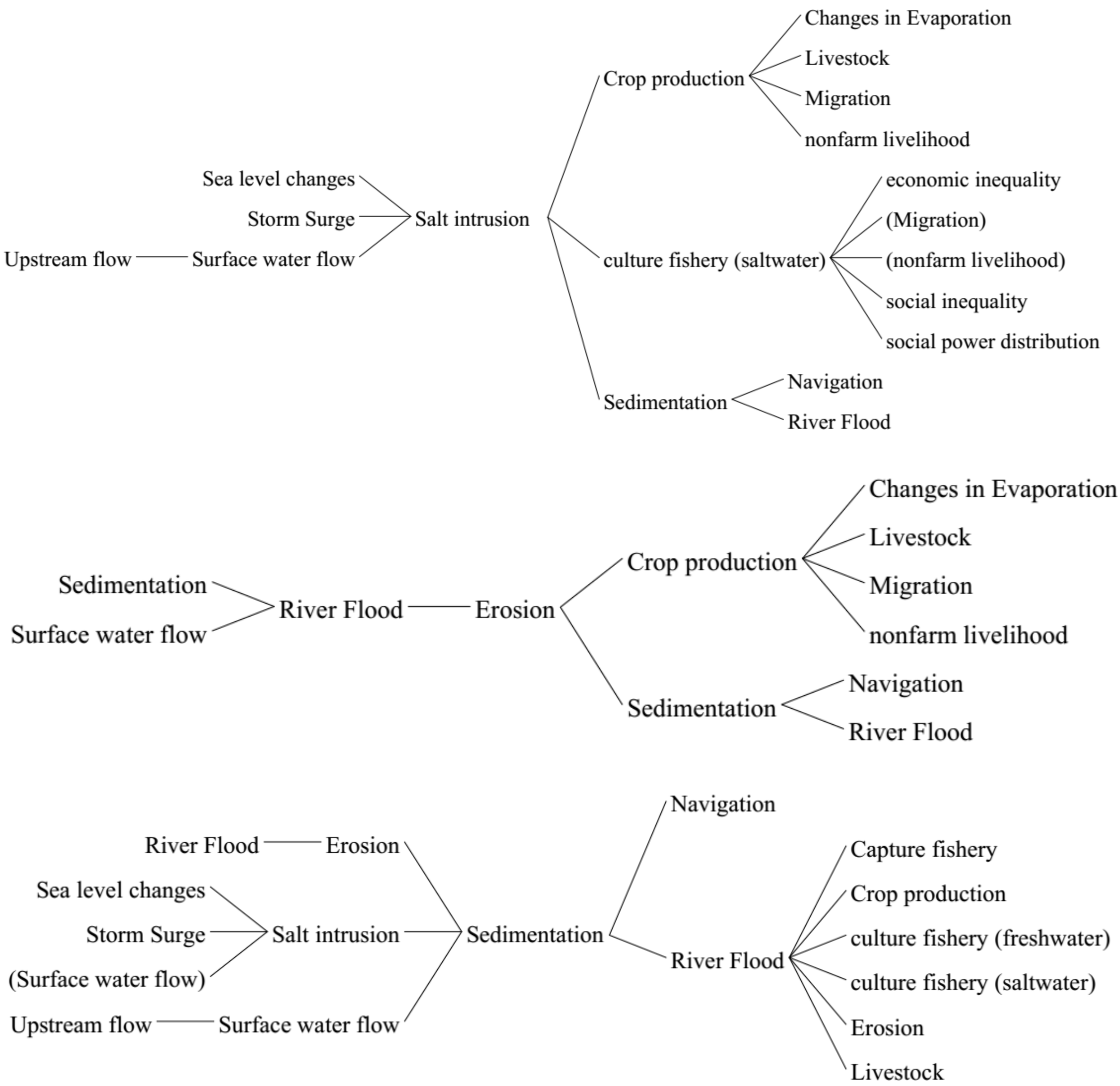

Figure 5: Cause-effect relation for salt intrusion, erosion and sedimentation

The livelihood activities specifically crop production have generally positive relations with climate parameters, negative relations with disasters and positive impacts on socio-economic parameters. Figures 6 and 7 shows the relation of the different livelihood activities with physical system parameters and other socio-economic parameters. The saltwater culture fishery (mainly shrimp) has various impacts on the overall system of which most are negative. As it is more suitable in saltwater, saltwater intrusion inside polder areas is most of the time occurring due to the demand from shrimp farms. This ingress of salinity negatively affects other livelihood activities. Shrimp farming practices encourage social/ economic inequality. It also increases the imbalance in social power distribution. Crop production is the main livelihood activity and it influences other activities also. If opportunity for this is reduced due to physical system barriers, then pressure on other activities increase and if there is not enough options left, migration takes place (Figure 7).

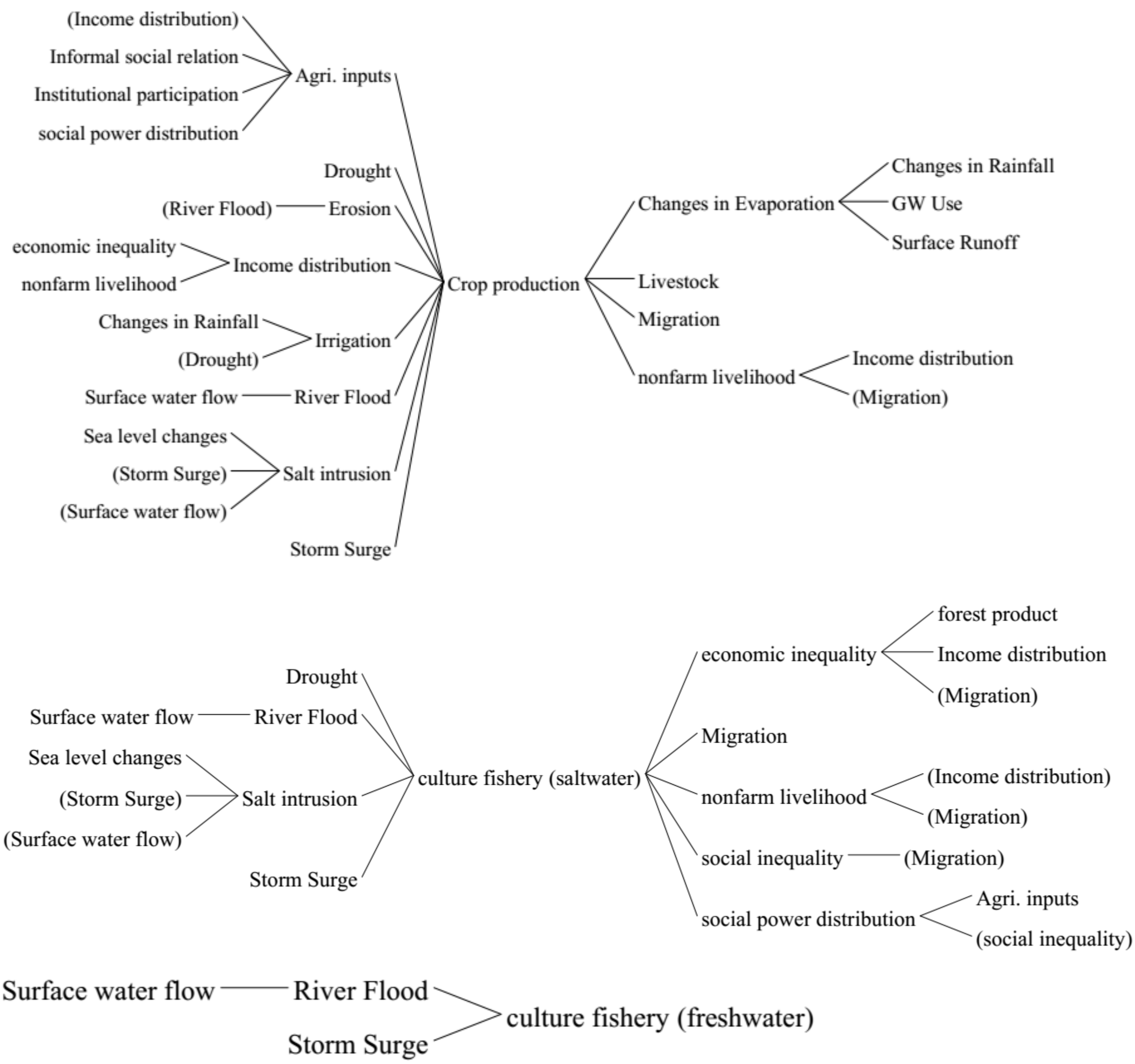

Figure 6: Cause-effect relation of crop production, culture fishery

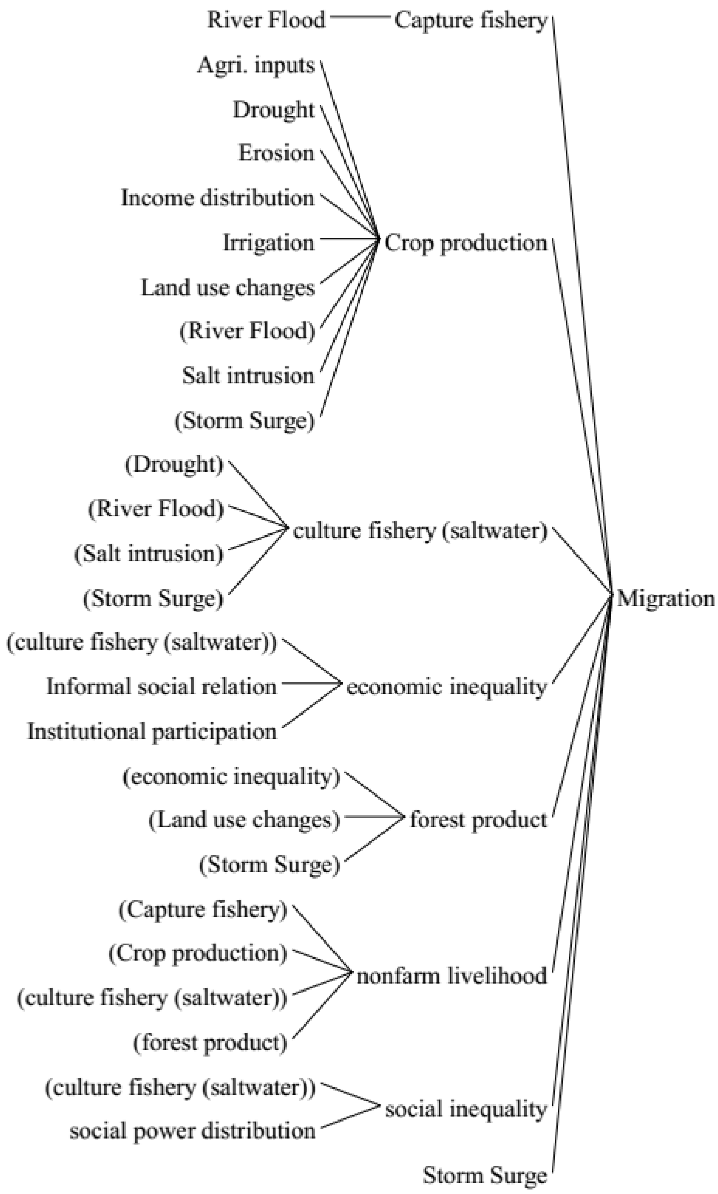

Figure 7: Cause-effect relation of migration

The socio-economic factors are mostly related to equality in society and economy (Figures 8). This can influence the livelihood activities both positively or negatively. For example, if the informal relation in society is better, the society will take decisions collectively and try to have equality in resources distribution. This will result in better access to agricultural inputs and better crop production. Additionally the social power distribution will be more equal. So, social/ economic inequality will be less. The migration is an outcome of the overall situation and appears when no type of adaptation can survive the livelihood activities.

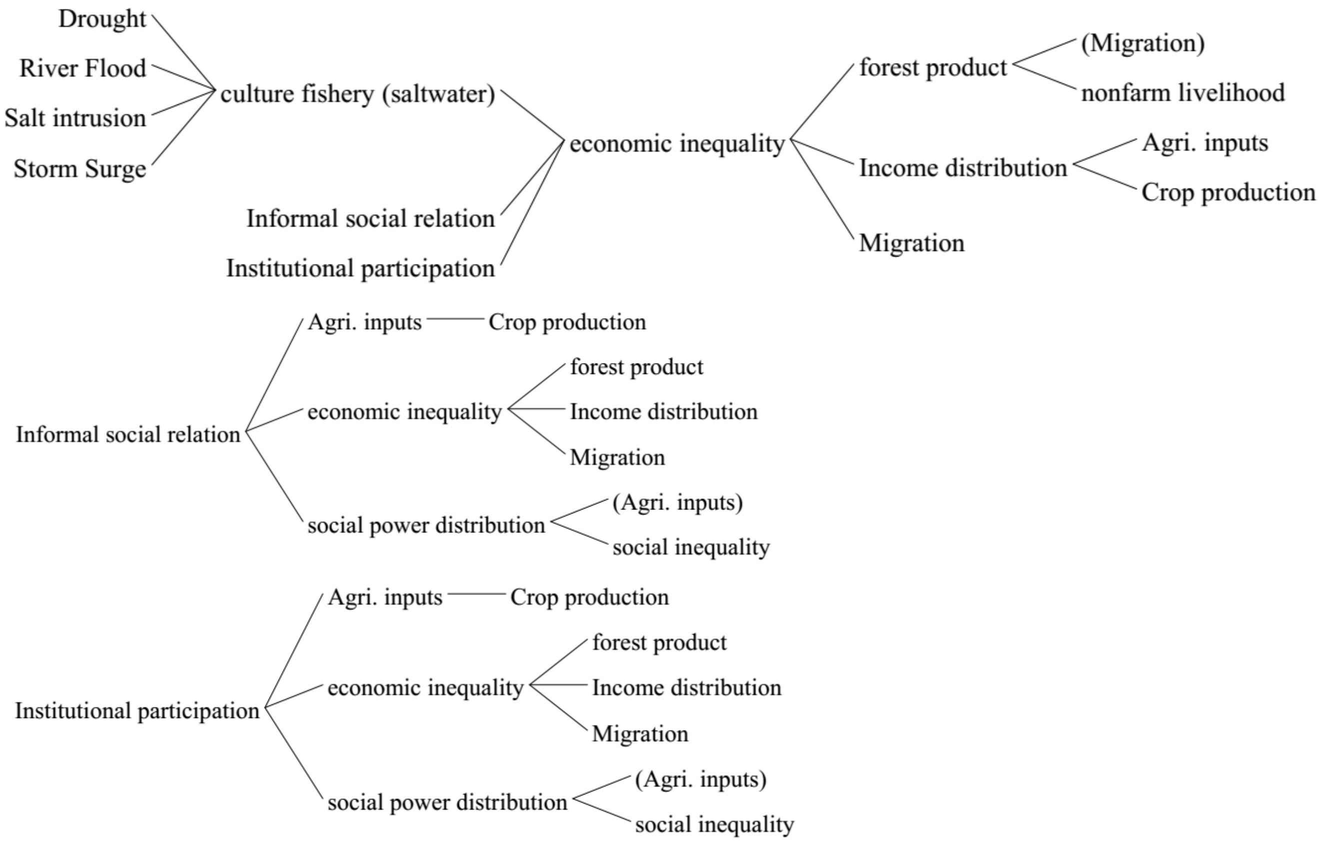

Figure 8: Cause-effect relation of socio-economic factors

Discussion

The XLRM framework and system dynamics relationships of the overall system of Southwest region of Bangladesh have been analyzed. The physical, social and economic components of the region are influenced by both natural and human actions. Some of these are exogenous and some are endogenous relations. The major driving forces in the system are coming from changes in climate and natural hazards. These can negatively impact the production and livelihood activities. Ultimately this affects the socio-economic conditions. Besides these, some forces can be applied from human activities for economic needs which can similarly affect livelihoods. The socio-economic uncertainty and policy actions emerge out of socio-economic activities and policy/livelihood responses. There are multiple actions, multiple possible scenarios and multiple controlling factors which can result in a wide range of plausible futures. So, to address this deep uncertainty, adaptive and no regret actions are required for both policy regime and local community to adapt to the changes in such complex systems. The analysis and relations explained in this paper can assist exploring different policy actions and their consequences.

Conclusion:

This study explores the dynamic interaction of physical and socio-economic processes and community livelihood in southwest coastal Bangladesh. It is a first step in ongoing research work to better understand the future and its response to long term policy strategies. Based on the understanding from this work, a fast integrated model will be prepared for simulation of different future scenarios and policy actions. Finally this research work will contribute in improved knowledge on dynamic interactions of the complex delta system. As Bangladesh has started its journey to explore the full potential of the adaptive delta planning approach, this knowledge will be helpful for policy decision and researchers.

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