MODELLING OF FARMERS' LIVELIHOOD DECISION MAKING TO UNDERSTAND THEIR ADAPTATION RESPONSE TO CHANGING CONDITIONS IN SOUTHWEST COASTAL BANGLADESH IN THE GANGES DELTA

Umme Kulsum[1*], Jos Timmermans[2], Marjolijn Haasnoot[3] , M. Shah Alam Khan[4], Wil Thissen[5], Hans Middelkoop[6] and Eelco van Beek[7]

[1] *PhD Fellow, Adaptive Delta Management (ADM) Project, Institute of Water and Flood Management, BUET, Dhaka 1000, Bangladesh email: u.kulsum-1@tudelft.nl, ummek14@gmail.com*
[2] *Senior Researcher, Delft University of Technology, Faculty of Technology, Policy & Management, Delft, The Netherlands, email: j.s.timmermans@tudelft.nl*
[3] *Senior Researcher, Delft University of Technology, Faculty of Technology, Policy & Management, Delft, and Deltares, PO Box 177, 2600 MH Delft, The Netherlands, email: marjolijn.haasnoot@deltares.nl*
[4] *Professor, Institute of Water and Flood Management, BUET, Dhaka 1000, Bangladesh, email: msalamkhan@iwfm.buet.ac.bd*
[5] *Professor, Delft University of Technology, Faculty of Technology, Policy & Management, Delft, The Netherlands, email: W.A.H.Thissen@tudelft.nl*
[6] *Professor, Utrecht University, Department of Physical Geography, Utrecht, The Netherlands email: H.Middelkoop@uu.nl*
[7] *Professor, University of Twente, Department of Water Engineering and Management, Enschede, The Netherlands email: eelco.vanbeek@deltares.nl*

ABSTRACT

Uncertain socio-economic development, biophysical processes and natural disasters in the Ganges delta in Bangladesh continuously transform the state of the socio-ecological system, which challenges local livelihood opportunities to be sustainable. Farmers living in the polders of delta make decisions on their livelihood in response to the changing state of this system. Planning for appropriate adaptation strategies might be achieved when underlying rules of decision making are well understood by all those involved in science, practice and decision making. This paper aims to improve the understanding of the decision rules of farmers in adapting their livelihood to changing climate and socio-economic conditions, using a simulation model. It presents a stepwise method for integrating cognitive mapping of perceptions and decision rules of farmers into a formal agent-based simulation model. We apply this method in a case study of farmers' community of southwest coastal region of the Ganges delta, one of the most dynamic and densely populated deltas of the World. Results show that the cognitive mapping can capture the richness of decision making and can inform quantitative model building. The agent based model enables exploring simple decision rules in farmers' livelihood to changing conditions.

Keywords: *modelling, farmers, livelihood, adaptation, decision*.

1. INTRODUCTION

The community in the world's populous and dynamic deltas are facing challenges in their life and livelihood due to uncertain changes in climate and socio-economy. The farmers' community of the Ganges Delta in Bangladesh is lacking sustainable livelihood opportunities due to the changing state of the complex socio-ecological system. Uncertain socio-economic development, biophysical processes and natural disasters continuously transform the state of this dynamic system. The complex behavior of socio-ecological system is strongly driven by the collective outcomes of decisions made by actors at multiple level of the system (Elsawah et al., 2015), for example, regulations affect the individual behavior, and individual behavior affects the resource state (Chave and Levin, 2003). Moreover, different actors such as resource consumers, policy makers and managers employ different strategies and decisions to satisfy their goals and interests that may differ across or even within the actor groups. (Elsawah et al., 2015). The farmers' community in Bangladesh interacts with the government regulations, and responds to the change in nature and society. Adaptation decisions of the farmers' community in their livelihood are made to meet their goals in response to the changing state of the system. The goals and decision rules may change over time and they adapt to changes by learning from experiences (Sterman, 2000). Planning for appropriate adaptation strategies might be achieved when underlying rules of decision making are well understood by all involved in science, practice and decision making (Dasgupta et al., 2014).

This paper is motivated by the need to understand and incorporate human elements as for example peoples' perceptions, decisions and actions into decision making and modelling in complex dynamic system. A range of fields related to decision support, such as adaptive delta planning (Haasnoot et al., 2013), evidence-based planning, decision science and Agent Based Models (ABMs) (Elsawah et al., 2015) supported this need. Their first argument is that peoples' decision and action influence resource use directly and indirectly. Hence, to change the behaviour of resource users and the resource dynamics, policies need to understand and target factors that influence peoples' decisions, effects of decisions on biophysical environment, and future decisions. The second argument is that when individuals and groups make decision to satisfy their own short-term personal interests, this may often lead to long-term resource overexploitation, pre-mature lock-in the system and occurrence of Adaptation Tipping Points (ATP). The third argument relates to the limited capacity of integrated modelling to address the sheer complexity of the human and social dimensions of complex systems, and calls to move beyond simple treatment of human response as an input model scenario, or single parameter, and simplistic rational assumptions about human cognition and behaviour. Elsawah et al. (2015) emphasized that modelers need to capture and represent the decision rules or guiding protocols that generate a flow of decisions. Their final argument is about the capacity of models to capture and communicate the complexity of decision making, and how relevant and useful the non-expert model users in particular perceive them. The users' perception about the model's utility as well as the model's success can be improved by incorporating highly qualitative nature of decision making into formal and numerical modelling. A key challenge for addressing these needs is bridging gap between capturing the highly qualitative, subjective and rich nature of peoples thinking and translating it into formal quantitative data to be used in decision support tools (Kok, 2009). Elsawah et al. (2015) addressed this challenge with a stepwise method to understand the land and water use decision making. This paper made the usefulness of this methodology by modifying and applying in the farmers' strategic decision making in their livelihood adaptation choices in a polder area of southwest coastal Bangladesh. The ultimate aim of this paper is to improve the understanding of the decision rules of farmers in adapting their livelihood to changing climate and socio-economic conditions. The methodology, illustrations and conclusion are presented in the next sections.

2. METHODOLOGY

A modified stepwise method of Elsawah et al., (2015) was applied for integrating cognitive mapping of perceptions and decision rules of farmers into a formal agent-based simulation model.

Below the sub-sections present purpose of step, brief introduction of methods followed by discussion of methods applied in this research for each step.

Step 1: literature review and farmers interviews to elicit their mental models

This step was designed to elicit the mental models or personal constructs of farmers' decision making with minimum instruction of the researcher. Literature of the case study area and methods were reviewed. Polder 31, one of the disaster prone polder in Dacope Upazila of southwest Khulna region was selected as case study. The semi-structure questionnaire was prepared by the researcher group for capturing the data about how farmers think, interpret information and make adjustments. A set of open questions related to their decisions, influential factors, relevance of decision etc. were included in the questionnaire and reviewed by the team. A team of three researchers, with specified role of facilitation, note taking and recording, facilitated the interview session of a group of 10 farmers at the village of Pankhali in Polder 31. In-depth interviewing of two farmers followed the group interview session. During session, the objectives of the interview were explained. The information and data were cross-checked, and provided thanks to the interviewee for their contribution at the end of the session.

Step 2: Cognitive mapping to represent farmers' mental model

The purpose of this step was to develop a cognitive map to represent individual farmer's mental model as a basis for developing numerical Agent Based Models (ABMs). Cognitive mapping is a causal mapping technique and can be seen as a visual representation of a person's mental model about a particular issue or situation at a particular point of time (Elsawah et al., 2015). Cognitive mapping is a commonly used method to (i) understand decision making (Axelrod, 1976); (ii) to support a group working on strategy development or analyses a complex issue (Eden and Ackermann, 2004); (iii) to inform quantitative model building (Elsawah et al., 2011; Giordano et al., 2013) and (iv) to elicit and represent individual mental models for ABMs (Elsawah et al., 2015). In this paper, we use the Eden's cognitive mapping approach that is grounded on the Kelly's Personal Construct Theory (PCT). According to the PCT, People continually develop and revise hypothesis depending on how they reason about a situation (Kelly, 1955). A cognitive map is a hierarchical network of nodes and arrows that represents chain of arguments in the format of means and ends. For example, certain conditions may lead to these decisions, which in turn might lead to these outcomes (Elsawah et al., 2015). Based on interview records and transcript, the researchers develop the cognitive map of individual interviewees in MS Visio. Then, a summery cognitive map was produced that encompasses the concepts of all interviewees. Whenever possible the ideas were formulated in bi-polar statements "A rather than B" to capture the individuals preferences and diversity of perceptions. The concepts were formulated as "action oriented" statements that make the map explicit about "what action is taken" and "by whom". Arrows represents implications, not causality, and are interpreted as "may lead to".

Step 3: Collective mapping to represent farmers' group mental models

The summery cognitive maps that encompasses individuals' view were transferred into a collective map to develop a more structured and single unifying view. The goals and core concepts were identified to structure the collective map and to define the key issues that determine decision making. In this map, the goals are head nodes that have no outgoing links. Core concepts or head nodes link together a cluster of nodes or sub issue. The core concepts are identified based on their content and their link with other concept. The sub issues and decisions that have both incoming and outgoing links are clustered as intermediary concepts, decisions and actions of farmers. The 'triggering concepts' or 'source nodes' that have no incoming arrow or exogenous factors are identified from the core concepts and their link. Triggering concepts are of special importance in decision making and ABM as they represent the contextual (i.e change in climate) and internal (e.g. personal interests and experience) drivers that affect actors' decision (Elsawah et al., 2015).

Step 4 Time sequence analysis to structure the strategic decision making chronologically;

This step was to translate information from collective map to a decision making structure of time sequence diagram. This diagram used as Unified Modelling Language (UML) to map out the chronological sequence of activities that constitute the decision making process, the condition under which these activities take place, and their outcomes (Elsawah et al., 2015). This UML time sequence diagram basically abstracts all functions required to represents decisions identified in the collective map. The focus is on logical flow of information from one function to another. In our case the time of strategic decision is for seasons (specifically dry season) of multi-year. Additional information from farmers' interview and secondary sources were utilized for developing this decision diagram. This diagram can be included in establishing conceptual model for ABM.

Step 5 establishing a conceptual model of farmer's decision making;

The purpose of this step was to catalogue possible implementations for specifying the UML time sequence diagrams to the ABM design. We followed this transitional exercise of qualitative to quantitative to be explicit to identify what models and data required to implement the functions in time sequence diagram. The assumptions, simplifications and consistency were checked with the qualitative data. A simplified decision rule of farmers in the time sequence decision diagram for shifting from rice to shrimp was selected to form an exercise table of concepts and models/data required for implementation in next step.

Step 6 implementing conceptual model into an Agent Based computational model;

This step was to develop an ABM as 'Models as microworlds' to objectively understand how the system "functions" under different scenarios of community decision making rules in their livelihood. ABM represents a system as many autonomous interacting agents, which adapt and co-evolve based on information received from the environment and each other (Elsawah et al., 2015). ABMs are primarily used for simulating socioeconomic or socio-ecological processes to improve understanding of dynamic interactions between agents and their settings in policy analysis, for example, ecosystem management (Bousquet and Le Page, 2004) and agriculture (Berger, 2001). ABMs are able to represent agents' behavior with a rule-based approach (Kelly et al., 2013). Simplified decision rule derived from time sequence diagram were implemented in MS excel.

Step 7 validation of the model results by farmers, experts and historical analysis

The structure and content of cognitive map, time sequence diagram and conceptual model was validated with recordings of farmers' interview, presented in expert meeting for feedback and updated with validated information accordingly. A simple rule was implemented using empirical data in the model.

3. ILLUSTRATIONS

3.1 Cognitive Map

The cognitive map in figure 1 encompasses the summery concepts of all interviewees for their strategic decision of cropping in dry season. Farmers usually decide in two levels- strategic decision at a season and day to day operational level. The concepts that have a link with a strategic decision are included in mapping, whereas the operational decision is not included in this paper.

The wet season cropping decision is less diverse, mostly, Aman rice cultivation. In the dry season, the strategic decisions taken by farmers' are mainly on crop variety, irrigation water and land planning. A total of 15 concepts may lead to the decision on crop variety. The concepts are based on farmers' experience and how they perceive their access to expert knowledge and information about production cost, availability of inputs, market demand, land suitability, farm size etc. Lower or higher crop production from an acceptable threshold is an important factor in the farmers' decisions. Farmers define irrigation water availability including investing in reservoir/integrated farming, land planning, and judicial water use as one of the major driver as well as decision that may lead to the decision of crop variety. The aim of farmers for family food demand, for quality or quantity, to adapt with adverse climate or water constraint may also determine to the decision of crop variety. The suitability of land type, soil salinity, and neighbors land cultivating rice / shrimp or fellow may lead to the decision of farmers' land planning ranges from fellow, rice, vegetable or switch to shrimp farming. Farmers' access to social network along with other concepts may lead to crop being productive and farmers' production profitable.

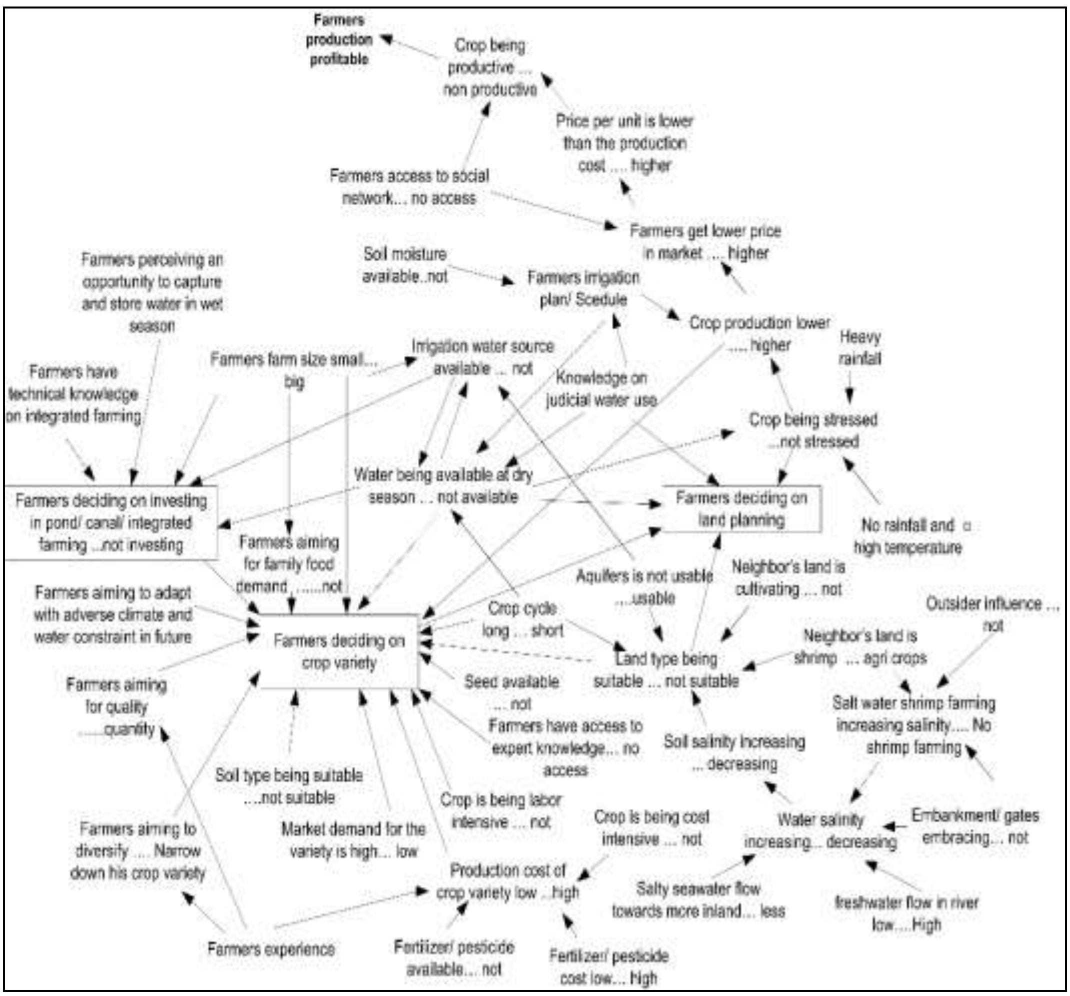

Figure 1: Cognitive map of farmers' strategic decision on cropping in dry season

3.2 Collective Map

We developed the collective map that underpinning strategic decision for multi-year in figure 2. Two key goals identified that farmers seek to achieve are: (1) annual crop production profitable (in terms of net income) and (2) crop production meeting family food demand. A total of 25 triggering concepts, 15 intermediary concepts and 3 decisions are identified.

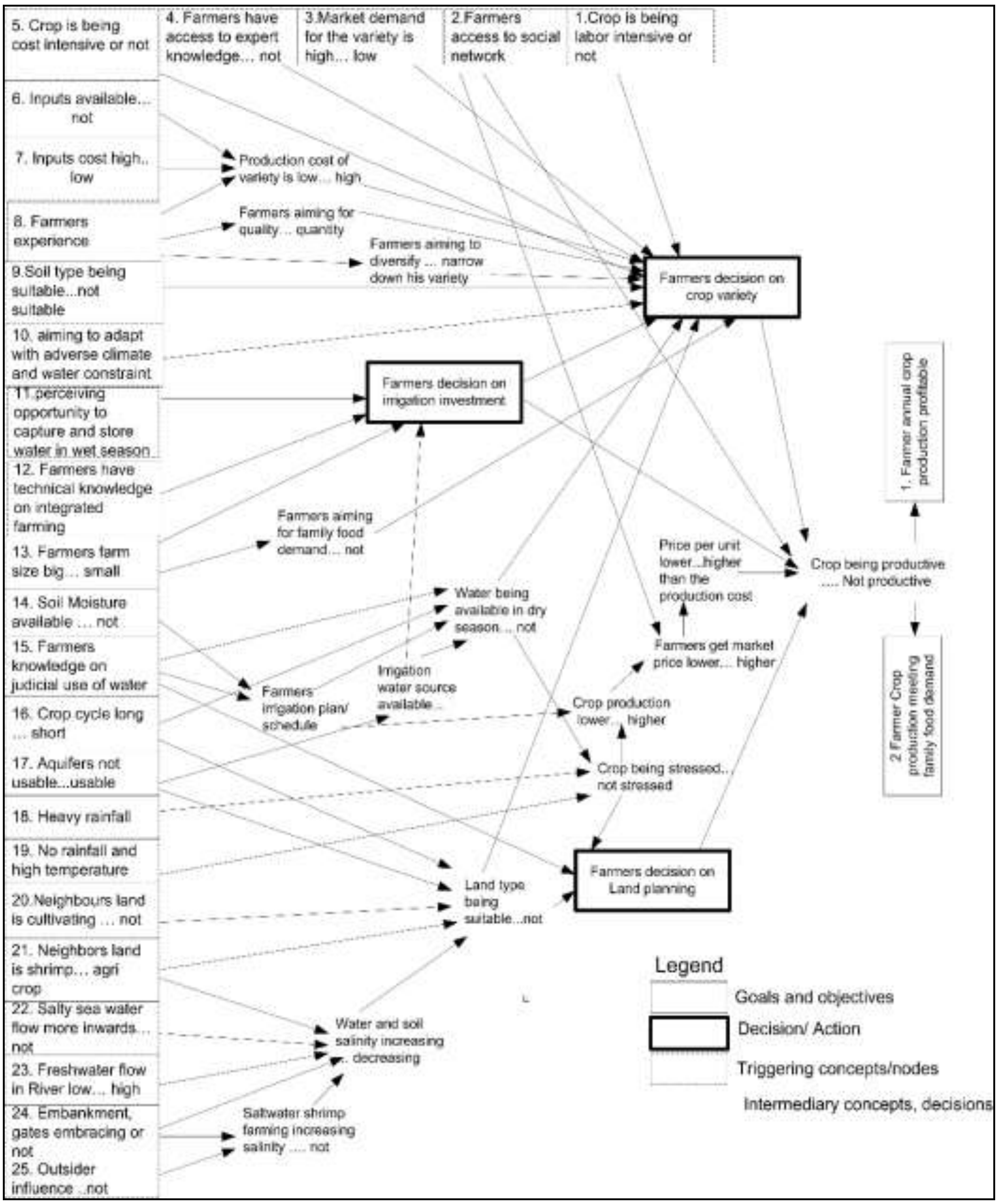

Figure 2: Collective map of farmers' strategic decision on cropping in dry season

3.3 Time Sequence Diagram of Strategic Decision

The farmers' strategic decision for crop selection is based on the triggering concepts of collective map that is simplified in developing the time sequence diagram of strategic decision. The farmers' experience, farm size, willingness to adapt with adverse climate and water constraints are considered to be the base factors in taking decision. We made the decision rules explicit and simplified for this step, which is consistent with available literature. Figure 3 shows the time sequence diagram of strategic decision making of farmers during the dry season:

- If rice production is reduced and drops below a certain amount of production, and the irrigation water and soil become saline due to neighbors' shrimp farm, then the farmers may shift to shrimp production. This is supported in Rahman et al. (2013) and Anisuzzman (2014).
- The farmers' perception and calculation of the irrigation water availability is another triggering factor for crop selection. If irrigation water is available for rice, then they decide for *Boro* rice cultivation in dry season; if they perceive lower availability of irrigation water, then they decide for less water demanding crop such as sesame. This result is supported by earlier research in a similar polder area by Kibria et al. (2015).
- The decision of farmers, particularly small holders, which crop to grow depends on the neighbors' decision on crop choice such as shrimp or fallow. If the neighbors' farm is kept fallow then the farmer is compelled to keep his land fallow. This reflects that the farmers not only decide as an individual but also as part of their community. This results in synchronized cropping patterns among the farmers within small community. This is supported in an earlier research of Mondal et al. (2015).

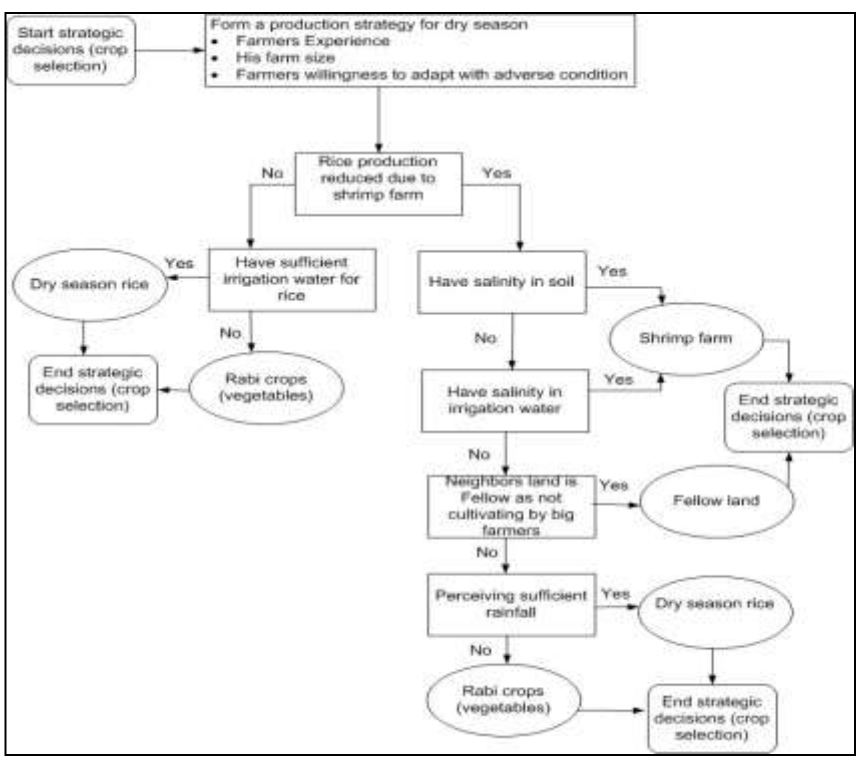

Figure 3: Time sequence diagram of strategic decision making of farmers during dry season

3.4 Conceptual model

The first decision rule derived from the time sequence diagram is that if rice production drops below the threshold then farmers may stop rice production. Based on the calculation of the net income resulting from a changed state of land and water due to salinity from neighboring shrimp farms and inflow of tidal river, farmers may decide to adopt shrimp farming. The farmer is then compelled to switch to shrimp farming if his land is small or the neighboring shrimp farmers' are more influential. If the farmers own a large area of land, they mostly stay outside of the polder and produce rice for income; they are intended to shift to shrimp farming easily. An exercise table of the conceptual model for the strategic decision making diagram is as in table 1.

Table 1: Model/data required for implementation the strategic decision rules

Decisions rules	Model/ data required for implementation	Triggering Factors
Farmers decision for shrimp farm if rice production reduced due to neighbors shrimp farm	1. Thresholds amount of rice production? 2. How many years this production loss farmers can tolerate? 3. The relation of salinity and production loss. 4. A reduction co-efficient due to salinity 5. The farm size relative to neighbors farm size	- Farmers' experience -Willingness to adapt - his farm size

3.5 Agent Based Model

A simplified version of farmers' decision for shrimp farm 'if rice production drops below threshold amount due to neighbors shrimp farm and inflow from tidal river' was implemented in an empirical case of polder in MS Excel. Each cell in MS excel sheet represents the decision of each farmer. Saline and non-saline condition of tidal river, canals and embankment boundary are represented by 0 and 1 respectively.
The computation builds on the relation as below:

1. Rice production = standard production - (reduction coefficient*number of shrimp farms in neighborhood) + min production
2. Land use change = IF production < threshold, THEN convert to 0 = shrimp farm OTHERWISE convert to 1= rice farm

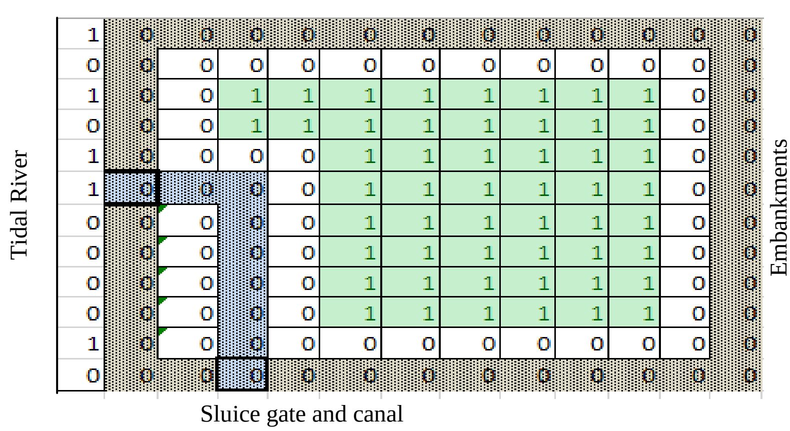

Figure 4: Farmers decision from Rice to shrimp farm

Result shows at figure 4 that the rice farms converted into shrimp farms step by step in saline condition. This simple experiment represents that ABM can implement the decisions and concepts of cognitive map.

4. CONCLUSIONS

The cognitive map can represent the individual farmer's mental model and forms a basis for developing an Agent Based Model (ABM). The farmers' strategic decisions, triggering concepts, intermediary concepts and goals are captured in the same frame of cognitive map. The cognitive map shows how farmers consider a rich number of physical and socio-economic factors or concepts and links among concepts in their strategic decisions. The richness of qualitative information such as farmers' perception, decisions and actions are structured and transferred to the numerical ABM implementation throughout the methodological steps. The agent based model enables exploring simple decision rules in farmers' livelihood in the case of rice to shrimp farm under changing conditions. Hence, ABM contributes to better understanding of the decision rules of farmers in adapting their livelihood to changing climate and socio-economic conditions. The complexity of decisions and outcomes for simulation of future scenarios in the model require further research and validation with historical analysis of farmers' adaptation decisions.

ACKNOWLEDGEMENTS

This paper is part of an ongoing PhD research on 'Exploring uncertainties in community livelihood adaptation for model based adaptive delta management in Ganges delta' at faculty of Technology, Policy and Management (TPM), Delft University of Technology (TuDelft) and Institute of Water and Flood Management (IWFM), Bangladesh University of Engineering and Technology (BUET) under Adaptive Delta Management: Development, Acculturation, and Dissemination in Bangladesh and Indonesia (ADM) project funded by Urbanizing Deltas of the World (UDW) Programme of Netherlands Organization for Scientific Research (NWO). We acknowledge the contribution of participants who took part in this research. We acknowledge the support of Research Assistant, Umme Sauda and Rudaba Raihan during farmers' interview and CCEC, a local NGO in organizing farmer's interview.

REFERENCES

Anisuzzman, M., 2014, shifting from rice production to shrimp culture due to climate change in coastal zones of Khulna district: likely impact on socioeconomic and food security status. MS Thesis. Department of Agricultural Statistics, Bangladesh Agricultural University, Mymensingh

Axelrod, R., 1976. Structure of Decision: The Cognitive Maps of Political Elites. Princeton University Press, Chichester

Berger, T., 2001. Agent-based spatial models applied to agriculture: a simulation tool for technology diffusion, resource use changes and policy analysis. Agricultural Economics 25.

Bousquet, F., Le Page, C., 2004. Multi-agent simulations and ecosystem management: a review. Ecological Modelling 176, 313e332.

Chave, J., Levin, S., 2003. Scale and scaling in ecological and economic systems. Environ. Resour. Econ. 26, 527e557.

Eden, C., Ackermann, F., 2004. Cognitive mapping expert views for policy analysis in the public sector. Eur. J. Oper. Res. 152 (3), 615e630.

Elsawah, S., Guillaume, H.A., Mitchell, M., 2011. Using Participatory Rapid Appraisal and DPSIR approaches for participatory modelling: a case study for groundwater management in South Australia. In: The International Congress on Modelling and Simulation (MODSIM), 12e16 December 2011 Perth, Australia

Elsawah, S., Guillaume, H.A, Filatova T., Rook, J., Jakeman, A.J., 2015. A methodology for eliciting, representing, and analyzing stakeholder knowledge for decision making on complex socio-ecological systems: From cognitive maps to agent-based models. Journal of Environmental Management. http://dx.doi.org/10.1016/j.jenvman.2014.11.028

Haasnoot, M., Kwakkel, J.H., Walker, W.E., Ter Maat, J., 2013. Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. Global Environ. Change 23 (2), 485e498.

Kelly, G., 1955. The Psychology of Personal Constructs: a Theory of Personality (Norton).

Kelly, R., Jakeman, A.J., Barreteau, O., Borsuk, M.E., Elsawah, S., Hamilton, S.H., Henriksen, H.J., Kuikka, S., 2013. Selecting among five common modelling approaches for integrated environmental assessment and management. Environ.Model. Softw. 47, 159e181.

Kibria, G., Saha, D., Kabir, T., Nahar, T., Maliha, S., Mondal, M.S., 2015. Achieving Food Security in Storm Surge- Prone Coastal Polders of South-West Bangladesh. In South Asia Water Studies (SAWAS) Journal, Volume 1, Issue 1, 2015.

Kok, K., 2009. The potential of fuzzy cognitive maps for semi-quantitative scenario development, with an example from Brazil. Glob. Environ. Change Hum. Policy Dimens. 19, 122e133.

Mondal, M.K., Humphreys, Tuong, T.P, Rahman, M.N., Islam, M.K., 2015. Community water management and cropping system synchronization: the keys to unlocking the production potential of the polder ecosystems in Bangladesh. In: Revitalizing the Ganges Coastal Zone: Turning Science into Policy and Practices Conference Proceedings, CPWF, CGIAR. Colombo, Srilanka, May 2015.

Rahman, M., Giedraitis, V. R., Lieberman, L.S., Akhtar, T., Taminskienė, V., 2013. Shrimp Cultivation with Water Salinity in Bangladesh: The Implications of an Ecological Model. Universal Journal of Public Health 1(3): 131-142, 2013. DOI: 10.13189/ujph.2013.010313

Sterman, J., 2000. Business Dynamics. Irwin-McGraw-Hill.