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DEPARTMENT OF AGRICULTURAL EXTENSION

SEMINAR REPORT

ON

FUZZY COGNITIVE MAPPING: A NEW DIMENSION FOR RESEARCH METHODOLOGY IN SOCIAL SCIENCES

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INTRODUCTION

Social science research is often carried out through quantitative analysis rather than qualitative research. One possible reason, for this could be lack of availability of easy-to-use methods for gathering data, based on which appropriate conclusions can be drawn and inferences made. In quantitative research, the major focus is on deriving outputs and proving their validity as well as reliability with the use of appropriate statistical tests and fitting the data together. In qualitative research, major attention needs to be put on collection and gathering of data. Validity and reliability of the data is based on whether the data has been collected faithfully and represents the viewpoint of the respondents accurately. There are several methods for conducting qualitative research, such as content analysis, case study research, ethnographic research, etc. However, in the last few years, the Fuzzy Cognitive Mapping approach is gaining much importance in the field of social science research and gradually evolving as well as emerging as one of the most sought-after methods for capturing stakeholders' knowledge, belief, perception, etc., for carrying out evidence-based decision making. With this background, the present seminar has been conceptualized with the following objectives:

- To understand the concept of fuzzy cognitive mapping
- To understand the what, why and how of fuzzy cognitive mapping
- To highlight the scope and application of fuzzy cognitive mapping in social science research
- To review the studies related to fuzzy cognitive mapping

CONCEPT OF FUZZY COGNITIVE MAPPING

Cognitive mapping

Cognitive mapping is a mapping method used to create a visual representation of a person's (or a group's) mental model for a process or concept. It can be a useful tool throughout user research, from gathering data to analysing findings and articulating similarities and patterns. A cognitive map helps break down complex research questions, establish priorities for follow up research, and add clarity to abstract concepts. Cognitive maps have no visual rules that is needed to be obey and there is no restriction on how the concepts and the relationships between them are visually represented. In cognitive mapping sessions, users are asked to create a map of a process,

concept, or problem. The cognitive map is a representation of users' mental models. For instance, the routes that we store in our mind during navigation or whenever thoughts came is called cognitive maps. These routes are well ingrain in our mind and help us perform any task effortlessly. If we look back, we can see human store the routes of the places where they can find food, water and even potential mates. It is also important to note that not only human develop this ability but also among animals.

Cognitive maps can be developed through various ways like noticing landmarks, repeatedly checking the route or through verbal description by using orientations like left right or up down based on one's relative position.

Fuzzy logic

The term fuzzy refers to things that are not clear or are vague. In the real world many times we encounter a situation when we can't determine whether the state is true or false, their fuzzy logic provides very valuable flexibility for reasoning. In this way, we can consider the inaccuracies and uncertainties of any situation.

In the Boolean or traditional system truth value, 1.0 represents the absolute truth value and 0.0 represents the absolute false value. But in the fuzzy system, there is no logic for the absolute truth and absolute false value. But in fuzzy logic, there is an intermediate value too present which is partially true and partially false.

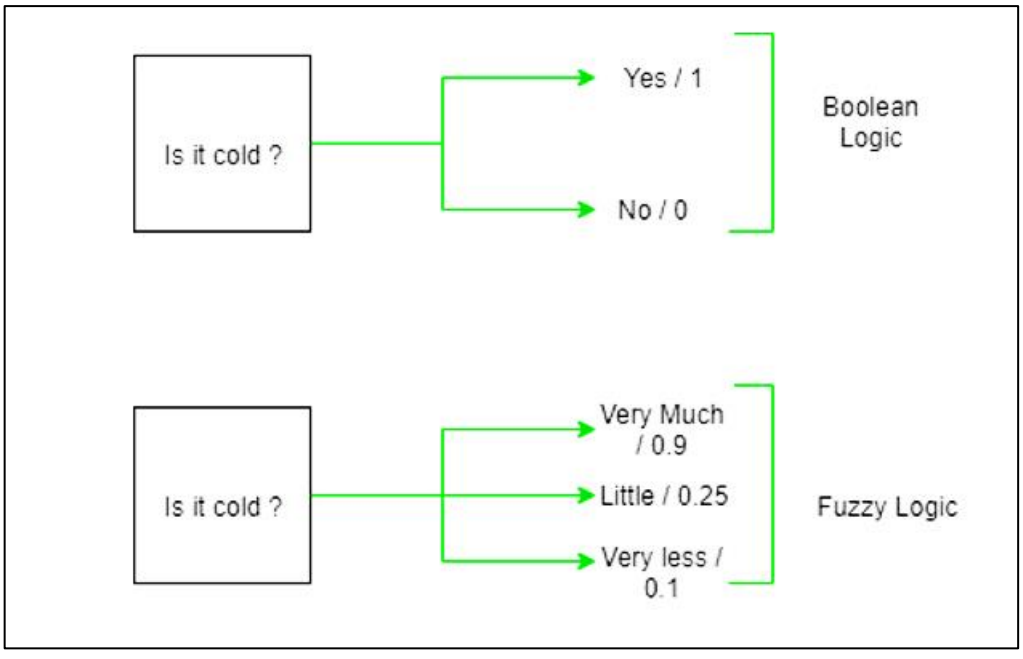


Fig. 1. Example of Fuzzy Logic

ARCHITECTURE OF FUZZY LOGIC

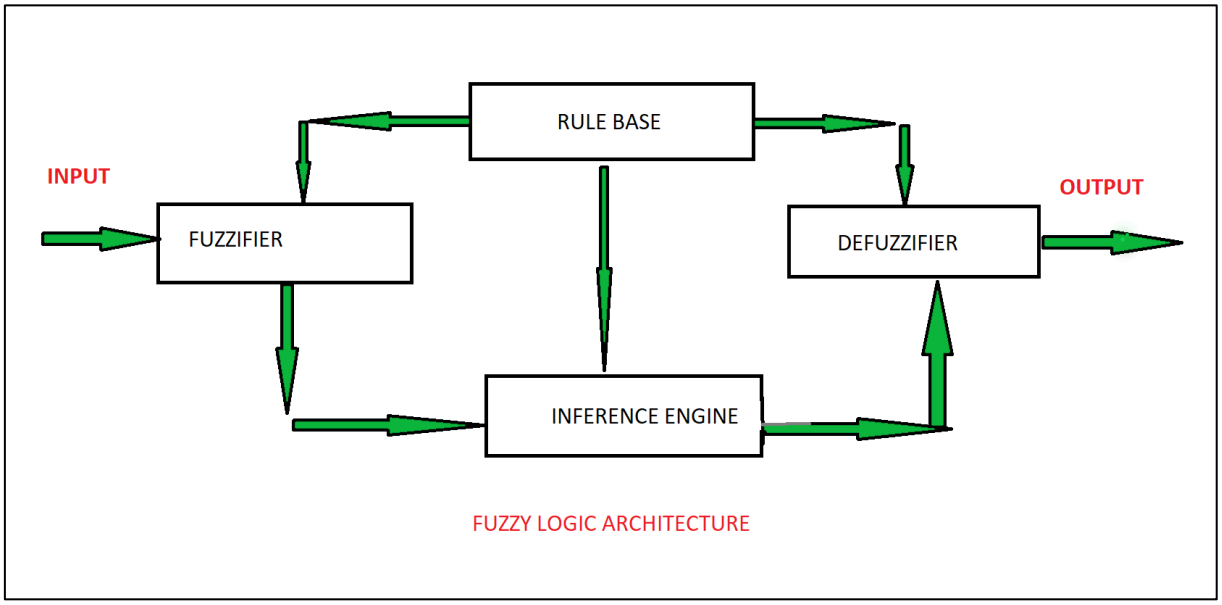


Fig.2. Architecture of Fuzzy Logic

Fuzzy Logic architecture contains four parts:

- **Rule base**: It contains the set of rules and the IF-THEN conditions provided by the experts to govern the decision-making system, on the basis of linguistic information. Recent developments in fuzzy theory offer several effective methods for the design and tuning of fuzzy controllers. Most of these developments reduce the number of fuzzy rules.

- **Fuzzification:** It is used to convert inputs i.e., crisp numbers into fuzzy sets. Crisp inputs are basically the exact inputs measured by sensors and passed into the control system for processing, such as temperature, pressure, rpm's, etc.

- **Inference engine**: It determines the matching degree of the current fuzzy input with respect to each rule and decides which rules are to be fired according to the input field. Next, the fired rules are combined to form the control actions.

- **Defuzzification**: It is used to convert the fuzzy sets obtained by the inference engine into a crisp value. There are several defuzzification methods available and the best-suited one is used with a specific expert system to reduce the error.

HISTORY OF FUZZY COGNITIVE MAPPING

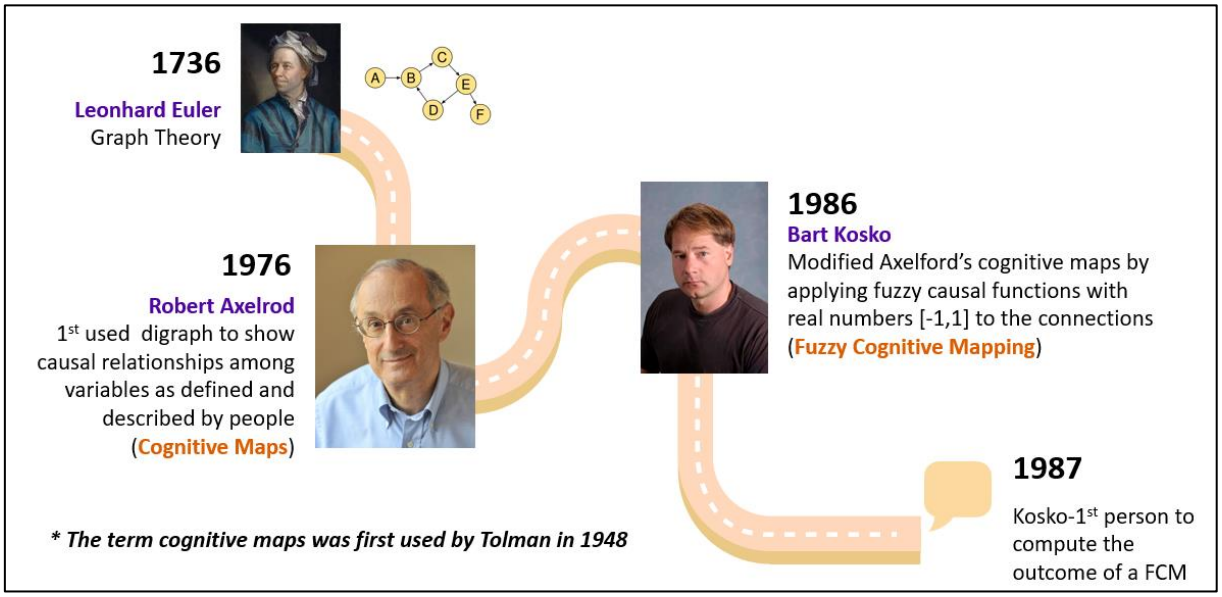
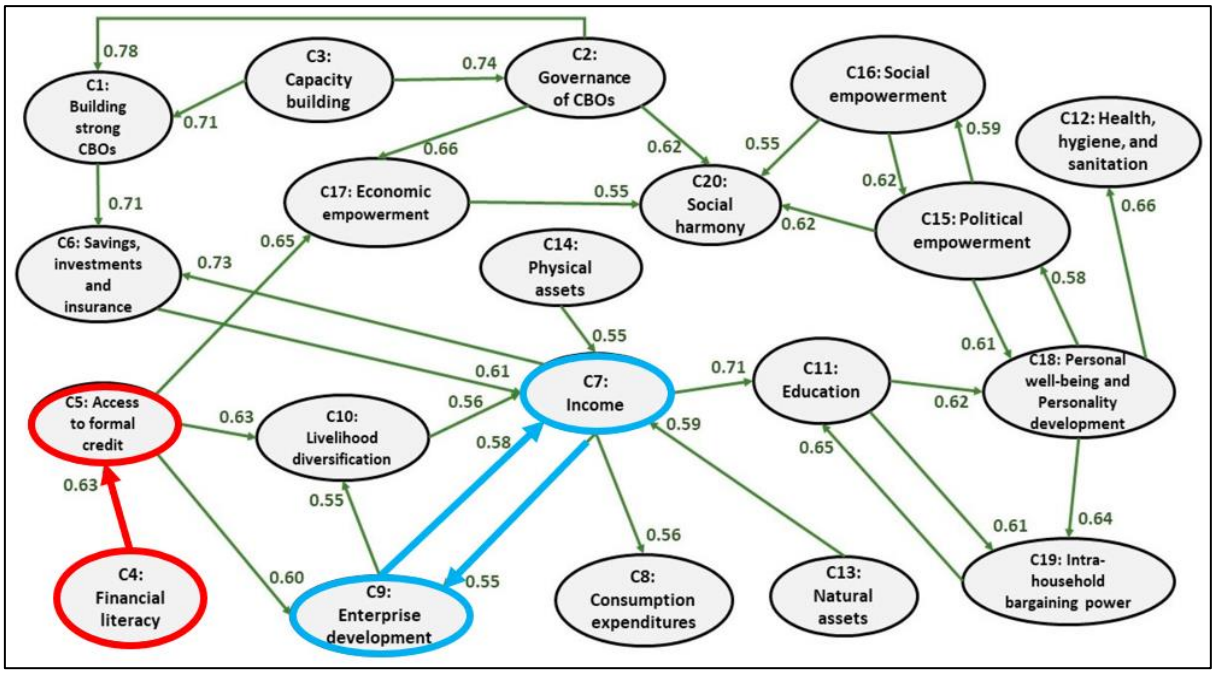


Fig. 3. History of Fuzzy Cognitive Mapping

Cognitive maps are directed graphs, or digraphs, and thus they have their historical origins in graph theory, which started with Euler in 1736 (Biggs *et al.*, 1976). In digraphs each link (line or connection) between variables (points or nodes) has a direction (Harary *et al.*, 1965). Axelrod (1976) was the first to use digraphs to show causal relationships among variables as defined and described by people, rather than by the researcher. He called these digraphs cognitive maps (term first used by Tolman, 1948). Kosko (1986) modified Axelrod's cognitive maps, which were binary, by applying fuzzy causal functions with real numbers in [−1, 1] to the connections, thus the term fuzzy cognitive map (FCM). Kosko was also the first to compute the outcome of a FCM, or the FCM inference, as well as to model the effect of different policy options using a neural network computational method (Kosko, 1987).

THE WHAT, WHY, AND HOW OF FUZZY COGNITIVE MAPPING

Fuzzy Cognitive Mapping is an approach of building a model of a system consisting of several boxes and its connections. Boxes are normally known as 'concepts' and can represent anything that can be expressed as a variable. The concepts are connected with the help of edges. Edges express the type of relationship existing between two concepts of a system. It may be both directed and undirected, i.e., if both the concepts are influencing each other then, the edge shall be undirected, however, if one is influencing the other and vice versa, the edge shall then be a directed one.



Source: Singh *et al.* (2020)
Note: ● Directed influence ● Undirected influence

Fig.4. Expert-based FCM model

Bringing it all together, a Fuzzy cognitive map is a special kind of cognitive/concept map within which the components and relationships between the components are defined in specific ways.

ATTRIBUTES OF FUZZY COGNITIVE MAPPING

The two main attributes of Fuzzy Cognitive Mapping are:

1. Components: Examples- Wetlands, Law Enforcement, Income, Fish, Lake Pollution

2. Relationships

Two main characteristics:

(a) The **direction** of a relationship (which way the arrow is pointing)

(b) The **degree of influence** one component can have on another (positively or negatively) parameterized between a fuzzy set from -1 and 1.

An FCM includes a number of concepts (C=C1, C2, C3, C4, …, Cn) and they are connected with the help of various edges. The links between the concepts are assigned weights (w) with values ranging between -1 to +1. The weight describes the cause-effect relationship between the concepts in the following manner.

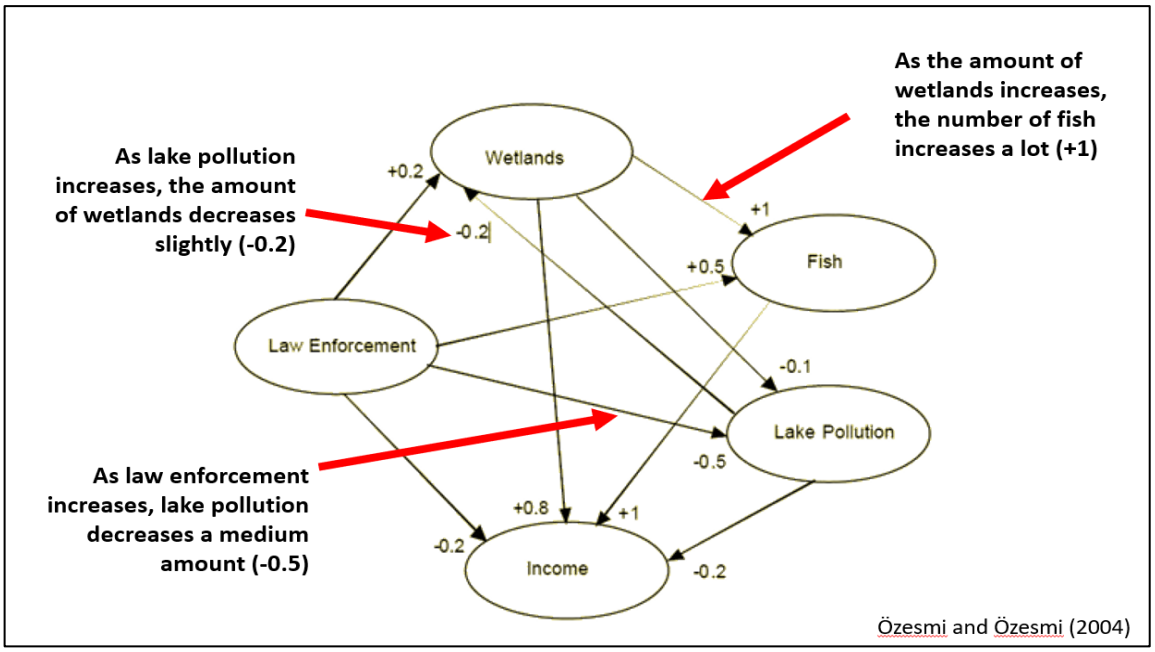


Fig. 5. Example of Fuzzy Cognitive Mapping

The weight describes the cause-effect relationship between the concepts in the following manner:

- If w = +1, there is a positive relationship existing between the concepts
- If w = -1, there is a negative relationship existing between the concepts
- If w = 0, there is no relationship existing between the concepts.

As mentioned earlier, the direction of the edge between the concepts carries significant meaning and is of great concern during analysis of FCMs. If,

- C1 C2, C1 is the cause and C2 is the effect.
- C2 C1, C2 is the cause and C1 is the effect.
- C1 C2, both C1 and C2 is the cause and effect of each other.

Rule of thumb for relationships

1. When this component increases, does the other component increase or decrease?
2. Is it a high increase/decrease, medium increase/ decrease or low increase/decrease?

Why Fuzzy Cognitive Mapping?

Fuzzy Cognitive Mapping is very useful for visualizing and understanding how concepts/factors/variables etc., affect each other, while maintaining self-loop and feedback mechanism within a complex system.

How to Fuzzy Cognitive Mapping?

Data collection and analysis in FCM is seen as a quasi-quantitative approach, since quantification of concepts and their relationship is expressed in relative terms (Gray *et al.*, 2015). It allows the participants to debate cause-effect relationship among qualitative concepts and, at the same time generate quantitative data based on respondent's experience, knowledge, perception of interrelationships among the concepts (Singh and Nair, 2014). The maps can be done by both individuals and groups.

STEPS FOR CONDUCTING FUZZY COGNITIVE MAPPING

The steps for conducting FCM (Goswami *et al.*, 2021; Singh and Chudasama, 2017) are as follows:

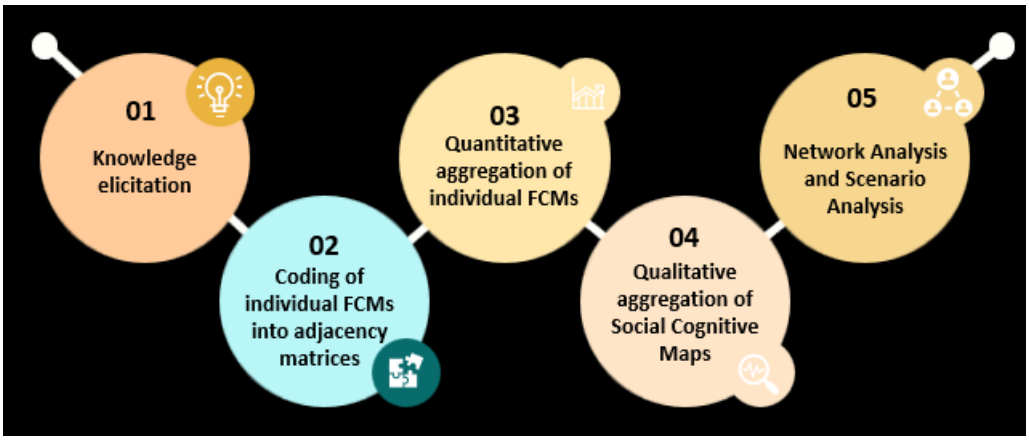


Fig.6. Steps for conducting Fuzzy Cognitive Mapping

(i) Knowledge elicitation

The first step for conducting FCM includes identification of the concepts already existing in the system. This has to be done through a participatory approach where certain stimulation (personal interview, focus group discussion, etc.) helps respondents to identify the concepts which they perceive to be imperative with respect to the study being done. Identification of concepts can be carried out in two steps:

a. **Open concept design approach**: This stage focusses on generating concepts from experts, progressive farmers, etc. Identification of concepts in this phase remains unrestricted. Role of the researcher in this phase remains limited to determining the boundary for the study, while the respondents are free to identify any type of existing boundary in the system that is related to the topic. This phase is particularly useful in case there is insufficient knowledge for modelling of the system (Singh and Chudasama, 2020). Questions generally asked in this approach may be cited with an example from Singh and Chudasama (2021):

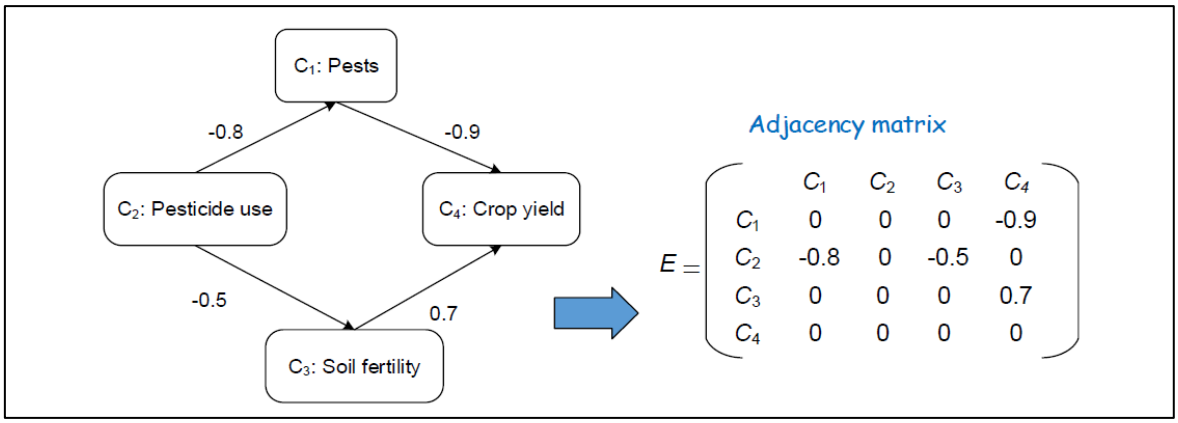
   "What have been the impacts of temperature and rainfall variability and extreme climatic events on your lives and livelihoods?"

   "What adaptation interventions are being carried out in your village to reduce these impacts?"

b. **Pre-concept design approach:** In this phase, concepts are identified and determined either by experts or researchers with the help of extensive review of literature. Concepts generated in the open design approach can also be used in this phase, if any study combines both the approaches. Unlike the former approach, the researcher puts a restriction to the determination of concepts by the respondents. Although it puts an end to the diversity of the knowledge in the study, it still is very efficient in the context of the time required for building a model of the system. Soon after the concepts are determined in the open concept design approach or in the preconcept design approach, the participants are asked to indicate the relationship between the concepts, following a continuum, i.e., 1-2: Very low; 3-4: Low; 5-6: Moderate; 7-8: High; 9-10: Very high. Participants can be either asked to draw maps, after providing them with the basic knowledge of mapping, or maps can be drawn by the researcher with the help of software based on the causal links the participants have indicated. Values of the causal link are hereafter normalized between -1 and +1.

(ii) Coding of individual FCMs into adjacency matrices

Individual FCMs are then coded into matrices in a spreadsheet, with all the concepts used in the analysis listed in both column and row, forming a square adjacency matrix (Singh and Chudasama, 2017; Singh and Nair, 2014). Values of the link between the concepts should be normalized between -1 and +1; with -1 indicating a strong negative relationship and +1 indicating a strong positive relationship.



Source: Mourhir *et al.*, 2017

(iii) Quantitative aggregation of individual FCMs

Matrices of individual FCMs are then quantitatively aggregated to form the matrix for mapping, and the map formed based on this matrix is known as Social Cognitive Map. This enables a superior representation of the system with more reliable results.

(iv) Qualitative aggregation of Social Cognitive Maps

Maps with large number of concepts and sub-concepts become a hindrance in gaining insights from the map. So, it is essential to aggregate them qualitatively into a fewer number of concepts and the approach helps in simplification of the Social Cognitive Map. Concepts are aggregated into categories under a broad concept; however, care must be taken so that the type of relationship between any pair of concepts does not get distorted after aggregation.

(v) Network analysis

Network analysis of the final product is carried out with the help of various software; and notable parameters considered for analyzing the network includes degree centrality (includes both indegree centrality and outdegree centrality), betweenness centrality, closeness centrality, etc. Nodes in the network are also categorized into driver, receiver and transmitter based on their linkages with other nodes.

(vi) Scenario analysis

Scenario analysis asks ‘What if’ type of questions, regarding the behaviour of the system, to be specific, behaviour of the concepts and sub-concepts included in the system, under various contexts. Concepts with highest centrality values are selected, and their initial values are activated (value of ‘1’: activated; value of ‘0’: deactivated), and then the values of all other concepts in the

system are observed, leading to the formation of a scenario. This analysis is carried out several times in order to gain insights into the types of possible scenarios that can be observed. This also helps in having comprehensive clarity on the need of the system as well as any shortage in terms of adoption and adaptation prevalent in the system.

SOFTWARE USED IN CONDUCTING FCMs ANALYSIS

There are a number of software available for carrying out FCM. Most popular software among them is:

- Mental modeler (www.mentalmodeler.com)
- FCMapper (http://www.fcmappers.net/joomla/)
- FCM Bridge (FCM Bridge (midasuser.com)).

Analysis can also be done using R programming (Dikopoulou *et al.*, 2018) and Python (Mkhitaryan *et al.*, 2021).

Mental Modeler is a recently proposed software tool. It features a web-based modelling implementation to support group decision making, thus allowing experts to collaboratively represent and test their assumptions about a system. Mental Modeler can be mainly used by non-IT people, usually experts or stakeholders in a given domain who need to design a simple cognitive map (with signed and weighted relationships) and simulate its behavior for some scenarios. The most important disadvantages of this tool are related to the lack of learning algorithms and its limited set of experimental options. However, the web-based approach is appreciated, especially to be used by unsavvy users in the field.

STRENGTH OF FUZZY COGNITIVE MAPPING

Strength of FCMs, as explained in detail by Singh and Chudasama (2020), over other mapping approaches includes:

- FCMs are not driven by lack of data, it is responsible to generate data.
- It is able to model complex and ambiguous mechanism systems and reveal hidden but important existing feedback mechanism in the system.
- It empowers the researcher to represent, integrate and compare the data using FCM with the help of knowledge, perceptions and experiences of diverse stakeholder groups included in the research.

- Interactive scenario analysis of FCM enables simulations of various policies, and particularly in extension-based research helps in understanding the adoption and adaptation deficit in both current and future scenarios

SCOPE OF FUZZY COGNITIVE MAPPING

Fuzzy Cognitive Mapping, a popular and prominent way of carrying out mental modelling of the respondents, has scope with high potential in the field of social science research. Goswami and Roy (2021) explained in detail the scope of using mental modelling in the field of social science research. They are as given below.

1. It is very useful in understanding as well as regulating the effects of human action in a defined system.
2. It has a great role to play whenever the system is lacking critical scientific data, and there is utmost need for the professional to develop a model of the system.
3. This methodology has high utility whenever there is a complex problem which needs clear solutions; however, obtaining distinct solution involves diverse stakeholder groups.
4. It helps the researcher in understanding how people belonging to a particular system, individually or collectively, conceive a concept or a construct and how they ultimately link it to their decision-making process.

APPLICATIONS OF FUZZY COGNITIVE MAPPING IN SOCIAL SCIENCE RESEARCH

SL. NO.	APPLICATIONS	AUTHOR
1.	Measure the perceived impacts of cyclones on fisheries (both inland and coastal fisheries) and the adaptation measures adopted by the fishermen.	Singh and Chudasama (2017)
2.	Used to elicit knowledge and to integrate perceptions of different stakeholders regarding climate change, its impact, and the efficiency of available adaptation measures in the Sundarbans region of India.	Singh *et al.* (2019)
3.	Identify and analyze the determinants of digital entrepreneurship	Ladeira *et al.* (2019)
4.	It was also used to measure the dual impacts of COVID-19 and cyclone Amphan on the coastal community in West Bengal, India	Goswami *et al.* (2021)

5.	Studied several pathways of different adaptation measures adopted by the smallholder farming community apropos climate change in arid and semi-arid regions across twelve districts of India	Singh and Chudasama (2021)
6.	Measuring perception of residents in the coastal socio-ecological system, and comparing it with respect to various stakeholder groups, in a post-disaster situation was done with the use of FCM	Furman *et al.* (2021)
7.	Conducted research on understanding how farmers from two different social contexts (Northeast US and Denmark) made their transition towards sustainability. FCM was implemented for building a model on their practices and perceived outcomes based on their gradual move towards sustainability.	Averbuch *et al*. (2022)
8.	Research was conducted to measure how intensified livestock production can be a promising pathway for the smallholder farming community	Alomia-Hinojosa *et al*. (2022)
9.	Differential perception of households to integrate livestock as a component in their farm	Murphy *et al*. (2021)
10.	This methodology also held a position in demonstrating policy option analysis for an existing Social-Ecological-System (SES) with assistance from diverse stakeholder groups.	Mehryar *et al.* (2017)

AREAS FOR APPLICATION IN AGRICULTURAL EXTENSION

In Agricultural Extension, this methodology could be applied for perception study, preferential study, impact study, effectiveness of training programmes, risk management, mapping indigenous knowledge, exploring precision farming scenario, factors influencing adoption and so on.

PROBLEM SOLVED USING FCM

The major problem solve by FCMs so far are listed as follows:

1. Classification
2. Prediction
3. Knowledge representation
4. Decision Making
5. Reasoning
6. Modelling
7. Planning
8. Management
9. Inference
10. Stakeholder's analysis
11. Navigation
12. Policy making

RESEARCH STUDIES

Research Study-1: Assessing impacts and community preparedness to cyclones: a fuzzy cognitive mapping approach

By: Singh and Chudasama (2017)

Singh and Chudasama (2017) conducted a study in Ganjam and Puri district of Odisha to identify the perceived impacts and preparedness levels of coastal and inland fishermen with the aid of fuzzy cognitive maps. They evaluated the effectiveness of current preparedness measures in the context of climate change by deploying various fuzzy cognitive mapping simulation-based preparedness pathways.

Why FCM was used?

FCM was used because it not only focuses on the physical components, mitigation and adaptation strategies associated with risk but also focus on the human, societal and cultural factors.

Research Methods

The process of data capture in the fuzzy cognitive mapping approach is quasi-quantitative with participants debating about the cause–effect relations between the qualitative concepts. The participants generate quantitative data based on their experiences, knowledge, and perceptions of inter-relationships between those concepts

Multi-step FCM approach was followed for the study which is outlined in the following sub-sections:

1. **Obtaining fuzzy cognitive maps from the stakeholders**

The focused group discussion helps in obtaining the fuzzy cognitive maps from the stakeholder which highlighted the escalating frequency of cyclonic events in the region over the last decade. Once participants arrived at a consensus on frequency and intensity of cyclones in the region, they were divided into 4–5 members groups; we separated the men and women to understand gender-based perceptions. The researcher demonstrated the participants how to draw a fuzzy cognitive map through a hypothetical situation. Once the participants understood the process of constructing a fuzzy cognitive map, they were asked to draw a map on cyclones and their impacts.

In order to understand the direct and indirect impacts of cyclones and preparedness measures augmenting their resilience the following questions were asked to the participants in instalments:

i. What are the major direct and indirect impacts of cyclonic events?

ii. What preparedness measures are there in place to cope with such catastrophic events?

The participant groups drew concepts indicating cyclone-related direct and indirect impacts along with preparedness measures and linked their relationships with concerned concepts. The participants assigned weights to each link on a scale of 1–10, with ten representing the highest strength and one the lowest. Numbers ranging 1–3 signified a relationship with low, 4–7 with medium, and 8–10 with high strengths.

After constructing their fuzzy cognitive maps, each group made a presentation to the researchers. Later, the researchers, based on the causal relationship between the variables, assigned positive and negative signs to each weight. The positive sign indicated a direct relationship between the concepts and the negative sign an inverse one. A sample fuzzy cognitive map obtained from the participant groups is displayed below.

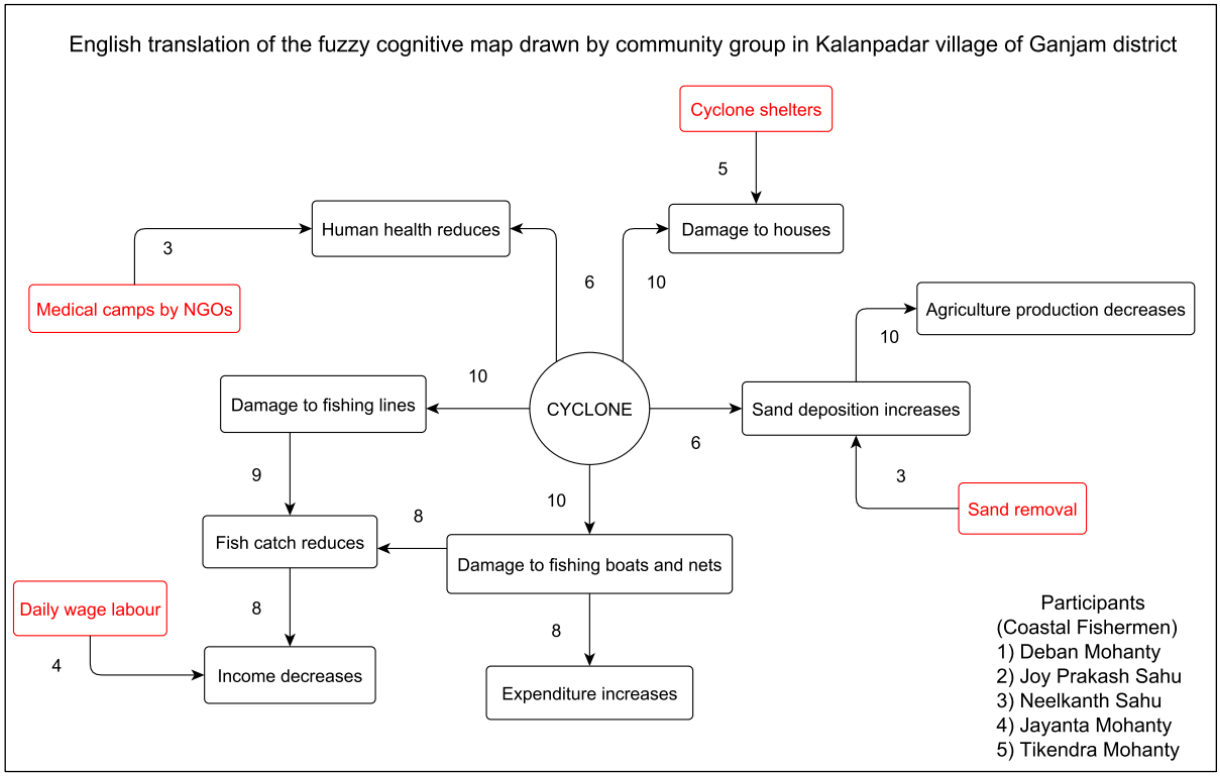


Fig 1. Sample fuzzy cognitive map obtained from the participant groups

2. Determining adequacy of samples

Individual FCMs were created with different participant groups in similar settings until the population to be represented was sampled adequately. To determine this, we examined accumulation curve of the total number of new concepts added per map versus total number of maps. For this study, average accumulation curves saturated at 19 and 22 cognitive maps for coastal and inland fishermen respectively. A total of 70 participant groups were facilitated to obtain FCMs from the villages under study, of which coastal fishermen constructed 33 FCMs and inland fishermen 37. Their sample size overcame the limitation of respondent bias (Kok, 2009; Özesmi and Özesmi, 2004) bringing robustness to the inferences.

3. Coding FCMs into adjacency matrices

Individual FCMs were then coded into separate spread sheets, with all the concepts listed in rows and columns, making it a digraph (Özesmi and Özesmi, 2004; Singh and Nair, 2014). Thus, a square adjacency matrix is formed with concepts on the vertical and horizontal axes; the weights assigned to every link were coded into the matrix (Özesmi and Özesmi, 2004). When respondents characterized the same concept with positive and negative connotation, one of the concepts needed to be converted for the standardization of concept names. To conserve the direction of causality, the arrow direction of converted concepts needed to be reversed (Jetter and Kok, 2014). All weights were normalized between −1 and +1 for coding into the adjacency matrix (e.g., if the weights assigned to the links in the map are −5 and +5, they were normalized to −0.5 and +0.5, respectively) (Singh and Nair, 2014).

4. Mathematical aggregation of individual cognitive maps

The mathematical aggregation of the individual FCMs gives consolidated useful information that was captured by individual FCMs enabling a superior representation of the system dynamics with more reliable results (Özesmi and Özesmi, 2004; Singh and Nair, 2014). The individual adjacency matrix was added and divided by the total number of matrices (Kosko, 1988; Jetter and Kok, 2014). Conflicting connections with opposite polarity decrease the causal relationship, while connections with similar polarities strengthen the causal relationships. Therefore, a negative-positive-neutral calculus is used to compute compound values for augmented maps in order to deal with any contradicting connections in the map (Özesmi and Özesmi, 2004). Here, aggregation of adjacency matrices is based on the equivalence properties of fuzzy causal relationships between variables; if the arrow directions are switched the polarity of the weight needs

to be switched as well. Doing so does not change the system behavior. The mathematical aggregation of the individual cognitive maps is useful for constructing a social (collective) cognitive map and has been followed by many researchers.

A large number of concepts in the social cognitive map with many interconnections and feedback loops form a complex system. Matrix algebra of a cognitive map provides many more indices in addition to the number of concepts and links such as density, in-degree, out-degree, and centrality (Özesmi and Özesmi, 2004). The in-degree of a cognitive map is the column sum of absolute values of a concept. It shows the cumulative strength of links entering the concept. The out-degree of a cognitive map is the row sum of absolute values of a concept in the adjacency matrix. It shows the cumulative strengths of links exiting the concept. The centrality of a concept is the summation of its in-degree and out-degree. Transmitter concepts have a positive out-degree and zero in-degree. Receiver concepts have a positive in-degree and zero out-degree. Ordinary concepts have both a non-zero in-degree and out-degree (Özesmi and Özesmi, 2004).

Table 1: Network statistics of concepts from aggregated cognitive map (coastal fishermen)

Concepts from augmented map*	Out-degree	In-degree	Centrality	Type of concept#		
				Transmitter	Receiver	Ordinary
Cyclone	17.04	0.00	17.04	1		
Accessibility to market	0.00	0.80	0.80		1	
Agriculture produce	0.70	2.20	2.90			1
Contraction of sea mouth	0.87	0.78	1.64			1
Crop destruction	0.00	1.10	1.10		1	
Damage to boats and nets	0.96	2.95	3.91			1
Damage to fishing line	1.70	3.03	4.73			1
Damage to trees	1.90	0.73	2.62			1
Effect on day to day life	0.00	0.80	0.80		1	
Difficulty in shifting affected people	0.00	0.60	0.60		1	
Difficulty in relief work	0.00	2.20	2.20		1	
Drinking water availability	0.55	3.91	4.46			1
Education	0.00	0.70	0.70		1	

5. Qualitative aggregation of the social cognitive maps

A social cognitive map with innumerable concepts and connections is counterproductive for gaining insights. In order to gain a better understanding the structure of the complex social cognitive map a qualitative aggregation of the social cognitive maps was carried out; this combines

the concepts mentioned in the social cognitive map into categories that represent a larger encompassing concept. An arithmetic mean of the weights of concepts mentioned in the social cognitive map was calculated at the interconnections between the larger encompassing concept. During qualitative aggregation of the social cognitive maps, interconnections between every concept are maintained (Özesmi and Özesmi, 2004). Coastal and inland fishermen identified a total of 54 and 56 concepts, respectively. These concepts were aggregated into 22 and 20 concepts for coastal and inland fishermen, respectively. The table below shows the sample of the concepts obtained after mathematical aggregation of individual cognitive maps drawn by coastal and marine fishermen as well as the categories of concepts used for qualitative aggregation of the social cognitive maps.

Table 2: Condensation of concepts from aggregated cognitive map

Condensed concepts	Concepts from augmented map
Concepts showing perturbations	
CC: Cyclone	Cyclone
C1: Agriculture production and Food availability	Agricultural production
	Horticulture and Vegetable produce
	Crop destruction
	Food availability
C2: Land resources	Salt deposition
	Sand deposition
	Soil fertility
C3: Fisheries	Fish catch
	Fish extinction
C4: Water resources	Drinking water availability
	Water contamination
	Water logging
	Shallowing of *Chilka* lake
C5: Uprooting of trees	Damage to trees
	Fuel wood
C6: Livestock number	Number of livestock
C7: Sea water intrusion	Sea water intrusion
C8: Education	Education

6. Data visualization of condensed social cognitive maps

The condensed social cognitive maps were analyzed using the FCMapper, an excel-based fuzzy cognitive mapping and modeling software. Later, cognitive interpretive diagrams (CIDs) were prepared using visualization software Visone2.16. The CID helps in understanding the contribution of a concept in the cognitive map and the connectedness of one concept to others. Concepts in CID were represented based on centrality, thus showing the importance of each concept

within the system. Larger the size of a concept, greater its importance in the system. Causal relationships with negative polarity are shown as dashed lines while causal relationships with positive polarity are shown as solid lines in CIDs.

7. Developing input vectors for preparedness pathways

The concepts showing preparedness were highlighted as input vectors through various plausible combinations based on their compatibility with one another. These input vectors were used to develop adaptation pathways through FCM simulations.

8. FCM simulations

For evaluating effectiveness of preparedness measures three pathways have been created FCM simulations were followed. The pathways were compared using two approaches:

- Kosko's activation rule with hyperbolic transformation function
- Modified activation rule with hyperbolic transformation function

An alternative approach has been introduced by Stylios *et al.* (1997), we call it modified activation rule. It has been increasingly popular allowing for "memory integration" into the FCM simulation since the system can hold information of its previous state and use that information while calculating its new state. The only difference between the two approaches is that in the later one the previous value of the concept is always added to itself in the present iteration in case of modified activation rule, each concept has a self-feedback link with weight 1. A transformation function is used to keep the activation value of concepts in the interval I = [0,1] or I = [−1,1]. The widely used transformation function is sigmoid but it has some limitations. The major limitation of sigmoid transformation function is that it converts the zero values in the FCM to 0.5. Hence, the value of inactive concepts (0) takes values 0.5. Also, in case of missing values in large and complex FCMs, it is not able to produce reliable results.

Singh and Chudasama (2017) reported that FCM simulation based on modified activation rule and hyperbolic transformation function work well in a complex human-environment system especially when the concepts are of both positive and negative polarities. It ascertains positive and negative changes in concepts after activation of input concepts during the simulation process. In our study, the concept values are in the range [−1,1]; hence, the hyperbolic transformation function, is used for simulations.

Conclusion

This study point to severe futuristic impacts on concepts like fisheries and agriculture, water quality etc. coupled with human health and sanitation owing to intensities and frequencies due to climate change. It is important to strengthen communities resilient. This study calls for appropriate policy supports and proactive measures for ensuring livelihood security and it is very useful for decision makers, planners and NGOs working on strengthening disaster management

Research Study-2: Pathways for climate change adaptations in arid and semi-arid regions

By: Singh and Chudasama (2021)

The study was done across 12 arid and semi-arid districts for evaluating the effectiveness of several adaptation pathways. Data was collected with the help of FCM developed by 427 community groups, each group containing four to five members each. Maps were developed based on the concepts of perceived impacts of climate-related disasters and adaptation measures implemented to cope with the impacts of climate change. Social Cognitive Map developed from the study is explained in figure below.

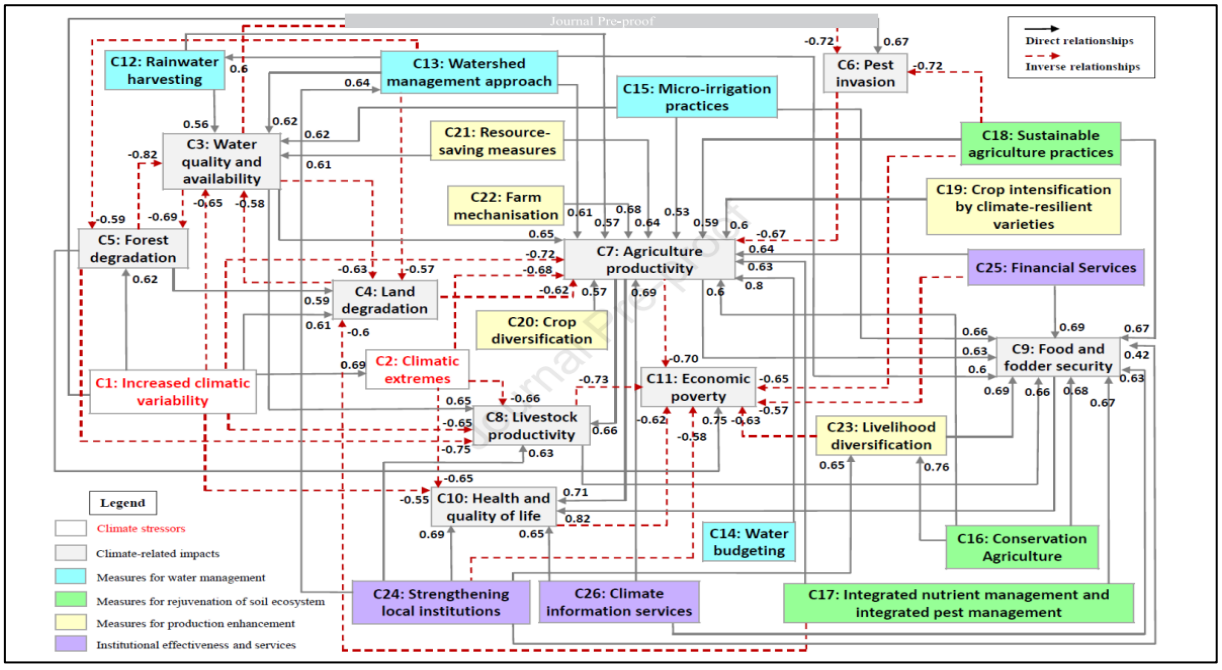


Fig. 1. Social Cognitive Map illustrating perception of respondents on climate change impacts and adaptation measures

From the figure we can see that the map consists of several types of nodes, such as climate stressors, climate-related impact and adaptation measures (water management, rejuvenation of soil ecosystem, production enhancement, institutional effectiveness). These nodes were linked to each other with the help of edges, with weights assigned to them. Let's try to briefly interpret this SCM, bearing in mind some of the concepts mentioned in the map. Livestock productivity (C8) was getting affected due to climatic extremes (C2) as well as bigger climatic variability (C1). Negative weights assigned on the edges between C1 and C2 to C8 explains the negative relationship existing between them. Further, degradation of forest (C5), an impact of climate change in the area was also hampering livestock productivity. This again was proving to be a major cause for economic poverty (C11) of the community belonging to arid and semi-arid regions. Economic poverty was also due to declining agricultural productivity (C7) in the region. Agricultural productivity was also getting affected due to climatic extremes, increased climate variability and land degradation (C4) and pest invasion (C6). For coping with this effect, respondents followed several adaptation measures.

Improvement in quality of water and increasing its availability (C3) was supporting livestock productivity as well as agricultural productivity in the region. Rainwater harvesting (C12), watershed management approach (C13), micro-irrigation measures (C15), sustainable agricultural practices (C18), crop intensification by climate resilient varieties (C19) and other resource saving measures (C21) proved to be beneficial in improving agricultural productivity despite severe climate change impacts. Improvement in agricultural productivity was also positively impacting the livestock productivity of the region. Good agricultural and livestock productivity in the region had a particularly positive impact on the food and fodder security (C9) of the community in arid and semi-arid regions. Positive value assigned on the edges connecting these nodes showed a positive relationship existing between the concepts.

Effectiveness of various adaptation pathways was also measured in the study with the help of scenario analysis. Twelve different scenarios for different adaptation pathways were developed based on the categories of interventions and combinations. Results of each of these scenarios were compared to the baseline scenario for evaluating adaptation pathways. Scenarios were classified into various categories, such as least effective adaptation pathways, low effective adaptation pathways, moderately effective adaptation pathways, effective adaptation pathways and highly effective adaptation pathways (Singh and Chudasama, 2021).

Research Study-3: Multi-faceted impact and outcome of COVID-19 on smallholder agricultural systems: Integrating qualitative research and fuzzy cognitive mapping to explore resilient strategies

By: Goswami *et al.* (2021)

Study Area: Cluster villages in Gosaba Block of South Parganas district in West Bengal

Approach of the study

To understand the dual impact of COVID-19 and cyclone Amphan, FCM approach was used and mental models of different stakeholders were developed, primarily because of the unpredictable and complicated outcomes expected in the agricultural and associated systems. Mental models are internally held cognitive structure of external reality. They can reasonably represent the knowledge structure held by individuals related to complex socio-ecological systems and thus help in managing uncertain conditions. Mental models exist in the human mind, and therefore, cannot be inspected or measured directly (Jones *et al.*, 2011). Fuzzy logic cognitive mapping has recently been used to develop mental models of individuals for better understanding of socio-ecological systems and collective decision-making in the premise of natural resource management (Gray *et al.*, 2014). They followed a multi-stage method to formulate mental models of stakeholders concerning the impact of COVID-19 and Amphan, and developed scenarios to understand probable system performance under different scenarios (Fig 1).

In the first stage, qualitative research was used to identify system elements. In the second stage, identified system elements were used in the fuzzy cognitive mapping exercise by all the stakeholders. All the stakeholders weighed relationships between element pairs. Network analysis was performed for all the mental models, and scenario analysis was done to study the system outcomes as a result of changes in one or more system elements. At the third stage, the study outcomes (shared model and scenario analysis) were validated by the stakeholders. The hollow arrows suggest sequential stages and the narrow solid arrows are associated with independent operations with the cognitive maps

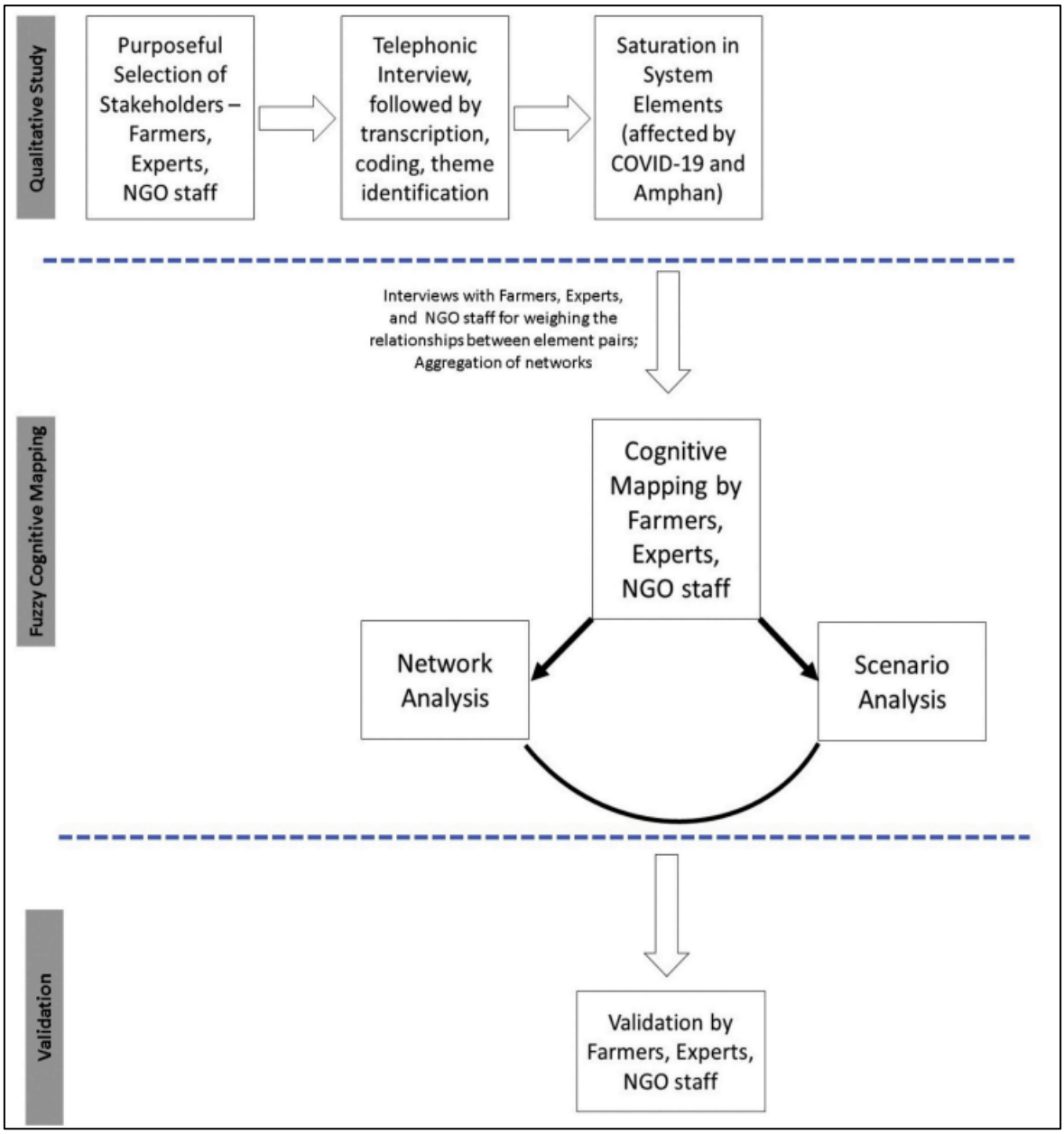


Fig. 1. The methodological outline of the research.

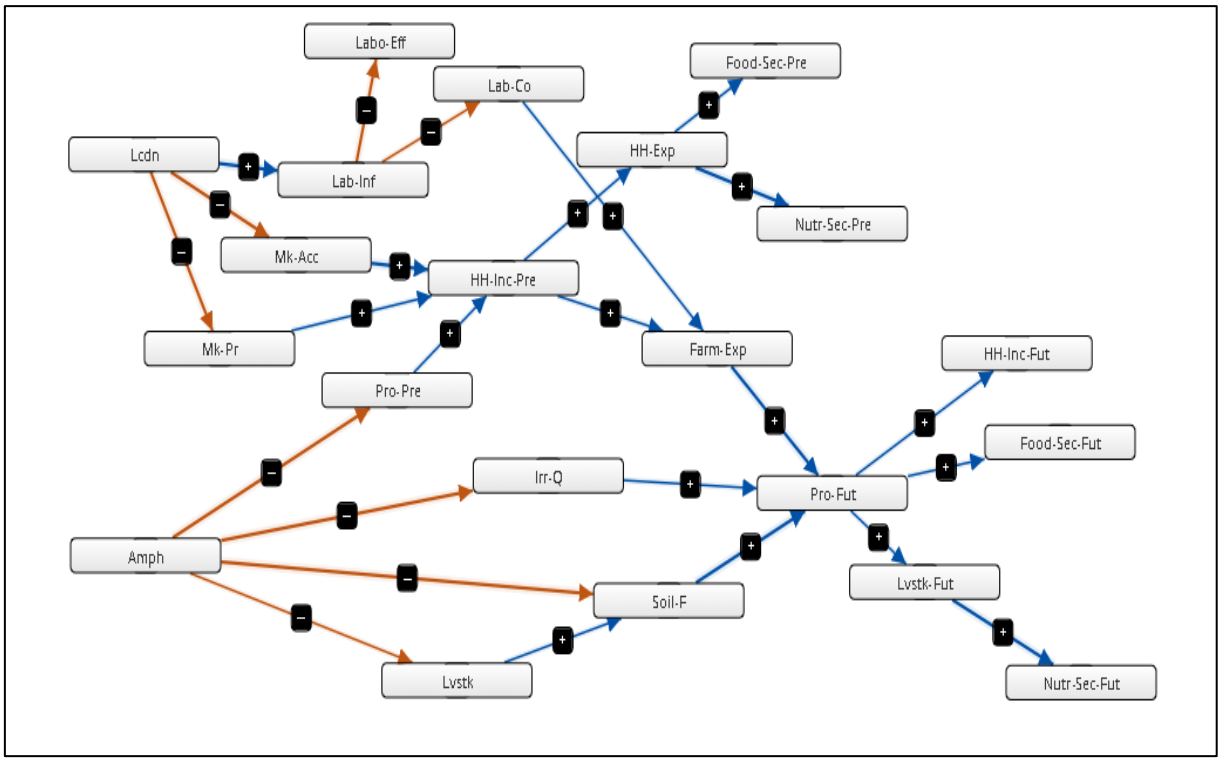
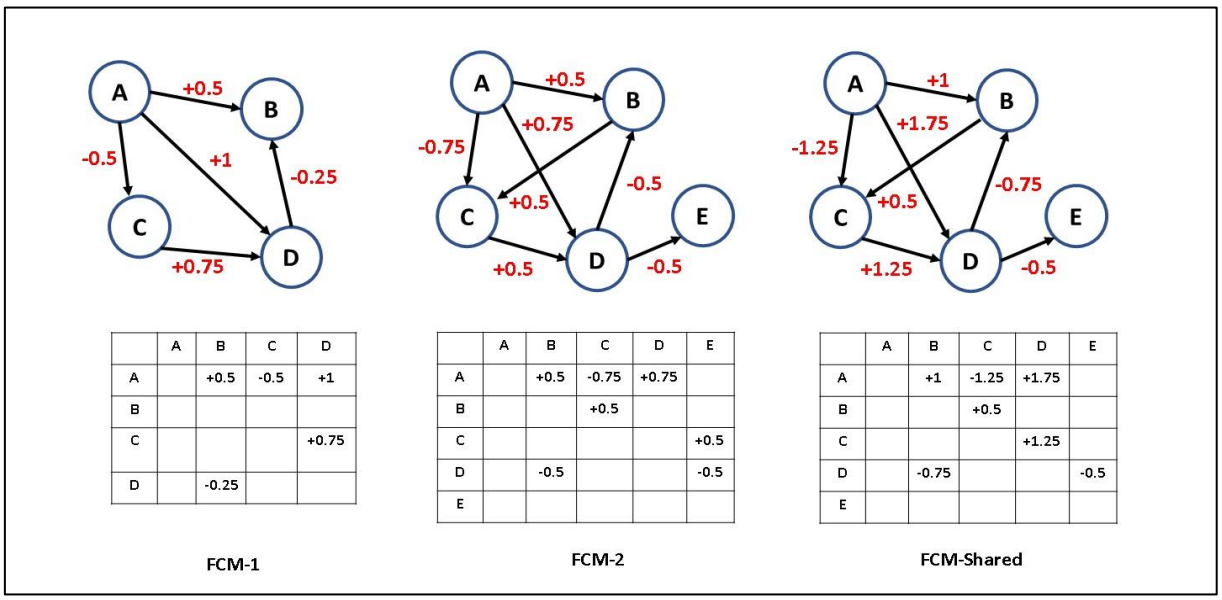


Fig. 2. Mental model of farmers generated in Mental Modeler software



	A	B	C	D
A		+0.5	-0.5	+1
B				
C				+0.75
D		-0.25		

	A	B	C	D	E
A		+0.5	-0.75	+0.75	
B			+0.5		
C					+0.5
D		-0.5			-0.5
E					

	A	B	C	D	E
A		+1	-1.25	+1.75	
B			+0.5		
C				+1.25	
D		-0.75			-0.5
E					

Fig. 3. An illustration on how shared cognitive map was developed by combining individual maps

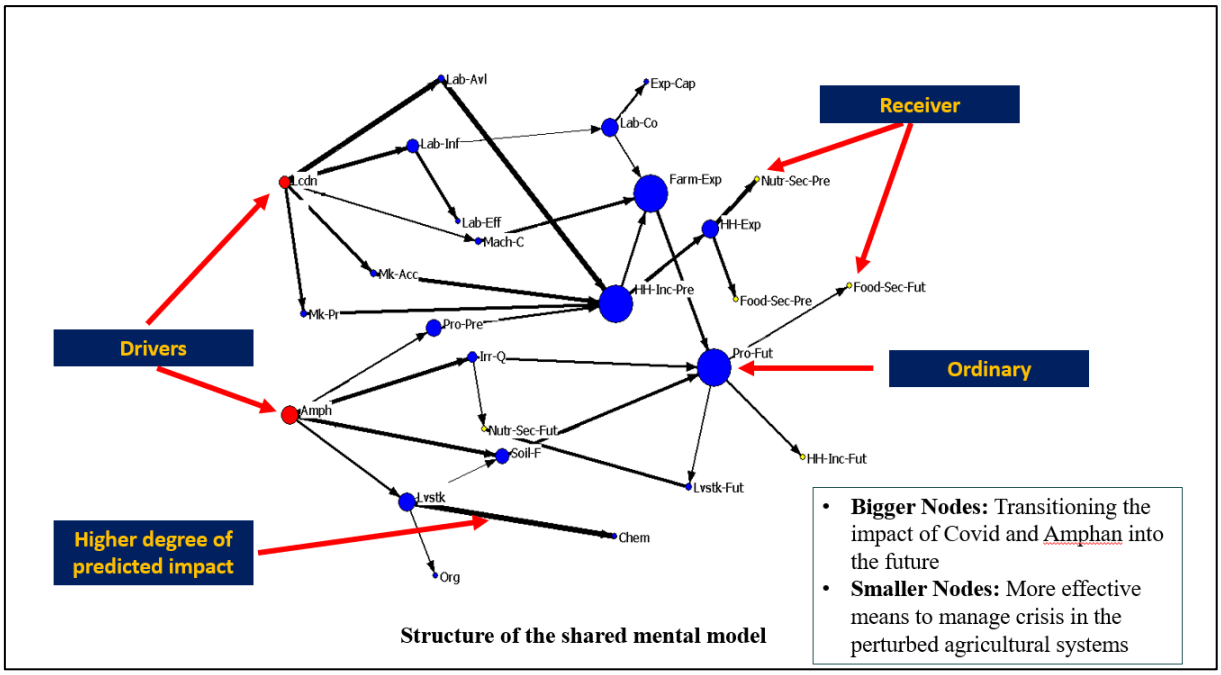


Fig. 4. Structure of shared mental model

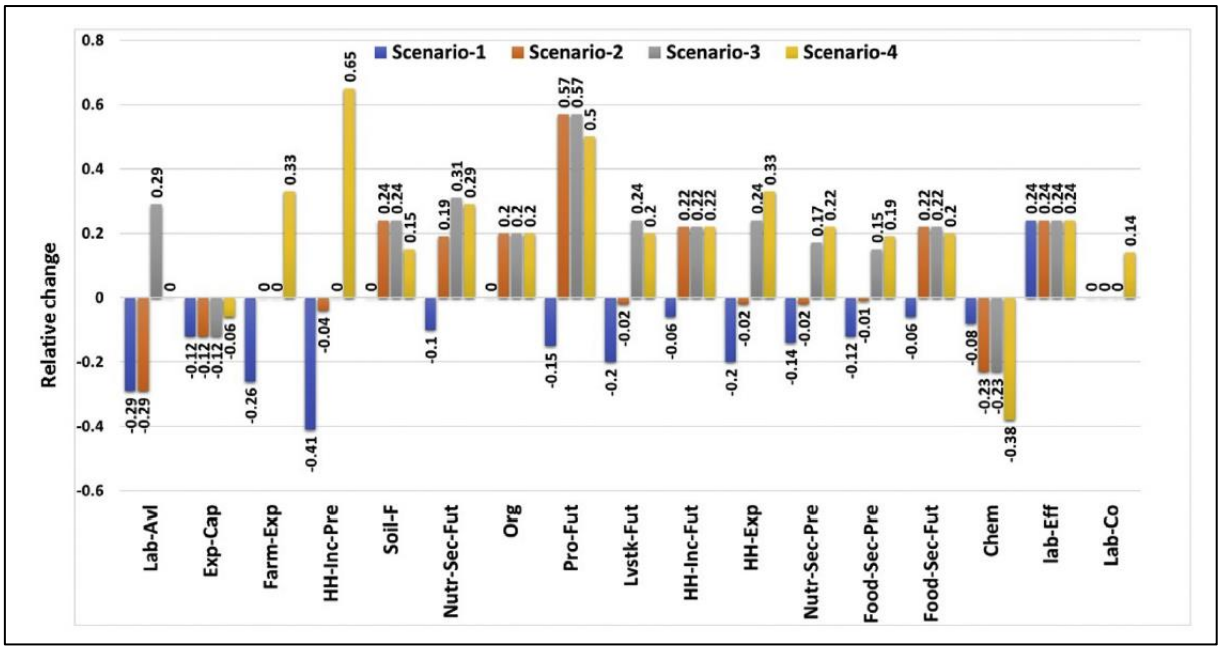


Fig.5. Scenario analysis showing the predicted impact on the system elements under four different scenarios

Implications: This study may help in formulating short and long-term intervention strategies in the post-pandemic communities. The methodological approach can be used elsewhere to understand perturbed socioecological systems to formulate anticipatory intervention strategies based on collective wisdom of stakeholders

OPPORTUNITIES FOR PUBLISHING

Journal	Published	Impact factor
Climate change	Springer	6.058
Journal of cleaner production	Elsevier	11.072
Agricultural systems	Elsevier	6.765
Sustainability	MDPI	3.889
Precision Agriculture	Springer	5.875
International Journal of Intelligent System	Wiley	8.993
International Journal of Human Computer Studies	Elsevier	4.866
IEEE Transactions on Fuzzy Systems	IEEE Xplore	12.253
Ecological Modeling	Elsevier	3.512

CONCLUSION

The Fuzzy Cognitive Mapping approach is now being used extensively in various fields and is one of the most prominent and useful methodologies in carrying out research in Social Sciences. It investigates the system and considers all of it for research, unlike pure quantitative methods where major focus is on selected aspects. This gives the methodology an edge over others and enables the method to become a boon for research in agricultural extension involving stakeholder's belief, perception and knowledge for evidence-based decision making.

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DISCUSSION

1. **We fit values to -1 and +1. How is the value concluded to normalisation?**

   Ans: In fuzzy cognitive mapping, after the expert weighted the relationship between two concepts, the average is taken as the final value and it is normalised between -1 and +1.

2. **Can we measure reliability and validity in qualitative research?**

   Ans: In qualitative research, reliability can be estimated by comparing different versions of the same measurement. Validity is harder to assess, but it can be estimated by comparing the results to other relevant data or theory. Validity can also be check by a technique known as respondent validation. This technique involves testing initial results with participants to see if they still ring true.

3. **How do we develop a shared FCMs?**

   Ans: A shared FCM can be develop by quantification of the individual FCM with the help of adjacency matrix. After obtaining the shared FCM, an FCM mental model is created with the help of a software such as mental modeler.

4. **How is mind mapping differing from cognitive mapping or are they the same?**

   Ans: Mind mapping and cognitive mapping are not the same. Mind maps have a central parent topic, with nodes that branch outwards the peripheral whereas, cognitive maps are freeform and can include numerous visualization methods, including bulleted list, flowcharts, concept diagramming, or affinity mapping.

5. **How can we get clarity over information clutter?**

   Ans: If maps contain large number of concepts and sub-concepts it become a hindrance in gaining insights from the map. So, it is essential to aggregate them qualitatively into a fewer number of concepts and this approach helps in simplification of the Social Cognitive Map. Concepts are aggregated into categories under a broad concept but care must be taken so that the type of relationship between any pair of concepts does not get distorted after aggregation.

6. **What are the major areas that the researcher can use FCMs?**

Ans: In Agricultural Extension or social science subject, this approach could be applicable for perception study, preferential study (Eg. Why farmers prefer Technology A over Technology B), effectiveness of any programmes and it can also be used for impact study as well as determinants study.

7. **FCM is an old concept but why it is not that prominent?**

Ans: It is no doubt that Fuzzy Cognitive Mapping is an old concept but if we look back at the history it was developed by Kosko in 1986. Over the last two or three decades, this methodology is widely used in the field of control business, medicine, robotics, environment and information technology. But in the recent years, we have seen several research that applied this approach in social sciences. Given the fact that social science is a branch of science that deals with people and the relationship between the people living in the society it is of utmost important to not only focus on quantitative research but also semi quantitative research.

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DEPARTMENT OF AGRICULTURAL EXTENSION
COLLEGE OF AGRICULTURE, GKVK, BENGALURU-560 065

Name	**:** Deinichwa Dkhar	**Venue :**	Dwarkinath Hall
ID. No.	**:** PAMB 0026	**Date**	**:** 24-12-2022
Class	**:** III Ph.D. (Agril. Extn.)	**Time**	**:** 10:30 am

Seminar III

Fuzzy Cognitive Mapping: A New Dimension for Research Methodology in Social Sciences

Synopsis

Social science research is often carried out through quantitative analysis rather than qualitative research. One possible reason, for this could be lack of availability of easy-to-use methods for gathering data, based on which appropriate conclusions can be drawn and inferences made. In quantitative research, the major focus is on deriving outputs and proving their validity as well as reliability with the use of appropriate statistical tests and fitting the data together. In qualitative research, major attention needs to be put on collection and gathering of data. Validity and reliability of the data is based on whether the data has been collected faithfully and represents the viewpoint of the respondents accurately. There are several methods for conducting qualitative research, such as content analysis, case study research, ethnographic research, etc. However, in the last few years, the Fuzzy Cognitive Mapping approach is gaining much importance in the field of social science research and gradually evolving as well as emerging as one of the most sought-after methods for capturing stakeholders' knowledge, belief, perception, etc., for carrying out evidence-based decision making. With this background, the present seminar has been conceptualized with the following objectives:

- To understand the concept of fuzzy cognitive mapping
- To understand the what, why and how of fuzzy cognitive mapping
- To highlight the scope and application of fuzzy cognitive mapping in social science research
- To review the studies related to fuzzy cognitive mapping

Concept of Fuzzy Cognitive Mapping

The concept of fuzzy cognitive map was first introduced by Bart Kosko in 1986. He modified Axelrod's cognitive maps by applying fuzzy causal relationship with real numbers [-1,+1] to the connections, thus the term fuzzy cognitive mapping (FCM). Fuzzy Cognitive Mapping is an approach of building a model of a system consisting of several boxes and its connections. Boxes are normally known as 'concepts' and can represent anything that can be expressed as a variable. The concepts are connected with the help of edges. Edges express the type of relationship existing between two concepts of a system. It may be both directed and undirected, i.e., if both the concepts are influencing each other then the edge shall be undirected, however, if one is influencing the other and vice versa, the edge shall then be a directed one.

Steps for conducting FCM

(i) Knowledge elicitation, (ii) Coding of individual FCMs into adjacency matrices, (iii) Quantitative aggregation of individual FCMs, (iv) Qualitative aggregation of Social Cognitive Maps, (v) Network analysis and (vi) Scenario analysis.

Scope of FCM

FCM is very useful in understanding as well as regulating the effects of human action in a defined system. It plays a great role whenever the system is lacking critical scientific data, and there is utmost need for the professional to develop a model of the system. It has high utility whenever there is a complex problem which needs clear solutions. In Agricultural Extension, this methodology would be useful for perception study, preferential study and so on.

Research Studies

Singh and Chudasama (2017) conducted a study in Ganjam and Puri district of Odisha to identify the perceived impacts and preparedness levels of coastal and inland fishermen with the aid of fuzzy cognitive maps. They evaluated the effectiveness of current preparedness measures in the context of climate change by deploying various fuzzy cognitive mapping simulation-based preparedness pathways. FCM was used because it not only focuses on the physical components, mitigation and adaptation strategies associated with risk but also focus on the human, societal and cultural factors.

Singh and Chudasama (2021) conducted a study across 12 arid and semi-arid districts for evaluating the effectiveness of several adaptation pathways. Data was collected with the help of FCM developed by 427 community groups, each group containing four to five members each. Maps were developed based on the concepts of perceived impacts of climate-related disasters and adaptation measures implemented to cope with the impacts of climate change. Social Cognitive Map was developed for the study. The map consists of several types of nodes, such as climate stressors, climate-related impact and adaptation measures. These nodes were linked to each other with the help of edges, with weights assigned to them.

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