

# Analyzing The Impacts Of Climate Change On Human Health Using Induced Fuzzy Associative Memories (IFAM)

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## Abstract:

*Governments and health organizations across the world have rung alarm bells about the spread of new diseases and about an unusual increase in the frequency of health risks. Though many factors contribute to these concerns, climate change has been identified as playing a lead role. The effects of climate change have an adverse impact on the health indices. In this paper we analyze the health impacts of climate change using Induced Fuzzy Associative Memories*

**Keywords:** climate change, health impact, Induced FAM, human health.

## 1. Introduction

### 1.1 Climate change and Human health

Climate change poses a big threat to life on earth. Its impacts are being felt on every sphere of livelihood. Climate change can be defined broadly as “a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity” [IPCC synthesis report, 2007]. It is one of several global environmental changes that affect human health. Various large-scale environmental changes now simultaneously impinge on human population health, often interactively.

An obvious example is the transmission of vector-borne infectious diseases. These are affected by: climatic conditions; population movement; forest clearance and land-use patterns; freshwater surface configurations; human population density; and the population density of insectivorous predators. While anomalies in temperature and rainfall in a particular

season cause a number of vector-borne and water-borne epidemics; storms, cyclones and extreme rainfall can cause immediate death and injuries, as well as psychological stress on affected communities in the long-term. Pollution in air and water becomes the root cause for many communicable diseases. While on one hand severe drought leads to a decrease of lack of fresh water, flood on the other hand takes huge stock of life and livelihood. These are some of the observed and established effects of climate change.

It is needless to mention that the change in the weather is directly to proportional to changes in the health conditions. Researchers suggest that extremes of heat can cause heat exhaustion, cardiovascular disease (heart attacks and strokes) while cold spells can lead to hypothermia and increase morbidity and mortality from cardiovascular disease. World Health Organization (WHO) estimates more than one billion people worldwide to be without access to safe drinking water, and that every year approximately 1.7 million die prematurely because they do not have access to safe drinking water and sanitation.

IPCC Synthesis report also suggests that the health status of millions of people is projected to be affected through, for example, increases in malnutrition; increased deaths, diseases and injury due to extreme weather events; increased burden of diarrhoeal diseases; increased frequency of cardio-respiratory diseases due to higher concentrations of ground-level ozone in urban areas related to climate change; and the altered spatial distribution of some infectious diseases.

As World Health Organization Constitution states “the enjoyment of the highest attainable standard of health is one of the fundamental rights of every human being without distinction of race, religion, political belief, economic or social condition”. Thus analyzing the threats climate change poses to human health and to frame concrete action plan to wage a war against these threats becomes more imperative

and it is in the noble sense of assuring this fundamental right to good health.

## 2. Fuzzy Associative Memories (FAM)

A fuzzy set is a map  $\mu: X \rightarrow [0, 1]$  where  $X$  is any set called the domain and  $[0, 1]$  the range. That is to every element  $x \in X$ ,  $\mu$  assigns membership value in the interval  $[0, 1]$ . Fuzzy theorists often picture membership functions as two-dimensional graphs with the domain  $X$  represented as a one-dimensional axis.

The geometry of fuzzy sets involves both domain  $X = (x_1, x_2, \dots, x_n)$  and the range  $[0, 1]$  of mappings  $\mu: X \rightarrow [0, 1]$ . A fuzzy subset equals the unit hyper cube  $I^n = [0, 1]^n$ . The fuzzy set is a point in the cube

$I^n$ . Vertices of the cube  $I^n$  define a non-fuzzy set. Now within the unit hyper cube  $I^n = [0, 1]^n$  we are interested in distance between points, which led to measures of size and fuzziness of a fuzzy set and more fundamentally to a measure. Thus within cube theory directly extends to the continuous case when the space  $X$  is a subset of  $R^n$ . The next step is to consider mappings between fuzzy cubes.

A fuzzy set defines a point in a cube. A fuzzy system defines a mapping between cubes. A fuzzy system  $S$  maps fuzzy sets to fuzzy sets. Thus a fuzzy system  $S$  is a transformation  $S: I^n \rightarrow I^p$ . The  $n$ -dimensional unit hyper cube  $I^n$  houses all the fuzzy subsets of the domain space or input universe of discourse  $X = (x_1, x_2, \dots, x_n)$ .  $I^p$  houses all the fuzzy subsets of the range space or output universe of discourse,  $Y = (y_1, y_2, \dots, y_p)$ .  $X$  and  $Y$  can also denote subsets of  $R^n$  and  $R^p$ . Then the fuzzy power sets  $F(2^X)$  and  $F(2^Y)$  replace  $I^n$  and  $I^p$ .

In general a fuzzy system  $S$  maps families of fuzzy sets to families of fuzzy sets thus  $S: I^{n_1} \times \dots \times I^{n_r} \rightarrow I^{p_1} \times \dots \times I^{p_s}$ . Here too we can extend the definition of a fuzzy system to allow arbitrary products or arbitrary mathematical spaces to serve as the domain or range spaces of the fuzzy sets. We shall focus on fuzzy systems  $S: I^n \rightarrow I^p$  that map balls of fuzzy sets in  $I^n$  to balls of fuzzy set in  $I^p$ . These continuous fuzzy systems behave as associative memories. The map close inputs to close outputs. We shall refer to them as Fuzzy Associative Maps or FAMs.

The simplest FAM encodes the FAM rule or association  $(A_i, B_i)$ , which associates the  $p$ -dimensional fuzzy set  $B_i$  with the  $n$ -dimensional fuzzy set  $A_i$ . These minimal FAMs essentially map one ball in  $I^n$  to one ball in  $I^p$ . They are comparable to simple neural networks. But we need not adaptively train the minimal FAMs. In general a FAM system  $F: I^n \rightarrow I^p$  encodes the processes in parallel a FAM bank of  $m$  FAM rules  $(A_1, B_1) \dots (A_m, B_m)$ . Each input  $A$  to the FAM system activates each stored FAM rule to different degree.

The minimal FAM that stores  $(A_i, B_i)$  maps input  $A$  to  $B_i'$  a partly activated version of  $B_i$ . The more  $A$  resembles  $A_i$ , the more  $B_i'$  resembles  $B_i$ . The corresponding output fuzzy set  $B$  combines these partially activated fuzzy sets  $B_1', B_2', \dots, B_m'$ .  $B$  equals a weighted average of the partially activated sets  $B = w_1 B_1' + \dots + w_m B_m'$  where  $w_i$  reflects the credibility frequency or strength of fuzzy association  $(A_i, B_i)$ . In practice we usually defuzzify the output waveform  $B$  to a single numerical value  $y_j$  in  $Y$  by computing the fuzzy centroid of  $B$  with respect to the output universe of discourse  $Y$ .

More generally a FAM system encodes a bank of compound FAM rules that associate multiple output or consequent fuzzy sets  $B_1^1, \dots, B_i^s$  with multiple input or antecedent fuzzy sets  $A_1^1, \dots, A_i^r$ . We can treat compound FAM rules as compound linguistic conditionals. This allows us to naturally and in many cases easily to obtain structural knowledge. We combine antecedent and consequent sets with logical conjunction, disjunction or negation. For instance, we could interpret the compound association  $(A^1, A^2, B)$ ; linguistically as the compound conditional "IF  $X^1$  is  $A^1$  AND  $X^2$  is  $A^2$ , THEN  $Y$  is  $B$ " if the comma is the fuzzy association  $(A^1, A^2, B)$  denotes conjunction instead of say disjunction.

We specify in advance the numerical universe of discourse for fuzzy variables  $X^1, X^2$  and  $Y$ . For each universe of discourse or fuzzy variable  $X$ , we

specify an appropriate library of fuzzy set values  $A_1^r, \dots, A_k^2$  Contiguous fuzzy sets in a library overlap.

In principle a neural network can estimate these libraries of fuzzy sets. In practice this is usually unnecessary. The library sets represent a weighted though overlapping quantization of the input space X. They represent the fuzzy set values assumed by a fuzzy variable. A different library of fuzzy sets similarly quantizes the output space Y. Once we define the library of fuzzy sets we construct the FAM by choosing appropriate combinations of input and output fuzzy sets Adaptive techniques can make, assist or modify these choices.

### 2.1 Induced Fuzzy Associative Memories

Suppose that there are n attributes, say  $x_1, x_2, \dots, x_n$ , where n is finite, associated with the effects of climate change and let  $y_1, y_2, \dots, y_p$  be the attributes associated with the health system. The connection matrix M of order n X p is obtained through the expert. Let  $C_1$  be the initial input vector. A particular component, say  $c_1$ , is kept in ON state and all other components in OFF state and we pass the state vector  $C_1$  through the connection matrix M. To convert the resultant vector as a signal function, choose the first two highest values to ON state and other values to OFF state with 1 and 0 respectively. Denote this process by the symbol. The resulting vector is multiplied with  $M^T$  and thresholding yields a new vector  $D_1$ . This vector is related with the connection matrix and that vector which gives the highest number of attributes to ON state is chosen as  $C_2$ . That is, for each positive entry we get a set of resultant vectors; among these vectors the one which contains maximum number of 1s is chosen as  $C_2$ . If there are two or more vectors with equal number of 1s in ON state, choose the first occurring one as  $C_2$ . Repeat the same procedure till a fixed point or a limit cycle is obtained. This process is done to give due importance to each vector separately as one vector induces another or many more vectors into ON state. Get the hidden pattern by the limit cycle or by getting a fixed point.

Next we choose the vector with its second component in ON state and repeat the same to get another cycle. This process is repeated for all the vectors separately. We observe the hidden pattern of some vectors found in all or many cases. Inference from this hidden pattern highlights the causes.

### 3. Adaptation of IFAM to the problem

We select the following attributes related with the effects of climate change as nodes of the domain space from the opinion of the experts:

- $C_1$  – Heat waves and cold spells
- $C_2$  - Air, water and land pollution
- $C_3$  – Threatened food supply
- $C_4$ - Weather disasters such as floods, droughts
- $C_5$ - Species extinction
- $C_6$ –Higher concentrations of ground level ozone in urban areas
- $C_7$  – Decrease in fresh water availability
- $C_8$  - Sea level rise
- $C_9$  – Ecological disturbance (Altered infectious disease patterns)
- $C_{10}$  – Migration and displacement
- $C_{11}$  – Shifts in farming and Land use
- $C_{12}$  – Loss of Biodiversity

The following attributes related with human health are taken as nodes of the range space:

- $P_1$  - Increased frequency of cardio vascular and respiratory illness
- $P_2$  – Asthma
- $P_3$  – Malaria, Typhoid, Dengue, Yellow fever, Encephalitis
- $P_4$  – Toxic algae, cholera
- $P_5$  - Increase in malnutrition
- $P_6$ - Infectious diarrhoea/Infectious disease vector
- $P_7$  – Over-crowding, poor sanitation
- $P_8$  – Impacts of thermal stress
- $P_9$  – Epidemic outbreaks
- $P_{10}$  – Communicable diseases
- $P_{11}$  – Stress and other psychosocial health issues

The expert’s opinion is given in the form of the relational matrix M

$$M = \begin{matrix} & \begin{matrix} P_1 & P_2 & P_3 & P_4 & P_5 & P_6 & P_7 & P_8 & P_9 & P_{10} & P_{11} \end{matrix} \\ \begin{matrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \\ C_8 \\ C_9 \\ C_{10} \\ C_{11} \\ C_{12} \end{matrix} & \begin{bmatrix} 0.7 & 0.6 & 0.7 & 0.5 & 0.7 & 0.8 & 0 & 0.9 & 0.8 & 0.8 & 0.2 \\ 0.4 & 0.7 & 0.9 & 0.6 & 0.3 & 0.4 & 0.2 & 0.1 & 0.8 & 0.9 & 0.4 \\ 0 & 0.1 & 0.3 & 0.5 & 1 & 0.3 & 0.2 & 0 & 0.3 & 0 & 0.2 \\ 0.1 & 0 & 0.8 & 0.8 & 0.8 & 0.6 & 0.7 & 0.5 & 1 & 0.9 & 0.4 \\ 0.2 & 0.1 & 0.1 & 0.1 & 0.6 & 0.1 & 0.2 & 0.4 & 0 & 0 & 0 \\ 0.9 & 0.5 & 0.2 & 0.1 & 0.1 & 0.4 & 0.6 & 0.7 & 0.2 & 0.2 & 0 \\ 0.3 & 0 & 0.7 & 0.7 & 0.8 & 0.8 & 0.7 & 0.8 & 0.8 & 0.9 & 0.2 \\ 0.1 & 0.1 & 0.2 & 0.2 & 0.3 & 0.1 & 0.6 & 0.6 & 0 & 0 & 0 \\ 0.3 & 0.2 & 0.7 & 0.7 & 0.4 & 0.8 & 0 & 0.3 & 0.6 & 0.7 & 0 \\ 0 & 0 & 0.5 & 0.3 & 0.3 & 0.3 & 0.8 & 0.1 & 0.6 & 0.7 & 0.8 \\ 0.1 & 0 & 0 & 0 & 0.9 & 0 & 0.6 & 0.5 & 0.2 & 0 & 0 \\ 0 & 0 & 0.4 & 0.4 & 0.8 & 0.3 & 0.7 & 0.8 & 0.5 & 0.5 & 0 \end{bmatrix} \end{matrix}$$

Let us choose the input vector  $C_1 = (1 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0)$ . That is the attribute Heat wave and Cold spells in kept in ON and the rest of the nodes in OFF state.

$$C_1 = (1 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0)$$

$$C_1 M = (.7 \ .6 \ .7 \ .5 \ .7 \ .8 \ 0 \ .9 \ .8 \ .8 \ .2)$$

$$\hookrightarrow (0\ 0\ 0\ 0\ 0\ 1\ 0\ 1\ 1\ 1\ 0) = C_1'$$

$$C_1' M^T = (.9\ .9\ .3\ 1\ .4\ .7\ .9\ .6\ .8\ .7\ .5\ .8)$$

$$\hookrightarrow (1\ 1\ 0\ 1\ 0\ 0\ 1\ 0\ 0\ 0\ 0\ 0) = C_1$$

$$C_1^{(1)} = (1\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0)$$

$$C_1^{(2)} = (0\ 1\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0)$$

$$C_1^{(3)} = (0\ 0\ 0\ 1\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0)$$

$$C_1^{(4)} = (0\ 0\ 0\ 0\ 0\ 0\ 1\ 0\ 0\ 0\ 0\ 0)$$

$$C_1^{(2)} M = (.4\ .7\ .9\ .6\ .3\ .4\ .2\ .1\ .8\ .9\ .4)$$

$$\hookrightarrow (0\ 0\ 1\ 0\ 0\ 0\ 0\ 0\ 1\ 1\ 0) = C_1^{(2)}$$

$$C_1^{(2)} M^T = (.8\ .9\ .3\ 1\ .1\ .2\ .9\ .2\ .7\ .7\ .2\ .5)$$

$$\hookrightarrow (0\ 1\ 0\ 1\ 0\ 0\ 1\ 0\ 0\ 0\ 0\ 0)$$

The sum is 3.

$$C_1^{(3)} M = (.1\ 0\ .8\ .8\ .8\ .6\ .7\ .5\ 1\ .9\ .4)$$

$$\hookrightarrow (0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 1\ 1\ 0) = C_1^{(3)}$$

$$C_1^{(3)} M^T = (.8\ .9\ .3\ 1\ 0\ .2\ .9\ 0\ .7\ .7\ .2\ .5)$$

$$\hookrightarrow (0\ 1\ 0\ 1\ 0\ 0\ 1\ 0\ 0\ 0\ 0\ 0)$$

The sum is 3.

$$C_1^{(4)} M = (.3\ 0\ .7\ .7\ .8\ .8\ .7\ .8\ .9\ .9\ .2)$$

$$\hookrightarrow (0\ 0\ 0\ 0\ 1\ 1\ 0\ 1\ 1\ 1\ 0) = C_1^{(4)}$$

$$C_1^{(4)} M^T = (.9\ .9\ 1\ 1\ .6\ .7\ .9\ .6\ .8\ .7\ .9\ .8)$$

$$\hookrightarrow (1\ 1\ 1\ 1\ 0\ 0\ 1\ 0\ 0\ 0\ 1\ 0)$$

The sum is 6.

Therefore  $C_2 = (1\ 1\ 1\ 1\ 0\ 0\ 1\ 0\ 0\ 0\ 1\ 0)$

$$C_2 M = (.7\ .7\ .9\ .8\ .9\ .8\ .7\ .9\ 1\ .9\ .4)$$

$$\hookrightarrow (0\ 0\ 1\ 0\ 1\ 0\ 0\ 1\ 1\ 1\ 0) = C_2'$$

$$C_2' M^T = (.9\ .9\ 1\ .9\ .6\ .7\ .9\ .6\ .7\ .7\ .9\ .8)$$

$$\hookrightarrow (1\ 1\ 1\ 1\ 0\ 0\ 1\ 0\ 0\ 0\ 1\ 0) = C_2$$

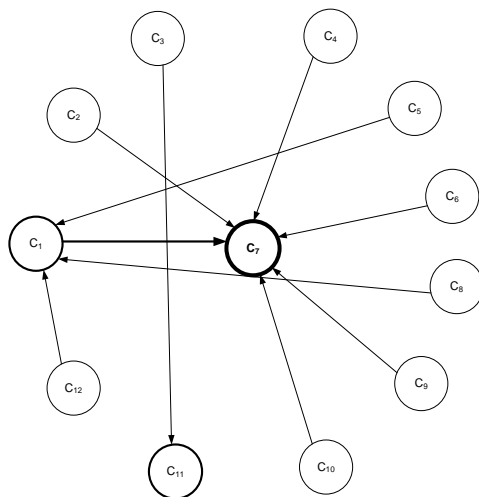
Thus the binary pair

{(0 0 1 0 1 0 0 1 1 1 0), (1 1 1 1 0 0 1 0 0 0 1 0)} represents the fixed point.

The following table gives different limit points and triggering patterns for various input vectors.

Input vector	Limit point	Triggering pattern
(1 0 0 0 0 0 0 0 0 0 0 0)	(00101001110), (111100100010)	$C_1 \Rightarrow C_7 \Rightarrow C_7$
(0 1 0 0 0 0 0 0 0 0 0 0)	(00101001110), (111100100010)	$C_2 \Rightarrow C_7 \Rightarrow C_7$
(0 0 1 0 0 0 0 0 0 0 0 0)	(00001010000), (001000000010)	$C_3 \Rightarrow C_{11} \Rightarrow C_{11}$
(0 0 0 1 0 0 0 0 0 0 0 0)	(00101001110), (111100100010)	$C_4 \Rightarrow C_7 \Rightarrow C_7$
(0 0 0 0 1 0 0 0 0 0 0 0)	(00101001110), (111100100010)	$C_5 \Rightarrow C_1 \Rightarrow C_7 \Rightarrow C_7$
(0 0 0 0 0 1 0 0 0 0 0 0)	(00101001110), (111100100010)	$C_6 \Rightarrow C_7 \Rightarrow C_7$
(0 0 0 0 0 0 1 0 0 0 0 0)	(00101001110), (111100100010)	$C_7 \Rightarrow C_7$
(0 0 0 0 0 0 0 1 0 0 0 0)	(00101001110), (111100100010)	$C_8 \Rightarrow C_1 \Rightarrow C_7 \Rightarrow C_7$
(0 0 0 0 0 0 0 0 1 0 0 0)	(00101001110), (111100100010)	$C_9 \Rightarrow C_7 \Rightarrow C_7$
(0 0 0 0 0 0 0 0 0 1 0 0)	(00101001110), (111100100010)	$C_{10} \Rightarrow C_7 \Rightarrow C_7$
(0 0 0 0 0 0 0 0 0 0 1 0)	(00001010000), (001000000010)	$C_{11} \Rightarrow C_{11}$
(0 0 0 0 0 0 0 0 0 0 0 1)	(00101001110), (111100100010)	$C_{12} \Rightarrow C_1 \Rightarrow C_7 \Rightarrow C_7$

These induced paths can be combined as a graph as given below.



It can be seen that the node  $C_7$  (Decrease in fresh water availability) becomes the converging point. Decrease in fresh water availability impinges more on human health than any other factor. The node  $C_1$  (Heat waves and cold spells) becomes the intermediary in at least three cases. It is also important to note that the node  $C_{11}$  (Shifts in farming and Land use) plays the next leading role in taking a stock on human health.

#### 4. Conclusion and suggestions

- From our study we suggest that efforts must be taken to reduce the risk of decreasing fresh water availability. Existing water bodies should be protected and maintained with utmost care. Programmes and schemes such as rainwater

harvesting should be implemented to increase the level of ground water. As water is essential for life on earth, any instance of its pollution becomes direct threat to health. Industrial policies should not be in conflict with healthy environment.

2. Climate change inflicts very much upon agriculture. This forces the farmers either to change their crop pattern or to abandon farming completely. Census of India (2011) states that 8.7 lakh farmers in Tamilnadu have abandoned farming in the past ten years. This has a direct impact on nutrition and results in low health indices.
3. Lack of Food supply also causes severe health risks. Hence actions should be taken to provide hygienic food and water.

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