



Fuzzy Cognitive Mapping (FCM) application to Climate Change & Water Resources Engineering



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Presentation Ahead



Why FCM



1 2 3 local, For very crops productivity indigenous level of water i Hard to rivers and lake complex and Quantify increase in mployemen questions traditional Human salinity and farmers income where *many* quatic species knowledge is **Behaviour** & different available scientific construction of positions are ams and reservoir data public included but community satisfaction is incomplete opinion is where no Tourism and navigation or entirely positive impact on desired environment simple or missing correct Flow of answers are Information available



Structured Participative Process	Cause Effect	Mapping of Complex systems
Sign of each relationship	- 1 to +1 ; Weak, Medium strong	Scenarios Mental Modeler FC Mapper



Irrigation Planning





Adjacency Matrix/interface

	farmers	irrigati	level of water in rivers and lakes	crops productivi	aquati c specie	Positive environ mental impact	increase in employe	fertility	salini ty & defo resta	ground	fisheries	community	Dams/Reserv	Tourism +navigation
farmers income	income				5	inpuct	ment	oriana		Water	Institution	0.7		
irrigation	0.4			0.9			0.5		-0.6	0.4	0.1	0.4		
level of water in rivers and lakes	0.6	0.8		0.7	0.8	0.6			-0.6	0.5	0.7	0.2		0.2
crops productivity	0.99						0.5					0.7		
aquatic species	0.2						0.2							
Positive environmental impact	0.6	0.45	0.6	0.5	0.5					0.2	0.4	0.5		0.4
increase in employement												0.9		
fertility of land	0.6			0.7			0.2					0.1		
salinity & deforestation	-0.5			-0.5	-0.3	-0.5	-0.45	-0.7		-0.2	-0.5	-0.5		
ground water	0.55	0.7	0.3	0.6		0.6	0.4	0.7				0.8		
fisheries	0.4					0.2	0.4					0.2		0.1
community satisfaction														
Dams/Reservoirs		0.7	0.5	0.6	0.7	0.5	0.4	0.2	-0.5		0.6			0.1
Tourism +navigation					0.2	2	0.5	5				0.4	1	

Cognitive Mapping in the form of Adjacency matrix

To simulate the outcomes of possible scenarios and the strength of impact on other elements

activation factors play a major role

activation vector is multiplied to the adjacency matrix and the iterations are continued until it is stabilized

Components	Notatio n
Farmers income	C1
Irrigation	C2
Level of water in rivers and lakes	C3
Crops productivity	C4
Aquatic species	C5
Positive environmental impact	C6
Increase in employment	C7
Fertility of land	C8
Salinity & deforestation	С9
Ground water	C10
Fisheries	C11
Community satisfaction	C12
Dams/Reservoirs	C13
Tourism +navigation	C14

 $[C1\ C2\ C3\ \dots Cn]_{NEW} = [C1\ C2\ C3\ \dots Cn]_{OLD} * \begin{bmatrix} C11 & \cdots & C1n \\ \vdots & \ddots & \vdots \\ Cn1 & \cdots & Cnn \end{bmatrix}$



Case 1:Construction of dams and reservoirs

Activation factor : [0 0 0 0 0 0 0 0 0 0 0 0 1 0]

- Final Activation vector: [1 1 1 1 1 1 1 1 1 1 1 1 0.8]
- Most of the factors in a positive direction
- Increase in salinity

Case 2:Increase in irrigation and salinity

Activation factor: [0 1 0 0 0 0 0 0 1 0 0 0 0 0] New: [-1 1 -0.7059 -1 -1 -1 -0.9471 1 -0.3529 -1 -1 0 -0.6412]

- Significant decrease in crop productivity, farmers income, fertility of land.
- Huge negative impact on environment

Impact of pollution

innovate achieve lead

- Air Pollution
 - Vehicles
 - Afforestation
 - Population Density
 - Agricultural materials like insecticides
 - Industrial exhaust
 - Mining waste
 - Smoking
 - Volcanoes
 - Government policies
 - Awareness programmes
 - Constructional waste
 - Power Generation

- Land Pollution
 - Agricultural sources
 - Ashes
 - Mining
 - Industrial sources
 - Sewage Wastes
 - Garbage
 - Construction sources
 - Deforestation
 - Chemical And Nuclear Plants
 - Oil Refineries
 - Overcrowded landfills
 - Government Policies
 - Awareness

Water Pollution

- •Sewage And Waste Water
- •Dumping
- Industrial Waste
- •Oil Leakage
- Acid Rain
- •Global Warming
- Agricultural Activities
- •Improper Drainage system
- •Groundwater contamination
- •Radioactive Waste
- •Underground storage leakage
- •Domestic Activities at Water Bodies
- Cremation Activities
- •Govt. Policies
- Awareness



FCM [Air Pollution]





Adjacency Matrix (Air)

	Air Pollution	Vehicles	Afforestation	Population Density	materials like insecticides	Industrial exhaust	Mining waste	Smoking	Volcano and tornado	Govt policies	Awareness programme s	Construct ional Waste	Power Consum ption	
Air Pollution	0	0	0.00	-0.34	0	0	0	0	0	0	0	0	0	
Vehicles	0.74	0	0	0	0	0.6	0	0	0	0	0	0	0	
Afforestation	-0.6	0	0	0	0	0	0	0	0	0	0	0	0	
Population Density	0.44	0.71	-0.62	0.95	0.64	0.64	0.52	0.23	0	0	0.34	0.48	0.63	
Agricultural materials like insecticides	0.27	0	-0.07	0	0	0	o	0	o	0	o	0	0	
Industrial exhaust	0.86	0	-0.59	0	0.1	o	0	0	o	o	0	o	0.63	
Mining waste	0.35	0	-0.37	0	0	0	0	0	0.26	0	0	0	0	
Smoking	0.24	0	0	-0.04	0	0	0	0	0	0	0	0	0	
Volcano and tornado	0.29	0	-0.21	-0.19	0	0	0	0	0	0	0	0	0	
Govt policies	-0.22	-0.16	0.2	-0.03	-0.13	-0.1	-0.02	-0.03	0	0	0.36	-0.19	-0.1	
Awareness programmes	-0.4	-0.2	0.22	-0.22	-0.12	-0.13	-0.06	-0.14	0	0	0	0	-0.05	
constructional waste	0.28	0	-0.49	0	0	0	0	0	0	0	0	0	0	
Power Consumption	0.2	0	0	0	0	o	0	0	o	o	o	0	0	



FCM [Land Pollution]



Adjacency Matrix (Land Pollution)

	Land Pollutio n	Agricult ural Sources	Ashes	Mining	Industria I Sources	Sewage Treatme nt	Garbage	Constru ctional Sources	Defores tation	Chemic al and Nuclear Plants	Oil Refineri es	Overcro wded Landfills	Govern ment Policies	Awaren ess
Land Pollution	0	0.2	0	0	0	0	0	-0.1	0.1	0	0	0.3	0.2	0
Agricultural sources	0.65	0.13	0	0	0	0	0	0	0.2	0	0	0	0	0
Ashes	0.28	0	0	0	0	0	0	0	0.18	0	0	0.09	0.19	0
Mining	0.46	0.28	0	0.61	0.44	0	0.27	0	0.66	0	0.06	0	0	0.36
Industrial sources	0.48	0	0.11	0.6	0	0.17	0.09	0.74	0	0	0	0.54	0.66	0
Sewage Treatment	0.43	0	0.41	0	-0.37	0		0	0.12	0	0	0.37	0	0.36
Garbage	0.51	-0.29	0	0	0.26	0.09	0	-0.21	0	0.28	0	0.74	0.37	0.63
Construction sources	0.43	0	0.23	0.32	0.54	0.22	0.33	0.55	0.51	0	0	0.46	0.23	0.09
Deforestation	0.42	0.17	0	0.23	0.38	0	0	0.27	0	0	0	-0.06	0.56	0.45
Chemical And Nuclear Plants	0.4	0.4	0	0.43	0.56	0.3	0.39	0.23	0.38	0	0.32	0.29	0	0
Oil Refineries	0.25	0	0	0.18	0.39	0	0	0	0.39	0.45	0	0	0.45	0
Overcrowded Iandfills	0.54	0.37	0.17	0	0	0	0	0	0.32	0	0	-0.34	0.32	0.42
Goverment Policies	-0.28	-0.39	-0.27	-0.33	-0.53	-0.13	-0.25	-0.2	-0.55	-0.42	-0.23	-0.21	0	0.61
Awareness	-0.38	-0.15	-0.24	-0.37	-0.29	-0.2	-0.33	-0.39	-0.32	-0.21	-0.32	-0.36	0	0.46



Combined Impact \rightarrow Pollution + Human Activity + Plants



and Vegetation + Animals + Natural Calamities



Climate Adjacency Matrix

innovate	achieve	lead

	Climate	Air Pa	lu Vohicla	s Affa	rart i	Populatir é	Agricultu	Indurtria	Mining	u Smak	cinq Nat	tural C Go	vtpali A	warono. (onstruc	Paulor Ce I	Wator Po S	owaqo f O	lumping	Dil Loaka i	Acid Rair	Global W.	Impropor (ārovndu	Radioact	Undorgre l	Domostic	Cromatic	LandPol	Arher	Sowago 1	Garbaqo	Chomica	Overcrai	Biarphor	Plants an A	Animalr
Climate		0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	1	0	0
Air Pollution		1	0	0	0	-0.34	0	0	1	0	0	0	0	0	0	0	0.3	0	0	0	0.5	0.7	0	0	0	0	0	0	0.52		0	0	0	0	0.5	-0.4	-0.6
Vehicler		0 0.	74	0	0	0	0	0.6		0	0	0	0	0	0	0	0	0	0.1	0.1	0.3	0.6	0	0	0	0	0	0	0		0	0.1	0.2	0	0.3	0	-0.3
Afforestation		0 -0	.6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	-0.1	-0.7	0	0	0	0	0	0	-0.42		0	0	0	0.06	-0.5	0.6	0.2
Population Denrit		0 0.	44 0.1	71 -	0.62	0.95	0.64	0.64	0.5	2 0	.23	0	0	0.34	0.48	0.63	0	0	0.3	0	0	0.3	0	0.2	0	0	0.6	0.5	0.4		0	0.3	0.2	0.4	0.5	-0.36	-0.53
Agricultural Activ		0 0.	27	0 -	0.07	0	0	0	1	0	0	0	0	0	0	0	0.42	0	0	0	0.26	0.31	0	0.32	0	0	0	0	0.65		0	0	0	0	0.4	0	0
Inductries		0 0.	86	0 -	0.59	0	0.1	0	1	0	0	0	0	0	0	0.63	0.53	0	0	0	0.51	0.45	0	0.23	0.35	0.27	0	0	0.48	0.1	0.17	0.09	0	0.54	0.3	-0.4	-0.4
Miningwarte		0 0.	35	0 -	0.37	0	0	0		0	0	0.26	0	0	0	0	0.2	0	0	0	0	0	0	0.4	0	0	0	0	0.46		0	0.27	0	0	0.3	-0.1	-0.2
Smaking		0 0.	24	0	0	-0.04	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0.01	0	0
Natural Calamitie		0 0.	29	0.	0.21	-0.19	0	0		0	0	0	0	0	0	0	0.6	0	0	0	0	0	0	0	0	0	-0.1	0	0.23		0	0	0	0	0.5	-0.5	-0.43
Govtpolicies		0 -0.	22 -0.1	16	0.2	-0.03	-0.13	-0.1	-0.0	2 -0	0.03	0	0	0.36	-0.19	-0.1	-0.38	-0.38	-0.28	0	0	-0.48	0	-0.23	-0.45	0	-0.25	-0.26	-0.28	-0.2	-0.13	-0.25	-0.42	-0.21	-0.5	-0.5	-0.5
Awaronoss progra		0 -0	.4 -0	.2	0.22	-0.22	-0.12	-0.13	-0.0	6 -0	0.14	0	0	0	0	-0.05	-0.4	-0.38	-0.48	0	0	-0.31	0	0	0	0	-0.39	0	-0.38	-0.2	-0.2	-0.33	-0.21	-0.36	-0.5	-0.5	-0.5
constructional wa		0 0.	28	0 -	0.49	0	0	0		0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0.43	0.23	0.22	0.33	0	0.46	0.15	-0.11	-0.07
Pawor Canzumpti		0 (.2	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	1	0	0	0	0	0.44	0	0
Water Pollution		1 0.	36	0	0	-0.12	0	0		0	0	0	0.57	0.5	0	0	0.46	0	0	0	0	0	0	0	0	0	0	0	0.33		0	0	0	0	0.5	-0.48	-0.34
Sowago And Wart		0	0	0	0	0	0	0		0	0	0	0	0	0	0	0.41	0	0	0	0	0	0.38	0.33	0	0	0	0	0		0.5	0	0	0	0.01	0	0
Dumping		0 (.2	0	0	0	0	0		0	0	0	0.45	0	0	0	0.46	0	0	0	0	0	0	0	0	0	0	0	0.3		0.4	0	0	-0.1	0.5	0	-0.3
OilLeakage		0	0	0	0	0	0	0	1	0	0	0	0.31	0	0	0	0.51	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0.3	0	-0.4
AcidRain		0	0	0	-0.3	0	0.5	0		0	0	0	0.23	0	0	0	0.53	0	0	0	0.35	0	0	0	0	0	0	0	0.4		0	0	0	0	0.1	-0.5	-0.5
Global Warming		0	0	0	0	-0.3	0	0		0	0	0.3	0.49	0.41	0	0	0.41	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0.8	0	-0.4
Improper Drainag		0	0	0	0	0	0	0		0	0	0	0	0	0	0	0.42	0.24	0	0	0	0	0	0.36	0	0	0	0	0		0.1	0	0	0	0.1	0	0
Groundwater conf		0	0	0	-0.1	-0.4	0.2	0		0	0	0	0.34	0	0	0.1	0.44	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0.1	-0.1	0
Radioactive Wart		0	04	0	0	0	0	0	1	0	0	0	0.46	0	0	0	0.43	0	0	0	0.34	0.32	0	0	0	0	0	0	0.2		0	0	0	0.1	0.1	0	0
Undergraundstar		0	0	0	0	0	0	0		0	0	0	0	0	0	0	0.42	0	0	0	0	0	0	0.51	0	0	0	0	0		0	0	0	0	0.01	0	0
Domertic Activiti		0	0	0	0	0	0	0		0	0	0	0.29	0	0	0	0.75	0.37	0	0	0	0	0	0	0	0	0	0	0		0.1	0	0	0	0.1	0	-0.2
Cromation Activi		0	0.1	0	0	0	0	0		0	0	0	0.34	0.15	0	0	0.35	0	0	0	0	0	0	0	0	0	0	0	0	0.	1 0	0	0	0	0.01	0	0
Land Pollution		1 0.	32	0	-0.4	0	0	0		0	0	0	0.2	0	0.43	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0		0	0	0	0.3	0.5	-0.46	-0.41
Arhor		0 0	.3	0	0	0	0	0		0	0	0	0.19	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0.28		0	0	0	0.09	0.12	0	0
Sowago Treatmor		0	0	0	0	0	0	0		0	0	0	0	0.36	0	0	-0.19	-0.26	0	0	0	0	0	0	0	0	0	0	0.43	0.4	1 0	0	0	0.37	0.16	0	0
Garbago		0 0.	12	0	0	0	0	0		0	0	0	0.37	0.63	0	0.1	0	0.15	0.4	0	0	0	0	0	0	0	0	0	0.51		0.09	0	0.28	0.74	0.6	0	-0.35
Chemical And Nuc		0 0.	15	0	0	0	0	0.1	0.	.2	0	0	0	0	0	0.6	0.4	0	0.3	0	0	0	0	0	0.4	0	0	0	0.4		0.3	0.39	0	0.29	0.25	-0.2	-0.17
Overcraudedland		0 0.	12	0 -	0.15	0	0	0		0	0	0	0.32	0.42	0	0	0.17	0.1	0.26	0	0	0	0	0	0	0	0	0	0.54	0.1	0	0	0	-0.34	0.2	0	-0.25
Biar phoric Palluti		1	0	0 -	0.18	-0.35	0.2	0		0	0	0.5	0.24	0.45	0	0	0	0	0	0	0	0	0	0.38	0	0	0	0	0		0	0	0	0	0	-0.5	-0.5
Plants and Vogota		0 -0.	52	0	0.2	0	0	0		0	0	0	0	0	0	0	-0.2	0	0	0	0	-0.2	-0.8	0	0	0	0	0	-0.44		0	0	0	0	-0.5	0	0.35
Animalz		0	0	0	-0.1	0	0	0		0	0	0	0	0	0	0	0	0	0	Ó	Ú	0	Ú	0	0	Ó	0	0	0		0	0	Ú	0	0	0.32	0



Case II: Humans and all Human Related Activities AV: [0 0 1 0 1 1 1 1 1 0 1 1 1 1 0 1 1 1 0 0 0 0 1 1 1 1 0 0 0 1 1 0 0 0 0] Afforestation is completely suppressed (-1) Plants and animals are adversely affected (-1)

Despite Govt. Policies and awareness, all pollutions and all the associated Harmful factors are on full rise (all 1)



<u>Case III</u>: Awareness and Government Policies AV: [000000001100000000000000000000000000]

- Climate is bettered (-1)
- All pollutions under control and their corresponding factors were decreased at all scales (-1)
- Afforestation is decently encouraged (0.55), acid rain was slightly decreased (-0.44) but GW is effectively handled (-1), plants and animals effectively protected (1)
- Population couldn't be controlled(1), industries(0.57) and mining(0.35) acts couldn't be handled, vehicular usage(0.35) and power consumption (0.46) also couldn't be reduced
- Smoking(0.06) and domestic activities at water bodies(0.03) had almost no impact
- Cremation activities couldn't be controlled(0.24)



<u>Case V</u>: Radioactivity, Chemical & Nuclear Plants, Oil Leakage AV: [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0] Negligible impact on Agricultural Activities (-0.063) Increase in industries and mining to support these industries (0.96 & 0.8) Constructional activities increase slightly (0.24) Power consumption increases largely (0.97) Sewage and waste water increase a lot (0.88) Overcrowded landfills increase very much (0.79)



Case VII: Industries

Global warming(1) and Acid rains (1) are promoted

Ground water contamination increases hugely(0.77), more ashes are being produced(0.37)

Landfills are being overcrowded largely(0.79), plants and animals are being Endangered(-1)



Climate Change

- Global Climate Models (GCMs)
- Models fail to capture many important phenomena of regional and lesser scales, such as clouds
- GCMs \rightarrow Physical, chemical and biological processes
- Examine the use of FCM in widening the understanding of a GCM



Concept Mapping



Pairwise Mapping - Cause and Effect



Matrix Tab Interface

	Stability of a GCM	Population	Procipitation	Historic Data and	Global Warming,Greenho uro Effocto	Chamical Efforts	Change in climate	Tidal Wayos
	Stability of a GCIVI	ropulation	Frecipitation	computation errors	use Lifects		Change in chinate	Tiudi waves
Stability of a GCM	0	0	0	0	0	0	0	0
Population	-0.7	0	-0.25	0	0.7	0.25	0.5	0
Precipitation	-0.25	0	0	0	0	0.4	0.7	0.6
Historic Data and compuation errors	-0.62	0	0	0	0	0	0	0
Global Warming,Greenho use Effects	-0.7	-0.6	-0.4	0	0	0	0.8	0.7
Chemical Effects	-0.62	-0.6	0	0	0.4	. 0	0	0
Change in climate	0.7	0.6	0 5		0.25	0	0	0.6
	-0.7	-0.6	0.5	0	0.25	0	0	0.0
Tidal Waves	-0.7	-0.6	0.3	0	0.25	0	0.2	0



Case 1:Increase in population

Activation Vector: [0 1 0 0 0 0 0 0] New Activation vector :[-1 1 0.15 0 1 0.3 1 1]

• There is an increase in tidal waves, global warming by an unit and the stability of GCM is decreased by one unit

Case 2:Increase in Global warming

Activation factor: [0 0 0 0 1 0 0 0]

New Activation factor:[-1 -1 0.6154 0 1 0 0.9308 1]

- The population is decreased by one unit
- The negative impact of chemicals have increased

Limitations/Future scope (Contd.)



Role of FCM in different situations

Individual knowledge and tedious process

Combined Adjacency matrix

Limitations/Future scope



Interface between Software and Matlab for effective analyzation

Rule based FCM

Explore for more Applications



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