Appendix A

Fuzzy Set Theory & Fuzzy Logic Concepts

A.1 Fuzzy Set

Members of a Crisp set take the value either 0 or 1. But members of a fuzzy set can take any value between 0 and 1, means it can take partial memberships. Thus a fuzzy set *A* in the universe of discourse U may be represented as a set of ordered pairs of element "u" and its membership grade "$\mu_{\overline{A}}(u)$", and it can be written as

$$\overline{A} = \{(u, \mu_{\overline{A}}(u)) / u \in U\}.$$

When U is continuous, a fuzzy set A can be written as

$$\overline{A} = \int_U \mu_{\overline{A}}(u) / u$$

When U is discrete, a fuzzy set A is represented as

$$\overline{A} = \sum_{i=1}^{n} \mu_{\overline{A}}(u_i) / u_i$$

A.2 Membership Function

Every Fuzzy Set has linguistic classes. Each linguistic class has its own definition about how & when each element in the universe of discourse can become the member of that linguistic class. This definition about belonging is called "membership function" of that class. **Figure 11** gives different membership functions and its graphical representation.

A.3 Fuzzy Operations: Union & Intersection

If $\overline{P}$ *and* $\overline{Q}$ be two fuzzy sets in U with membership functions $\mu_{\overline{P}}$ *and* $\mu_{\overline{Q}}$ respectively then union, intersection of them can be written as $\mu_{\overline{P}\cup\overline{Q}}$ for the union $\overline{P}\cup\overline{Q}$ and $\mu_{A\cap B}$ for $\overline{P}\cap\overline{Q}$ and can be written as

$$\mu_{\overline{P}\cup\overline{Q}} = \max\{\mu_{\overline{P}}(u), \mu_{\overline{Q}}(u)\} \quad \text{for all } u \in U$$

$$\mu_{\overline{P}\cap\overline{Q}} = \min\{\mu_{\overline{P}}(u), \mu_{\overline{Q}}(u)\} \quad \text{for all } u \in U$$

A.4 Fuzzy Rules

Fuzzy rule contains antecedents (the inputs) and consequents (the output). Antecedents may contain a single fuzzy set or may contain union or intersection of many fuzzy sets and Consequents normally refer to single fuzzy set for every rule. An example of fuzzy rule is

If $\overline{P}$ *is 'x' and* $\overline{Q}$ *is 'y' then* $\overline{R}$ *is 'z'*

Where x, y and z are the linguistic classes represented either by words or by numbers. A typical example of fuzzy rule is

If Ecolsus is 'Good' and Econsus is 'Good' and Socsus is 'Satisfactory' Then Osus is 'Good'

In most of the cases we may have to deal with group of input fuzzy rules, which leads to many output combinations, but as a total we are interested in the single output. In such cases Sup-Star compositions like Min [max ()] or Max [min ()], helps to integrate all of them. In the current research Max [min ()] composition is used, which means that the from the Antecedents groups, minimum value will be considered for every rule and from these outputs maximum values will be considered for final aggregation. In short we can say that UNION [INTERSECTION ()]. The output value of every rule will also have attached "linguistic class" and hence the reasoning stands valid irrespective of the value.

A.5. Fuzzy Inference

Fuzzy inference refers to the internal mechanism for producing output values for a given value through fuzzy rules. In short the inference process involves 3 steps: fuzzification, rule evaluation and defuzzification. Fuzzification process converts the input real world values or standardized values into grades of memberships and corresponding linguistic classes. These fuzzified grades/classes are evaluated through fuzzy rules for output grades/classes. Finally these output grades are again converted back to real world crisp output values through centroid calculation in defuzzification process. There are 2 known inference methods: Mamdani's approach and Sugeno approach. Mamdani approach considers complete fuzzy set for centroid calculation in defuzzification, but Sugeno approach take the Singletons as the highest membership value and corresponding x-point of output aggregated fuzzy set and finds the weighted average of these singletons as defuzzified output value.

A.4.1 Rule Implication & Aggregation Process

The implication process evaluates individual rule over fuzzified grades and generates an output grade and output class. Now the Aggregation does 2 things. First it truncates the Consequent Fuzzy Set according to the grade obtained and secondly it does the Union of all these fuzzy sets.

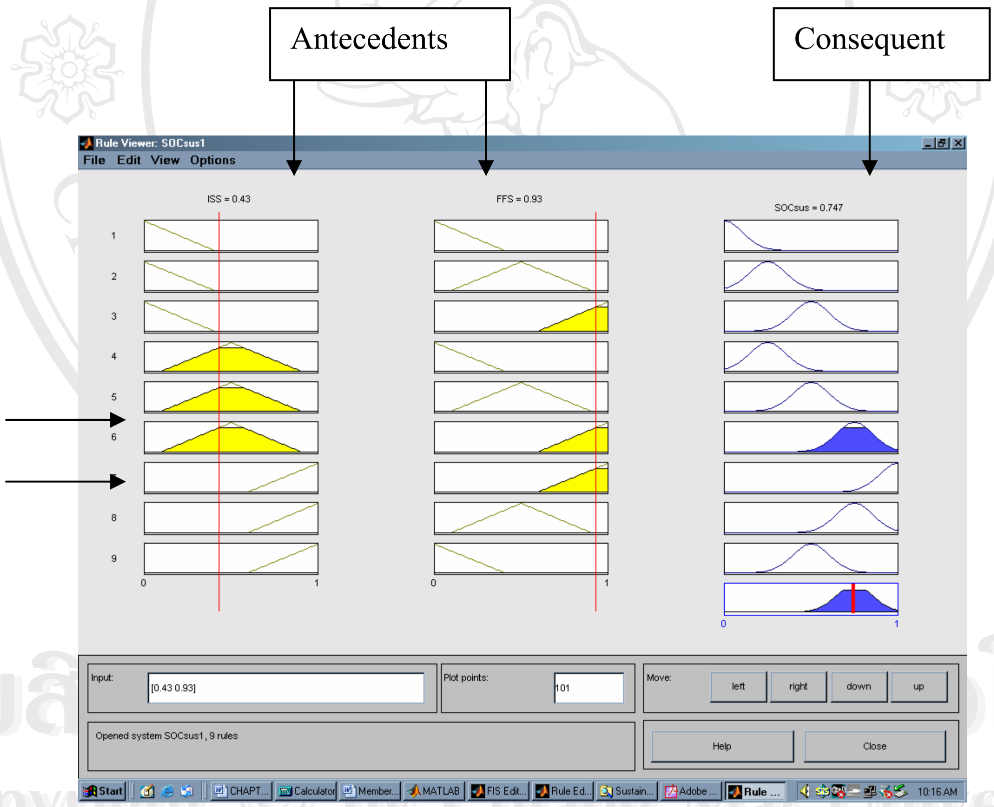


Figure A.1. Fuzzy Mamdani Inference over Indicator ISS and FFS for aggregation

Rule 5 = If (ISS) is (medium) and FFS is (medium) then SOCsus is satisfactory

Rule 6 = If (ISS) is (medium) and FFS is (high) then SOCsus is Good

A.4.2 Defuzzification

Defuzzification process calculates the output crisp value from the aggregated resultant fuzzy set derived after rule evaluation. There are different ways of calculating output value, but widely used methods are: Center of gravity method and Height method. In the centroid method all the elements within the aggregated fuzzy sets are considered with its respective memberships and it Height method only Mean of Maximum membership value and its corresponding x-element are considered.

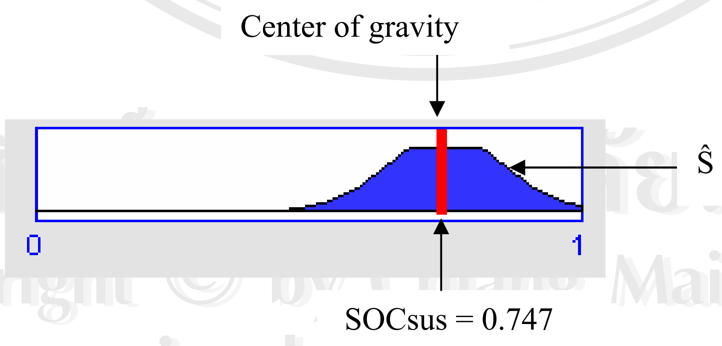
Example:

Let us consider Indicator Socsus, with normalized values 0.43 for the primary indicator ISS and 0.93 for FFS. Fuzzified values (Yj) for ISS and FFS are 0.75. There is only one possible combination Rule 6 [If (ISS) is (medium) and FFS is (high) then SOCsus is Good] is activated. The result of Rule 6 is (Good) with the grade $\mu TSOCsus = (0.1060,\ 0.75)$. Now the aggregation process truncates the good fuzzy set with the grade (0.1062, 0.75). Then finally output crisp value is calculated.

$$Def\left(TSOCsus\right) = \frac{\sum_j Yj * \mu TSOCsus(Yj)}{\sum_j \mu TSOCsus(Yj)}$$

$$= \frac{(0.75 * 0.1062) + (0.75 * 0.75)}{0.1062 + 0.75}$$

$$= 0.75$$



FigureA.2 : Defuzzification Process

Appendix B

Fuzzy Rules used at different levels

The process of adquiring fuzzy rule is an important process in fuzzy logic approach. Number of rules depends upon the number of linguistic classes present for each input parameter. If the number of linguistic classes are 5 and number of input variables are 2 then 5*5=25 rules are needed. In general form, number of rules needed can be written as L^n , where L is the number of linguistic classes and n refers to number of input variables.

For secondary variables; UCF………………..FFS, are associated with 3 linguistic classes. Primary variables; ECOLsus, ECONsus, SOCsus and Osus are 5 linguistic classes.

For aggregation of ECOLsus, 3^4= 81 rules are needed.
For aggregation of ECONsus, 3^3= 27 rules are needed.
For aggregation of SOCsus, 3^2 = 9 rules are needed.
For aggregation of Osus, 5^3 = 125 rules are needed. For each aggregation, the applied rules are presented in Figure B.1 and Table B.1.

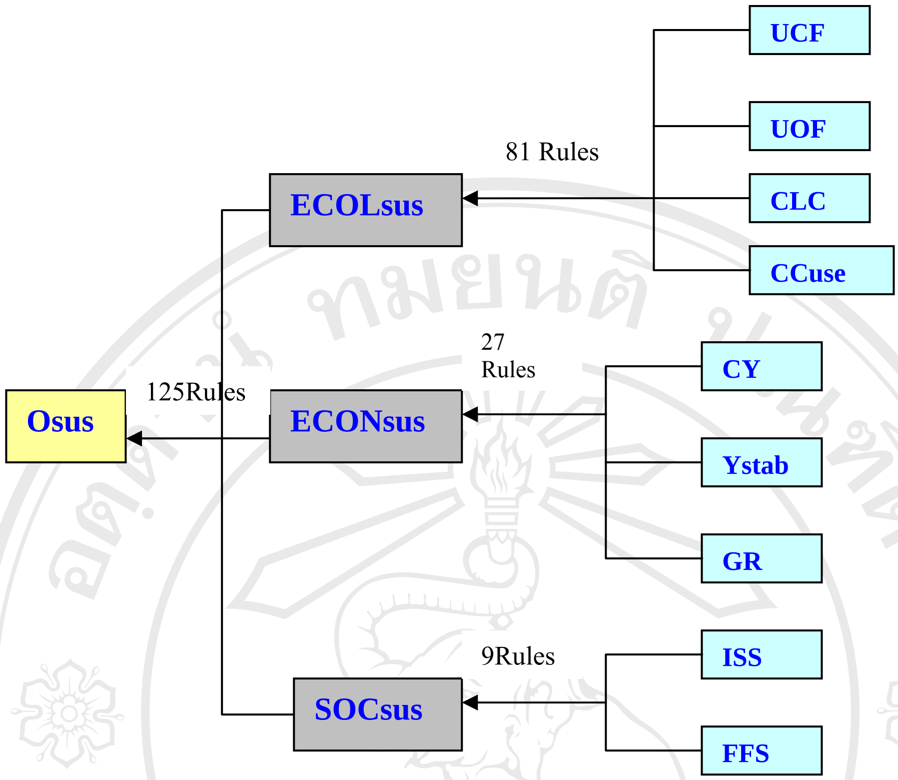


Figure B.1. Number of Rules required at different levels of aggregation

Table B.1. Rule application for overall sustainability assessment (125 Rules)

No.	IF (ECOLsus)=	AND (ECONsus)=	AND (SOCsus)=	THEN (Osus)=
1	Vbad	Vbad	Vbad	Vbad
2	Vbad	Vbad	Bad	Vbad
3	Vbad	Vbad	Satisfactory	Bad
4	Vbad	Vbad	Good	Bad
5	Vbad	Vbad	Vgood	Bad
6	Vbad	Bad	Vbad	Vbad
7	Vbad	Bad	Bad	Bad
8	Vbad	Bad	Satisfactory	Bad
9	Vbad	Bad	Good	Bad
10	Vbad	Bad	Vgood	Bad
11	Vbad	Satisfactory	Vbad	Bad
12	Vbad	Satisfactory	Bad	Bad
13	Vbad	Satisfactory	Satisfactory	Bad
14	Vbad	Satisfactory	Good	Bad
15	Vbad	Satisfactory	Vgood	Bad
16	Vbad	Good	Vbad	Bad
17	Vbad	Good	Bad	Bad
18	Vbad	Good	Satisfactory	Bad
19	Vbad	Good	Good	Bad
20	Vbad	Good	Vgood	Bad
21	Vbad	Vgood	Vbad	Bad
22	Vbad	Vgood	Bad	Bad
23	Vbad	Vgood	Satisfactory	Bad
24	Vbad	Vgood	Good	Bad
25	Vbad	Vgood	Vgood	Bad
26	Bad	Vbad	Vbad	Bad
27	Bad	Vbad	Bad	Bad
28	Bad	Vbad	Satisfactory	Bad
29	Bad	Vbad	Good	Bad
30	Bad	Vbad	Vgood	Bad
31	Bad	Bad	Vbad	Bad
32	Bad	Bad	Bad	Bad
33	Bad	Bad	Satisfactory	Bad
34	Bad	Bad	Good	Bad
35	Bad	Bad	Vgood	Bad
36	Bad	Satisfactory	Vbad	Bad
37	Bad	Satisfactory	Bad	Bad
38	Bad	Satisfactory	Satisfactory	Satisfactory
39	Bad	Satisfactory	Good	Satisfactory
40	Bad	Satisfactory	Vgood	Satisfactory
41	Bad	Good	Vbad	Bad
42	Bad	Good	Bad	Bad
43	Bad	Good	Satisfactory	Satisfactory
44	Bad	Good	Good	Satisfactory
45	Bad	Good	Vgood	Satisfactory
46	Bad	Vgood	Vbad	Bad

Table B.1 (continued)

47	Bad	Vgood	Bad	Bad
48	Bad	Vgood	Satisfactory	Satisfactory
49	Bad	Vgood	Good	Satisfactory
50	Bad	Vgood	Vgood	Satisfactory
51	Satisfactory	Vbad	Vbad	Bad
52	Satisfactory	Vbad	Bad	Bad
53	Satisfactory	Vbad	Satisfactory	Bad
54	Satisfactory	Vbad	Good	Bad
55	Satisfactory	Vbad	Vgood	Bad
56	Satisfactory	Bad	Vbad	Bad
57	Satisfactory	Bad	Bad	Bad
58	Satisfactory	Bad	Satisfactory	Satisfactory
59	Satisfactory	Bad	Good	Satisfactory
60	Satisfactory	Bad	Vgood	Satisfactory
61	Satisfactory	Satisfactory	Vbad	Bad
62	Satisfactory	Satisfactory	Bad	Satisfactory
63	Satisfactory	Satisfactory	Satisfactory	Satisfactory
64	Satisfactory	Satisfactory	Good	Satisfactory
65	Satisfactory	Satisfactory	Vgood	Good
66	Satisfactory	Good	Vbad	Bad
67	Satisfactory	Good	Bad	Satisfactory
68	Satisfactory	Good	Satisfactory	Satisfactory
69	Satisfactory	Good	Good	Good
70	Satisfactory	Good	Vgood	Good
71	Satisfactory	Vgood	Vbad	Bad
72	Satisfactory	Vgood	Bad	Satisfactory
73	Satisfactory	Vgood	Satisfactory	Good
74	Satisfactory	Vgood	Good	Good
75	Satisfactory	Vgood	Vgood	Good
76	Good	Vbad	Vbad	Vbad
77	Good	Vbad	Bad	Bad
78	Good	Vbad	Satisfactory	Bad
79	Good	Vbad	Good	Bad
80	Good	Vbad	Vgood	Bad
81	Good	Bad	Vbad	Bad
82	Good	Bad	Bad	Bad
83	Good	Bad	Satisfactory	Satisfactory
84	Good	Bad	Good	Satisfactory
85	Good	Bad	Vgood	Satisfactory
86	Good	Satisfactory	Vbad	Bad
87	Good	Satisfactory	Bad	Satisfactory
88	Good	Satisfactory	Satisfactory	Satisfactory
89	Good	Satisfactory	Good	Good
90	Good	Satisfactory	Vgood	Good
91	Good	Good	Vbad	Bad
92	Good	Good	Bad	Satisfactory
93	Good	Good	Satisfactory	Good
94	Good	Good	Good	Good
95	Good	Good	Vgood	Good
96	Good	Vgood	Vbad	Bad
97	Good	Vgood	Bad	Satisfactory
98	Good	Vgood	Satisfactory	Good

Table B.1 (continued)				
99	Good	Vgood	Good	Good
100	Good	Vgood	Vgood	Vgood
101	Vgood	Vbad	Vbad	Vbad
102	Vgood	Vbad	Bad	Bad
103	Vgood	Vbad	Satisfactory	Bad
104	Vgood	Vbad	Good	Bad
105	Vgood	Vbad	Vgood	Bad
106	Vgood	Bad	Vbad	Bad
107	Vgood	Bad	Bad	Bad
108	Vgood	Bad	Satisfactory	Satisfactory
109	Vgood	Bad	Good	Satisfactory
110	Vgood	Bad	Vgood	Satisfactory
111	Vgood	Satisfactory	Vbad	Bad
112	Vgood	Satisfactory	Bad	Satisfactory
113	Vgood	Satisfactory	Satisfactory	Satisfactory
114	Vgood	Satisfactory	Good	Good
115	Vgood	Satisfactory	Vgood	Good
116	Vgood	Good	Vbad	Bad
117	Vgood	Good	Bad	Satisfactory
118	Vgood	Good	Satisfactory	Good
119	Vgood	Good	Good	Good
120	Vgood	Good	Vgood	Vgood
121	Vgood	Vgood	Vbad	Bad
122	Vgood	Vgood	Bad	Satisfactory
123	Vgood	Vgood	Satisfactory	Good
124	Vgood	Vgood	Good	Vgood
125	Vgood	Vgood	Vgood	Vgood

Table B.2. Rule application for Environmental sustainability assessment (81 Rules)

No.	IF (UCF)=	AND (UOF)=	AND (CLC)=	AND (CCuse)=	THEN (ECOLsus)=
1	Low	Low	Low	Low	Vbad
2	Low	Low	Low	Medium	Vbad
3	Low	Low	Low	High	Vbad
4	Low	Low	Medium	Low	Vbad
5	Low	Low	Medium	Medium	Bad
6	Low	Low	Medium	High	Bad
7	Low	Low	High	Low	Vbad
8	Low	Low	High	Medium	Bad
9	Low	Low	High	High	Bad
10	Low	Medium	Low	Low	Vbad
11	Low	Medium	Low	Medium	Bad
12	Low	Medium	Low	High	Bad
13	Low	Medium	Medium	Low	Bad
14	Low	Medium	Medium	Medium	Satisfactory
15	Low	Medium	Medium	High	Satisfactory
16	Low	Medium	High	Low	Bad
17	Low	Medium	High	Medium	Satisfactory
18	Low	Medium	High	High	Satisfactory
19	Low	High	Low	Low	Bad
20	Low	High	Low	Medium	Bad
21	Low	High	Low	High	Bad
22	Low	High	Medium	Low	Bad
23	Low	High	Medium	Medium	Satisfactory
24	Low	High	Medium	High	Satisfactory
25	Low	High	High	Low	Bad
26	Low	High	High	Medium	Satisfactory
27	Low	High	High	High	Satisfactory
28	Medium	Low	Low	Low	Vbad
29	Medium	Low	Low	Medium	Bad
30	Medium	Low	Low	High	Bad
31	Medium	Low	Medium	Low	Bad
32	Medium	Low	Medium	Medium	Satisfactory
33	Medium	Low	Medium	High	Satisfactory
34	Medium	Low	High	Low	Bad
35	Medium	Low	High	Medium	Satisfactory
36	Medium	Low	High	High	Satisfactory
37	Medium	Medium	Low	Low	Bad
38	Medium	Medium	Low	Medium	Satisfactory
39	Medium	Medium	Low	High	Satisfactory
40	Medium	Medium	Medium	Low	Satisfactory
41	Medium	Medium	Medium	Medium	Good
42	Medium	Medium	Medium	High	Good
43	Medium	Medium	High	Low	Satisfactory
44	Medium	Medium	High	Medium	Good
45	Medium	Medium	High	High	Good
46	Medium	High	Low	Low	Bad
47	Medium	High	Low	Medium	Satisfactory
48	Medium	High	Low	High	Satisfactory
49	Medium	High	Medium	Low	Satisfactory
50	Medium	High	Medium	Medium	Good

Table B.2 (continued)					
51	Medium	High	Medium	High	Good
52	Medium	High	High	Low	Satisfactory
53	Medium	High	High	Medium	Good
54	Medium	High	High	High	Vgood
55	High	Low	Low	Low	Vbad
56	High	Low	Low	Medium	Bad
57	High	Low	Low	High	Bad
58	High	Low	Medium	Low	Bad
59	High	Low	Medium	Medium	Satisfactory
60	High	Low	Medium	High	Satisfactory
61	High	Low	High	Low	Bad
62	High	Low	High	Medium	Satisfactory
63	High	Low	High	High	Satisfactory
64	High	Medium	Low	Low	Bad
65	High	Medium	Low	Medium	Satisfactory
66	High	Medium	Low	High	Satisfactory
67	High	Medium	Medium	Low	Satisfactory
68	High	Medium	Medium	Medium	Good
69	High	Medium	Medium	High	Good
70	High	Medium	High	Low	Satisfactory
71	High	Medium	High	Medium	Good
72	High	Medium	High	High	Good
73	High	High	Low	Low	Bad
74	High	High	Low	Medium	Satisfactory
75	High	High	Low	High	Satisfactory
76	High	High	Medium	Low	Satisfactory
77	High	High	Medium	Medium	Good
78	High	High	Medium	High	Vgood
79	High	High	High	Low	Satisfactory
80	High	High	High	Medium	Vgood
81	High	High	High	High	Vgood

Table B.3. Rule application for Economic sustainability assessment (27 Rules)

No.	IF (CY)=	AND (Ystab)=	AND (GR)=	ECONsus=
1	Low	Low	Low	Vbad
2	Low	Low	Medium	Bad
3	Low	Low	High	Bad
4	Low	Medium	Low	Bad
5	Low	Medium	Medium	Satisfactory
6	Low	Medium	High	Satisfactory
7	Low	High	Low	Bad
8	Low	High	Medium	Satisfactory
9	Low	High	High	Good
10	Medium	Low	Low	Bad
11	Medium	Low	Medium	Satisfactory
12	Medium	Low	High	Satisfactory
13	Medium	Medium	Low	Satisfactory
14	Medium	Medium	Medium	Satisfactory
15	Medium	Medium	High	Good
16	Medium	High	Low	Satisfactory
17	Medium	High	Medium	Good
18	Medium	High	High	Good
19	High	Low	Low	Bad
20	High	Low	Medium	Satisfactory
21	High	Low	High	Satisfactory
22	High	Medium	Low	Satisfactory
23	High	Medium	Medium	Good
24	High	Medium	High	Good
25	High	High	Low	Satisfactory
26	High	High	Medium	Good
27	High	High	High	Vgood

Table B.4. Rule application for Social sustainability assessment (9 Rules)

No.	IF (ISS)=	AND (FFS)=	ECONsus=
1	Low	Low	Vbad
2	Low	Medium	Bad
3	Low	High	Satisfactory
4	Medium	Low	Bad
5	Medium	Medium	Satisfactory
6	Medium	High	Good
7	High	Low	Satisfactory
8	High	Medium	Good
9	High	High	Vgood

Appendix C

Maps of Myanmar

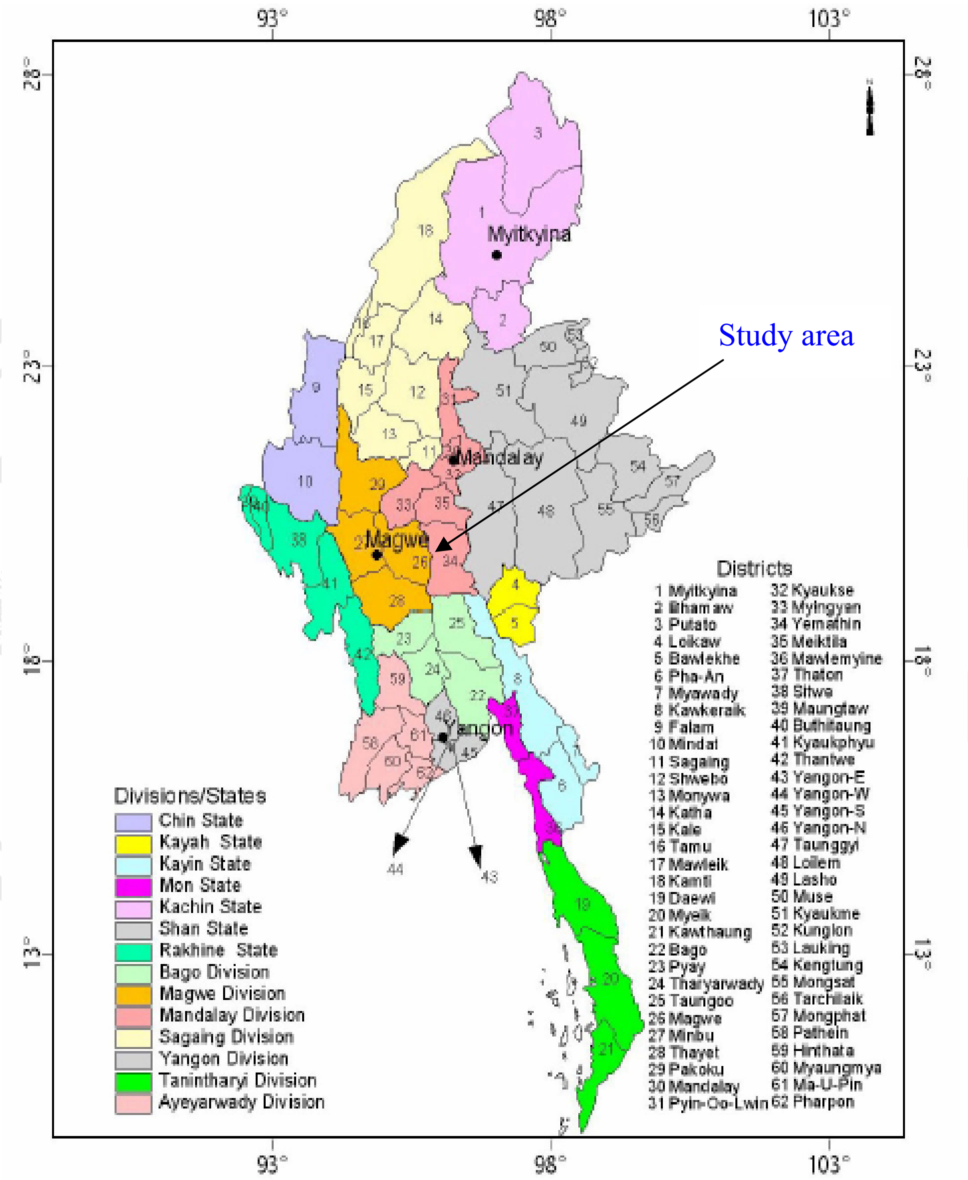


Figure C.1. Administrative map of Myanmar

(Source: Ramakrishna, 2000)

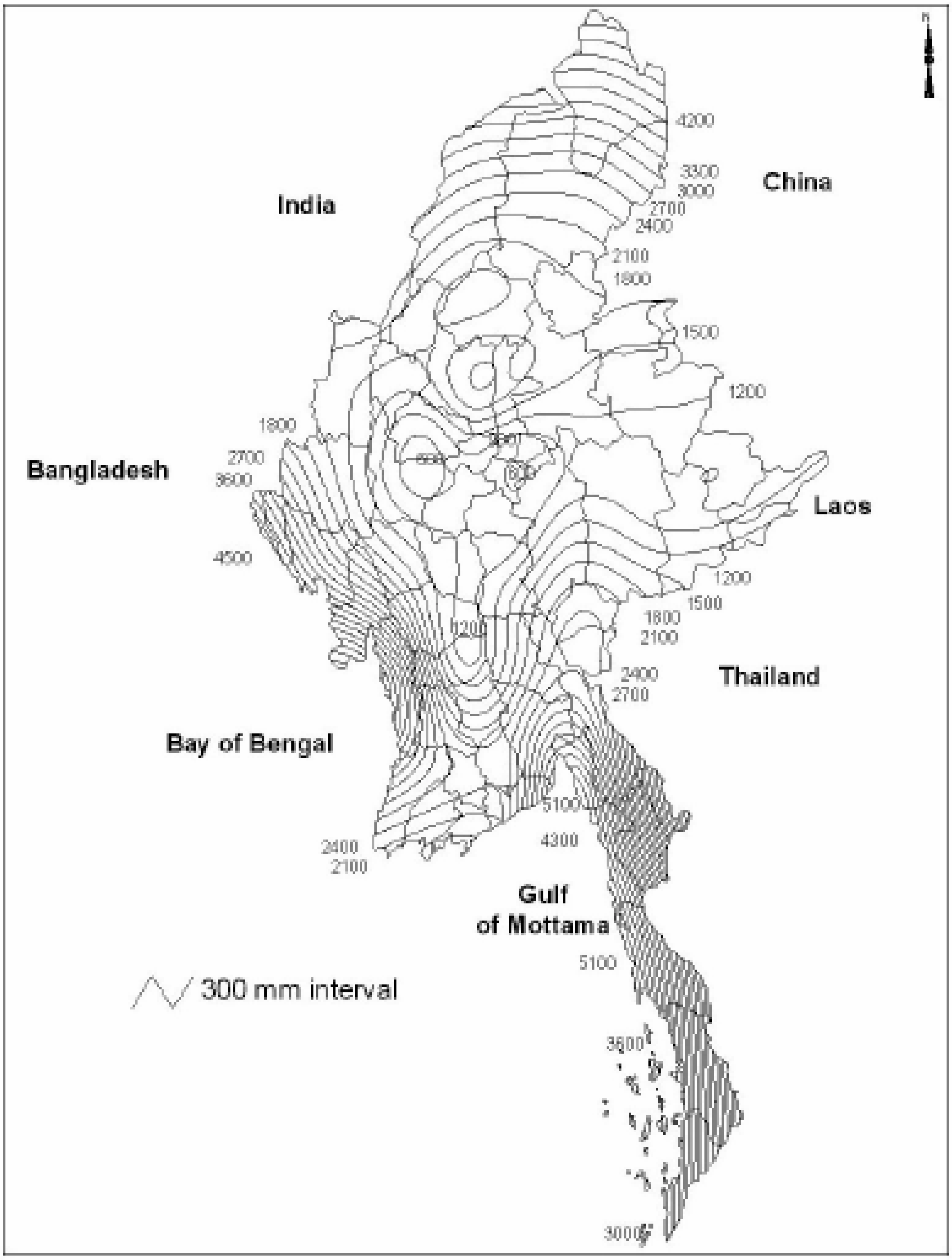


Figure C.2. Rainfall isohyets in Myanmar
(Source: University of Yangon, Myanmar)

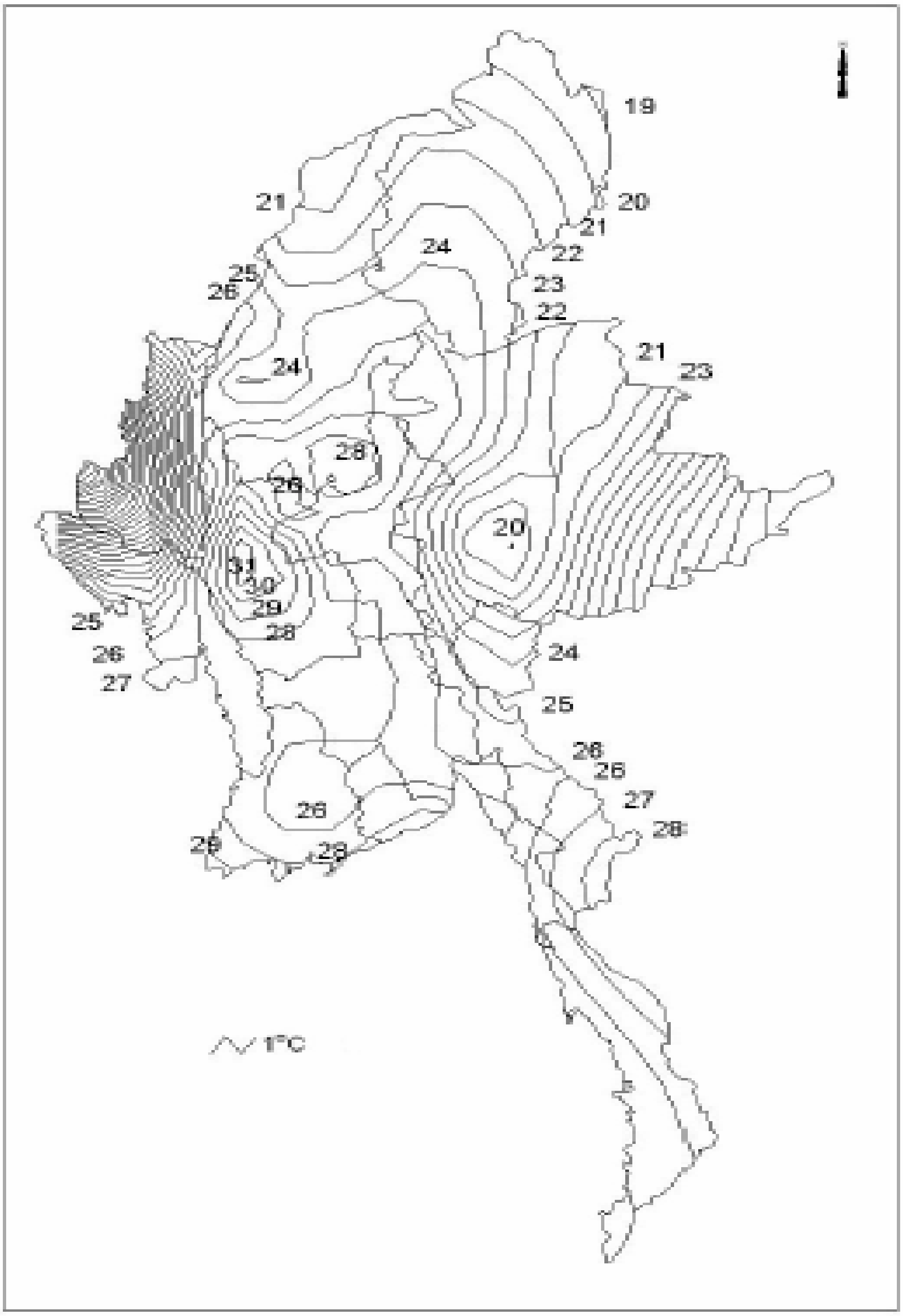


Figure C.3. Isotherms in Myanmar

(Source: University of Yangon, Myanmar)

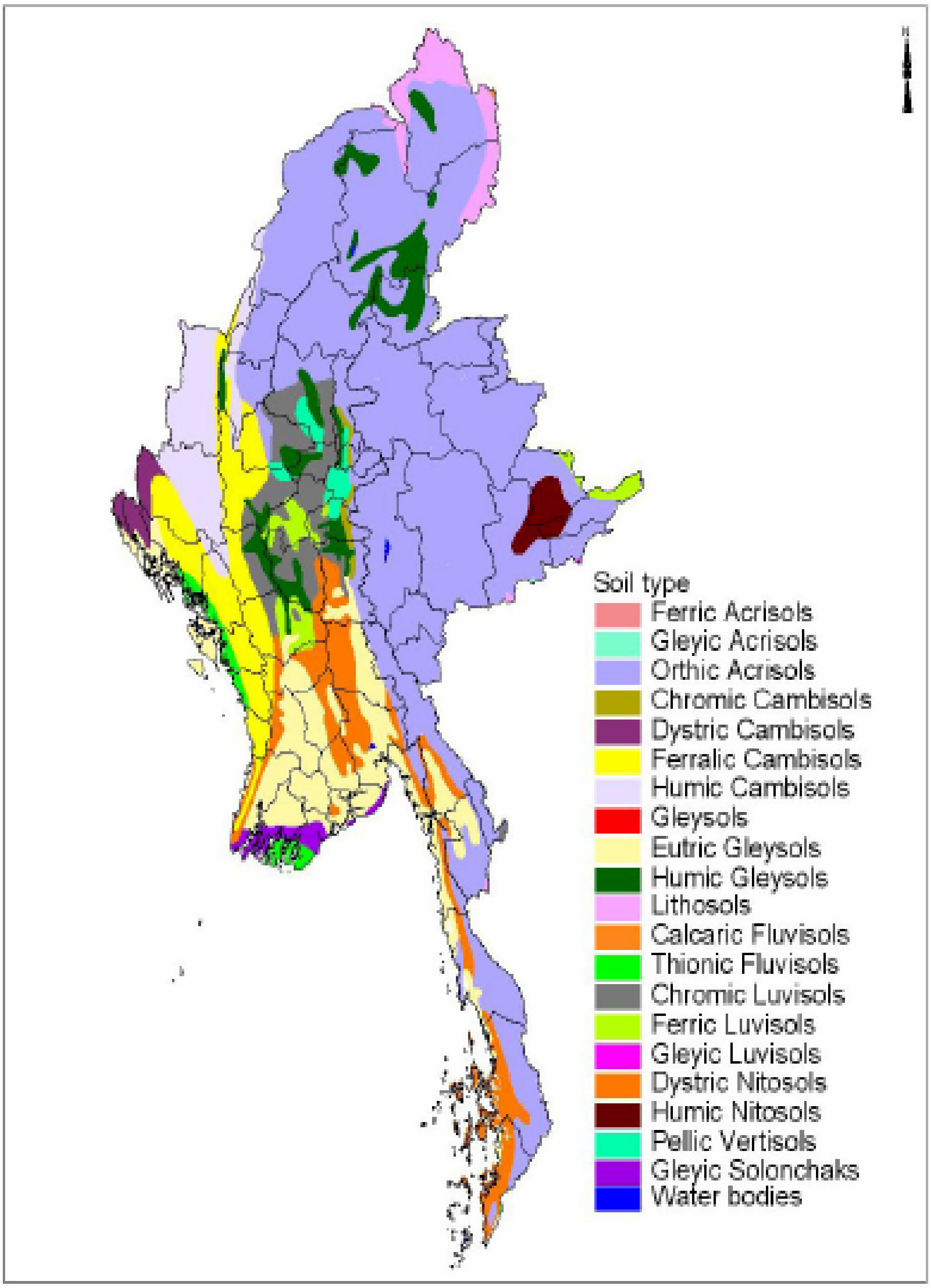


Figure C.4. Soils in Myanmar

(Source: FAO, Rome, Italy)

Appendix D
Software Used

For this research, a powerful analysis software (MATLAB 7.1, Release 14 SP3 student version from Mathworks Inc., Fuzzy logic toolbox) is used for SAFE (Sustainability Analysis by Fuzzy Evaluation) methodology.

SPSS version 13 software is used for analyzing each indicator by using descriptive statistics and compare means.

Then, for Multi-criteria Evaluation, Microsoft Office Excel 2003 software is used to visualize the Amoeba or Radar diagram. SIA (Sustainability Indicator Analysis) and all the basic calculation are calculated by Microsoft Office Excel 2003 to get the comparable values.

The required softwares are supported by MCC (multiple Cropping Center, Chiang Mai University) for this study.

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