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Vulnerability Assessment of Arunachal Pradesh to Floods

Sanayanbi.H[1], V.V.Zaphu[2], N.Monica[2], Vanlalremruatpuii TBC[2], A. Bandyopadhyay[3]

Research Scholar, Department of Agricultural Engineering, North Eastern Regional Institute of Science and Technology, Nirjuli (Itanagar), Arunachal Pradesh 791109, India. [1]

UG Student, Department of Agricultural Engineering, North Eastern Regional Institute of Science and Technology, Nirjuli (Itanagar), Arunachal Pradesh 791109, India[2]

Assistant Professor, Department of Agricultural Engineering, North Eastern Regional Institute of Science and Technology, Nirjuli (Itanagar), Arunachal Pradesh 791109, India[3]

***Abstract*— Developing, testing and implementing indicators to identify and assess vulnerability to floods are an important pre-requisite for effective disaster risk reduction. In the present study, the vulnerability assessment of Arunachal Pradesh for flood has been carried out.Vulnerability as a function of weighted indicators of hazard, exposure and adaptive capacity has been determined using HEAV (Hazard/ Exposure/ Adaptive Capacity/ Vulnerability) methodology. Analytic Hierarchy Process (AHP) was used to assign weights to normalized indicators. Among 16 districts, for two districts (East Siang and Lohit), vulnerability index is more than 0.5 and flood prone area is more than 15%; for three districts (Papumpare, Lower Subansiri and Lower Dibang Valley), vulnerability index is less than 0.5 but flood prone area is more than 15%; for one district (Changlang), vulnerability index is more than 0.5 but flood prone area is less than 15%; and for rest ten districts, vulnerability index is less than 0.5 and flood prone area is also less than 15%. In Arunachal Pradesh, two districts, East Siang and Lohit are the hotspots for vulnerability to floods.**

***Keywords*— Flood, Vulnerability assessment, Analytical Hierarchy Process, HEAV**

I. INTRODUCTION

Almost all countries in the world are prone to one or more forms of disaster. Frequent occurrence of natural disasters causes huge loss of lives, properties, and physical infrastructure. It also causes socio-economic disruptions and environmental degradation in the affected communities. The occurrence of disasters is almost unavoidable. However, suitable measures in proper timing can reduce the adverse effects and negative consequences caused by disasters. The consequences of a disaster event such as flood depend on vulnerability of affected socio-economic and ecological systems (Cutter, 1996). Therefore, vulnerabilities of different socio-economic and environmental systems need to be properly assessed. In addition, vulnerability assessment may help decision makers to adopt appropriate policies and actions (De Bruijn and Klijn, 2009). Vulnerability assessment is a prerequisite for disaster risk reduction and capacity building of communities. In assessing and measuring vulnerability, it is important that one understands its socio-economic context, i.e. the socio-economic status of a group is closely linked to the adaptive capacity of that particular group. Many factors contribute to social and economic vulnerability including rapid population growth, poverty and hunger, poor health, low levels of education, gender inequality, fragile, marginal and/or hazardous location, and lack of access to infrastructure, resources and services, including knowledge and technological means. Assessment of current vulnerability can be done using a variety of variables derived from these factors *(*Garg et al., 2007).

North-east India is vulnerable to water induced disasters because of its location in the eastern Himalayan periphery, fragile geo-environmental setting, and economic underdevelopment. The major river systems of the north-

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east India, namely, Brahmaputra and the Barak (Meghna) originate in the Himalayas. The vulnerability of the north-east India to water induced disasters is of vital importance because of its poor adaptive capacity. Developing, testing and implementing indicators to identify and assess vulnerability to floods are an important pre-requisite for effective disaster risk reduction. Although strengthening capacities to reduce hazardous events are important, it became evident that we have to live with natural hazards, such as floods. Therefore it is important to promote a paradigm shift form the quantification of the hazard and primary focus on technical solutions towards the identification and assessment of the various vulnerabilities of societies, their economy and environment.

Many studies on quantitative assessment of vulnerability such as Luers et al. (2003),Moss et al. (2001),Kaly et al. (2002),Downing et al. (2001), Pritchett et al. (2000), and Schimmelpfennig and Yohe (1999) illustrated the composite index approach to measuring vulnerability. For instance, Moss et al. (2000) in the Pacific Northwest Laboratory (PNL) used an index which is a composite of 16 variables selected from five sensitive sectors (settlement, food security, human health, ecosystem, and water) and three dimensions for coping capacity (economic, human resources, and environmental) to measure vulnerability to climate change for 38 countries. The present study has been undertaken to determine the hotspots of vulnerability for flood in Arunachal Pradesh.

II. Study Area and Data Acquisition

The state of Arunachal Pradesh is situated between 26º 30' and 29º 28' N latitudes and 91º 25' to 97º 24' E longitudes. It covers an area of 83,700 sq. km. The state is bounded by China and Tibet in the north, Assam in the south, in the east by Myanmar and Nagaland, and in the west by Bhutan. 16 districts of Arunachal Pradesh were selected as study area. The locations of the study area are presented in Fig.1. The climate of Arunachal Pradesh is humid to per humid subtropical characterized by high rainfall and high humidity and sub-Himalayan belt. However, temperate climate prevails at lower Himalayan region. The greater Himalayan region is covered with perpetual snow. The average annual rainfall varies from 1,380 to 5,500 mm.

Values of different indicators of hazard, exposure and adaptive capacity were collected for 16 districts of Arunachal Pradesh from Directorate of Economics and Statistics Government of Arunachal Pradesh Itanagar.

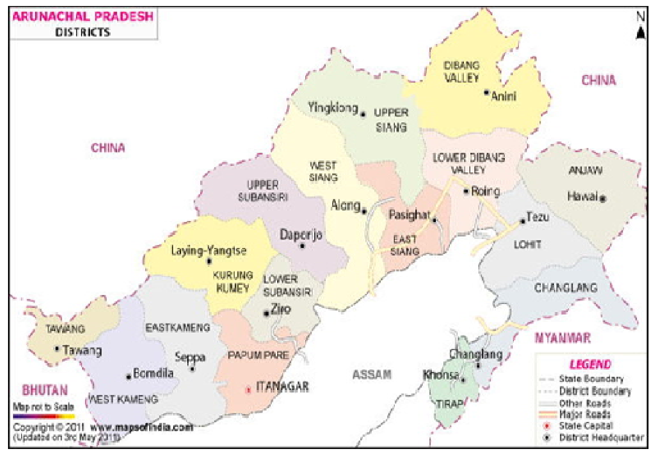

Fig. 1 Study area (16 Districts of Arunachal Pradesh)

III. Methodology

A. HEAV

Vulnerability can be assessed by three criteria, such as hazard, exposure, and adaptive capacity as follows (IPCC, 2001b):

Vulnerability = *f* (Hazard, Exposure, Adaptive Capacity)

Or $V = [H \times (E - A)]$ (1)

Vulnerability in a particular location can be obtained as below:

$$V(l) = \{wh_c \times H_c(l)\} \times [\{we_c \times E_c(l)\} - \{wa_c \times A_c(l)\}] \quad (2)$$

where,

$V(l)$ = vulnerability index at location *l*, $H_c(l)$ = commensurate composite indicator of hazard at location *l* and wh_c is its corresponding weight, $E_c(l)$ = commensurate composite indicator of exposure at location *l* and we_c is its corresponding weight, and $A_c(l)$ =

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commensurate composite indicator of adaptive capacity at location *l* and wa_c is its corresponding weight.

To construct the commensurate composite indicator for hazard, exposure, and adaptive capacity, different weights should be assigned to different indicators under hazard, exposure, and adaptive capacity as below:

$$H_c(l) = \sum_{k=1}^{NH} wh_k \times H_k(l) \quad (3)$$

$$E_c(l) = \sum_{k=1}^{NE} we_k \times E_k(l) \quad (4)$$

$$A_c(l) = \sum_{k=1}^{NA} wa_k \times A_k(l) \quad (5)$$

where,

$H_k(l)$ = k^{th}commensurated indicator of hazard at location*l*and wh_k is its corresponding weight,

$E_k(l)$ = k^{th}commensurated indicator of exposure at location*l*and we_k is its corresponding weight,

$A_k(l)$ = k^{th}commensurated indicator of adaptive capacity at location*l*and wa_k is its corresponding weight.

B. Normalization of Indicators

Difference in units and types of association can be resolved through converting indicators into normalized positive values that range from zero to one and positively associated with their respective variable (hazard, exposure, or adaptive capacity). To arrive at a dimensionless form for positive indicators, simple normalization can be carried out which fits indicators to relative positions between 0 and 1 as below:

$$\frac{X_i - \text{Min}(X_i)}{\text{Max}(X_i) - \text{Min}(X_i)} \quad (6)$$

The normalized indicators derived using Eqn. 6 for hazard, exposure and adaptive capacity are shown in Table. I, Table. II and Table. III respectively.

Table I. Normalized Value of Indicators for Hazard

Sl. No.	District	Maximum rainfall for a given duration	Elevation of Head quarters
1.	Tawang	0.23	0.00
2.	West Kameng	0.24	0.18
3.	East Kameng	0.25	0.92
4.	Papumpare	0.51	0.89
5.	Lower Subansiri	0.06	0.39
6.	KurungKumey	0.33	0.15
7.	Upper Subansiri	0.32	0.82
8.	West Siang	0.40	0.82
9.	East Siang	0.00	1.00

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10.	Upper Siang	1.00	0.07
11.	Dibang Valley	0.33	0.39
12.	Lower Dibang Valley	0.67	0.35
13.	Lohit	0.14	0.96
14.	Anjaw	0.12	0.55
15.	Changlang	0.53	0.83
16.	Tirap	0.12	0.58

Table II. Normalized Indicators for Exposure

Sl. No.	District	Density of population	% of Agril. land to total	% of rain fed land	% of workforce in agriculture	Cereal yield in qntls per ha	% of Rural population
1.	Tawang	0.414	0.162	0.268	0.018	0.452	0.553
2.	West Kameng	0.226	0.046	0.068	0.133	0.357	0.790
3.	East Kameng	0.317	0.202	0.265	0.061	0.274	0.464
4.	Papumpare	0.999	0.359	0.356	0.070	1.000	0.000
5.	Lower Subansiri	0.996	1.000	1.000	0.131	0.535	0.540
6.	Kurung Kumey	0.102	0.169	0.228	0.131	0.217	0.959
7.	Upper Subansiri	0.174	0.092	0.116	0.002	0.503	0.423
8.	West Siang	0.311	0.199	0.224	0.082	0.248	0.576
9.	East Siang	0.432	0.449	0.432	0.205	0.803	0.485
10.	Upper Siang	0.115	0.039	0.028	0.078	0.433	0.959
11.	Dibang Valley	0.00	0.000	0.000	0.644	0.134	0.959
12.	Lower Dibang Valley	0.295	0.284	0.377	0.644	0.236	0.581
13.	Lohit	0.248	0.131	0.180	0.684	0.662	0.556
14.	Anjaw	0.025	0.054	0.076	0.684	0.121	1.000
15.	Changlang	0.628	0.461	0.589	1.000	0.955	0.773
16	Tirap	1.000	0.448	0.729	0.000	0.000	0.672

Table III. Normalized indicators for Adaptive Capacity

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Sl. No.	Districts	% of population BPL	Land area in sq. km	Electrical Power Consumption (kwh per capita)	Population	Decadal growth rate(2001-2011)	Female % of total population	Literacy rate	% of Urban population	Primary stage	Secondary education	Tertiary education
1.	Tawang	0.07	0.93	0.92	0.73	0.79	0.25	0.50	0.58	0.88	0.00	0.66
2.	West Kameng	0.25	0.48	0.79	0.43	0.90	0.51	0.19	0.82	0.70	0.77	0.76
3.	East Kameng	0.38	0.76	0.98	0.58	0.70	0.45	0.66	0.48	0.70	0.84	0.00
4.	Papum pare	0.65	0.87	0.00	0.03	0.92	0.97	0.00	0.00	0.00	0.51	0.56
5.	Lower Subansiri	0.35	1.00	0.92	0.59	0.59	0.43	0.23	0.56	0.55	0.79	0.92
6.	Kurung Kumey	1.00	0.36	0.99	0.70	0.00	0.33	1.00	0.56	0.57	0.96	0.49
7.	Uppper Subansiri	0.27	0.51	0.96	0.59	0.58	0.43	0.44	0.44	0.38	0.78	0.11
8.	West Siang	0.46	0.46	0.93	0.18	0.98	0.82	0.22	0.60	0.29	0.48	0.16
9.	East Siang	0.38	0.71	0.95	0.32	0.93	0.69	0.20	0.51	0.54	0.57	0.85
10	Upper Siang	0.68	0.58	0.97	0.78	1.00	0.22	0.45	1.00	0.84	0.92	1.00
11	Dibang Valley	0.10	0.00	0.97	1.00	0.97	0.00	0.37	1.00	1.00	1.00	0.64
12	Lower Dibang Valley	0.28	0.78	0.97	0.63	0.99	0.36	0.22	0.61	0.80	0.83	0.23
13	Lohit	0.00	0.14	0.89	0.00	0.90	0.97	0.24	0.58	0.41	0.60	0.99
14	Anjaw	0.00	0.14	1.00	0.91	0.92	0.09	0.71	1.00	0.94	0.99	0.46
15	Changlang	0.33	0.71	0.89	0.00	0.88	1.00	0.41	0.81	0.50	0.72	0.70
16	Tirap	0.31	0.91	0.93	0.21	0.94	0.79	0.63	0.70	0.49	0.72	0.00

C. Analytical Hierarchy Process (AHP)

The Analytic Hierarchy Process is due to Saaty (1980) and is often referred to, eponymously, as the Saaty method. The AHP is used under the present approach for making priorities and assigning weights to the selected vulnerability domains and indicators.One of the most common scales for assigning of weight is the Saaty Rating scale (Table. 4). Using AHP pairwise comparison, the weights of the indicators have been assigned and a weight matrix is generated. The nth root of product of the entries in each row of the matrix was calculated. The nth roots for all indicators are summed and the eigenvector corresponding to each indicator is calculated by dividing each value of nth root of product by its total. The next stage is to calculate λ_{max} as to lead to the Consistency Index and the Consistency Ratio. Each row of weight matrix is multiplied by the eigenvector to get a new vector. To estimate λ_{max}, each component of new vector is divided by

the corresponding eigenvector element. The mean of these values gives λ_{max}. The Consistency Index for a matrix is calculated as below:

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$$CI = (\lambda_{max} - n)/(n-1) \quad (7)$$

The final step is to calculate the Consistency Ratio (CR) to measure how consistent judgment has been made.The CI for the different size of weight matrixare available in the Saaty's book. CR can be obtained as follows:

$$CR = CI/CI_{table} \quad (8)$$

If the value of CR is found to be less than 0.1 the judgment is trustworthy. And if the CR is greater than 0.1 the judgment are untrustworthy because they are too close for comfort to randomness and the exercise is valueless or must be repeated.

Table IV. The Saaty Rating Scale

Intensity of importance	Definition	Explanation
1	Equal Importance	Two factors contribute equally to the objective.
3	Somewhat more important	Experience and judgment slightly favor one over the other.
5	Much more important	Experience and judgment strongly favor one over the other.
7	Very much more important	Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice.
9	Absolutely more important	The evidence favoring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed.

IV. Results and Discussions

A. *Assigning of weights*

Using the Analytical Hierarchy Process, weights corresponding to the selected indicators for hazard, exposure and adaptive capacity were assigned. The consistency ratios were calculated for all three cases and were found less than 0.1. So, the assigned weights are trustworthy. Assigned weights for indicators of hazard, exposure and adaptive capacity are shown in Table. 5, 6 and 7 respectively. In Eqn.3, entering the normalized values of indicators for hazard from Table1. and corresponding weights from Table. 4, commensurate composite indicator of hazard at a particular district was calculated. The composite hazard values for all 16 districts of Arunachal Pradesh are shown in Table. 8. Similarly, the composite exposure and adaptive capacity values for all 16 districts were calculated using Eqn. 4 & 5 respectively and the values are shown in Table 9 & Table 10. Table 8 shows that the values of hazard are greater than 0.5 for seven districts i.e. Papumpare, Lohit, Changlang, East Kameng, East Siang, West Siang and Upper Subansiri. Table 9 shows that the values of exposure are greater than 0.5 for two districts i.e. Changlang and Anjaw. Table 10 indicates that the values of adaptive capacity are lesser than 0.5 for thirteen districts i.e. Upper Siang, Upper Dibang Valley, Anjaw, West Kameng, Lower Dibang Valley, Changlang, East Siang, Tawang, Lohit, East Kameng, Tirap, Lower Subansiri and KurungKumey.

Table V. Weight matrix for indicators of hazard assigned from Table IV

	Maximum rainfall for a given duration	Elevation of head quarter	Eigenvector or relative value vector
Maximum rainfall for a given duration	1.00	0.33	0.25
Elevation of head quarter	3.00	1.00	0.75

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Table VI. Weight matrix for indicators of exposure assigned from Table IV

	Density of population	% of agricultural land to total land	% of rain fed land	% of work force in agriculture	Cereal yield in qntls/ ha	% of rural population	Eigen vector
Density of population	1.00	0.20	1.00	0.20	0.33	0.14	0.04
% of agricultural land to total land	5.00	1.00	3.00	1.00	5.00	0.20	0.19
% of rain fed land	1.00	0.33	1.00	0.33	3.00	0.33	0.08
% of work force in agriculture	5.00	1.00	3.00	1.00	7.00	1.00	0.27
Cereal yield in qntls per ha	3.00	0.20	0.33	0.14	1.00	0.14	0.05
% of rural population	7.00	5.00	3.00	1.00	7.00	1.00	0.37

Table VII. Weight Matrix for Indicators of Adaptive Capacity Assigned from Table IV

	% of population BPL	Land area in sq.km	Electrical power consump- -tion (kwh per ha)	Population total	% of decadal growth rate (2001-2011)	Female % of total population	Literacy rate	% of urban population	Primary stage	Secondary stage	Tertiary stage	Eigen vector
% of population BPL	1.00	5.00	9.00	5.00	3.00	5.00	1.00	1.00	1.00	1.00	1.00	0.13
Land area in sq.km	0.20	1.00	7.00	1.00	0.33	0.33	0.14	0.20	0.11	0.14	0.20	0.02
Electrical power consumption	0.11	0.14	1.00	0.14	0.11	0.14	0.11	0.11	0.11	0.11	0.11	0.01
Population total	0.20	1.00	7.00	1.00	0.20	0.33	0.14	0.14	0.11	0.14	0.20	0.02
% of decadal growth rate(2001-2011)	0.33	3.00	9.00	5.00	1.00	1.00	0.14	0.14	0.11	0.14	0.20	0.04

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Female % of total population	0.20	3.00	7.00	3.00	1.00	1.00	0.20	0.20	0.14	0.20	0.33	0.04
Literacy rate	1.00	7.00	9.00	7.00	7.00	5.00	1.00	3.00	1.00	1.00	1.00	0.16
% of urban population	1.00	5.00	9.00	7.00	7.00	5.00	0.33	1.00	0.33	0.33	0.33	0.09
Total enrollment in primary educated	1.00	9.00	9.00	9.00	9.00	7.00	1.00	3.00	1.00	3.00	5.00	0.23
Total enrollment in secondary educated	1.00	7.00	9.00	7.00	7.00	5.00	1.00	3.00	0.33	1.00	3.00	0.16
Total enrollment in tertiary education	1.00	5.00	9.00	5.00	5.00	3.00	1.00	3.00	0.20	0.33	1.00	0.11

Table VIII. Hazard value for all the 16 Districts

Districts	Hazard
Tawang	0.06
West Kameng	0.19
East Kameng	0.75
Papumpare	0.79
Lower Subansiri	0.31
Kurung Kumey	0.19
Upper Subansiri	0.70
West Siang	0.71
East Siang	0.75
Upper Siang	0.30
Dibang Valley	0.37
Lower Dibang Valley	0.43
Lohit	0.76
Anjaw	0.44
Changlang	0.76
Tirap	0.46

Table IX. Exposure Value for all the 16 Districts

Districts	Exposure
Tawang	0.35
West Kameng	0.40
East Kameng	0.33
Papumpare	0.31
Lower Subansiri	0.42
Kurung Kumey	0.42
Upper Subansiri	0.31
West Siang	0.35
East Siang	0.39
Upper Siang	0.42
Dibang Valley	0.50
Lower Dibang Valley	0.45
Lohit	0.46
Anjaw	0.51
Changlang	0.60
Tirap	0.38

Table X. Adaptive Capacity value of all the 16 districts

Districts	Adaptive Capacity
Tawang	0.40
West Kameng	0.33
East Kameng	0.43

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Papumpare	0.62
Lower Subansiri	0.44
Kurung Kamey	0.47
Upper Subansiri	0.52
West Siang	0.54
East Siang	0.39
Upper Siang	0.20
Dibang Valley	0.21
Lower Dibang Valley	0.35
Lohit	0.42
Anjaw	0.22
Changlang	0.37
Tirap	0.43

B. *Determination of Vulnerability Hotspots for flood*

Assigned weights for indicators of vulnerability are shown in Table XI. In Eqn. 2, entering values of hazard, exposure and adaptive capacity from Table VIII, Table IX and Table X respectively, and corresponding weights from Table XI, vulnerability index for a particular district was calculated. The vulnerability indices for all 16 districts of Arunachal Pradesh are shown in Table XII. Table XII and Fig. 2 shows that the vulnerability indices are greater than 0.5 for three districts i.e. East Siang, Lohit and Changlang. Flood prone area percentages for 16 districts are presented in Table XIII as obtained from water resource department of Arunachal Pradesh in 2011. Based on these percentages and vulnerability indices (Table XIII), 16 districts can be categorized into four groups: 1. vulnerable and flood prone, 2. vulnerable but not flood prone, 3. not vulnerable but flood prone and 4. not vulnerable and not flood prone. Table XIV presents the name of districts under each category. Using vulnerability analysis of this study, for East Siang, Lohit, and Changlang vulnerability indices were found greater than 0.5. For East Kameng and West Siang vulnerability indices were moderately high i.e., 0.45 and 0.43. For Lower Dibang Valley, VI was found as 0.38.

Table XI. Weight assignment for indicators of vulnerability

	Hazard	Exposure	Adaptive capacity	Eigen vector
Hazard	1.00	3.00	5.00	0.64
Exposure	0.33	1.00	3.00	0.26
Adaptive capacity	0.20	0.33	1.00	0.10

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Table XII. Vulnerability for all the 16 districts

Districts	Vulnerability
Tawang	0.00
West Kameng	0.13
East Kameng	0.45
Papumpare	0.38
Lower Subansiri	0.23
Kurung Kumey	0.13
Upper Subansiri	0.36
West Siang	0.43
East Siang	0.59
Upper Siang	0.25
Dibang Valley	0.39
Lower Dibang Valley	0.38
Lohit	0.73
Anjaw	0.49
Changang	1.00
Tirap	0.32

Fig. 2 Map Indicating Vulnerability in the 16 Districts

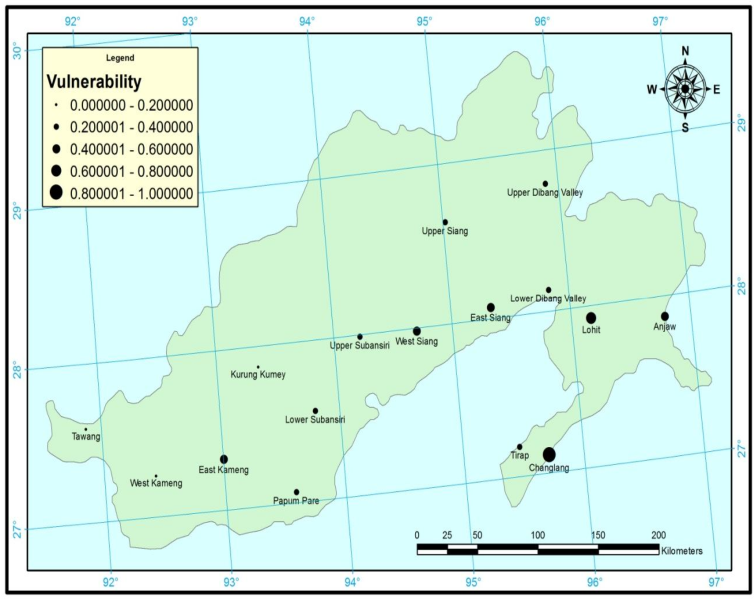

Table XIII. Flood Prone percentages

District	Flood prone percentages
Tawang	0.58
West Kameng	3.91
East Kameng	6.95
Papumpare	15.97
Lower Subansiri	16.40
Kurung Kumey	1.13
Upper Subansiri	3.07
West Siang	5.56
East Siang	35.47

Table XIV. Grouping of Districts

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Upper Siang	1.37
Dibang Valley	0.50
Lower Dibang Valley	42.56
Lohit	18.44
Anjaw	0.76
Changlang	6.76
Tirap	14.61

Group	VI	FPA (%)	Districts
1. Vulnerable and flood prone	> 0.5	> 15	Lohit, East Siang
2. Vulnerable but not flood prone	> 0.5	< 15	Changlang
3. Not vulnerable but flood prone	< 0.5	> 15	Papumpare, Lower Subansiri, Lower Dibang Valley
4. Not vulnerable and not flood prone	< 0.5	< 15	Tawang, KurungKumey, West Kameng, Upper Siang,Tirap,Upper Subansiri, Dibang Valley, West Siang, East Kameng, Anjaw

V. CONCLUSION

Among 16 districts of Arunachal Pradesh, the vulnerability indices are greater than 0.5 for three districts i.e. East Siang, Lohit and Changlang. Lohit and East Siang districts are both vulnerable and flood prone. Changlang district is vulnerable but not flood prone. Papumpare, Lower Subansiri and Lower Dibang Valley districts are not vulnerable but flood prone. Tawang, KurungKumey, West Kameng, Upper Siang, Tirap, Upper Subansiri, Dibang Valley, West Siang, East Kameng and Anjaw districts are not vulnerable and also not flood prone.

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