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Iyengar-sudarshan method application to drought social vulnerability: Free State Province, South Africa

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ABSTRACT

Free State province is one of the few provinces that was declared drought disaster-struck in 2015. This province is said to be the bread-basket of South Africa therefore protecting it and its human capital is crucial. Social vulnerability to drought was assessed in this study using Iyengar-Sudarshan method. The objective of the study was to; determine municipalities that are socially prone to drought disaster impacts and help with resource mobilisation and allocation in drought relief programmes. Indicators were drawn from Census (2011) data available online. The study appliedIyengar-Sudarshan method in vulnerability computation and munipalities grouped by statistical K-means clustering. The results showed major municipalities in the province less vulnerable compared to the rest of other municipalities. The results concur with reality where Mangaung, Metsimaholo and Matjhabeng are some of the largest municipalities in the province. However, about 80% of the municipalities in this province are prone to devastating effects of climate change variability. This implies that an attention should be given to areas with high population such a Maluti a Phofung which harbours the highest number of agricultural households in the province and all other areas in accordance with vulnerability levels.

***Key words** : Iyengar-Sudarshan method, Drought, Vulnerability index, Disaster,*

Introduction

Drought is such a complicated, hard to define phenomenon which is defined differently in different regions depending on the average precipitation an area is accustomed to (National Geographic Society, 2016). National Weather Services (2016) defined drought as deficiency in precipitation over an extended period of time normally over a season or more resulting in water shortages that negatively impacts on crops, animals and people. However according to Monacelli (2005) there are only two definitions of drought; conceptual and operational. The conceptual drought definition is formulated in such a way to help people understand what drought is while operational definition aimed at helping people identify beginning, degree of severity and the end of drought (Monacelli, 2005). Drought insidious nature results in other natural and manmade disasters such as food insecurity, famine, malnutrition, epidemics and displacement of communities (International Federation of Red Cross and Red Crescent Societies (IFRC), 2014: United Nations Convention to Combat Desertification, 2015). According to Wilhite and Glantz (1985) drought has various classifications. Meteorological drought which refers to significant decrease in expected precipitation as determined by Palmer Drought Severity IndexC (PDSI) (Zarafshani *et al*. 2016). Agricultural drought is another type of

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drought that links characteristics of meteorological and hydrological drought whose impacts affects crops growth. Hydrological drought is associated with effects of precipitation on streamflow, reservoir and lake levels and groundwater (National Drought Mitigation Center, 2016). Figure 1 below shows the cause and the inter-link of drought types.

Prior to any actions to be taken in disaster reduction initiatives, vulnerability assessment is of key importance in identifying risk reduction measures to prevent or lessen effects of expectedhazards and risks (IFRC, 2014). Various scholars define vulnerability differently depending on their aims and objectives and methodologies employed within individual context (Zarafshani *et al*. 2016). Global Network of Civil Society Organisations for Disaster Reduction (GNDR), 2015) define vulnerability as an inability of people or communities to respond to events which make them susceptible to calamities. Understanding of vulnerability requires quite more than simply communities' past and present relations with disasters. It should be about people's knowledge, perceptions of risks they are often experience (Singh *et al.* 2014). Vulnerability therefore exists in various dimensions one of which is social vulnerability. According to Singh *et al*. (2014) social vulnerability is determined by various factors such as physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. Poverty, occupation, caste, ethnicity, exclusion, marginalization and inequities in material consumption of a society or community also enhance social vulnerability. The current study used BBC vulnerability model as conceptual framework. Vulnerability in this framework is viewed from three pillars of sustainable development; social, economic and environmental dimensions. It is therefore de-

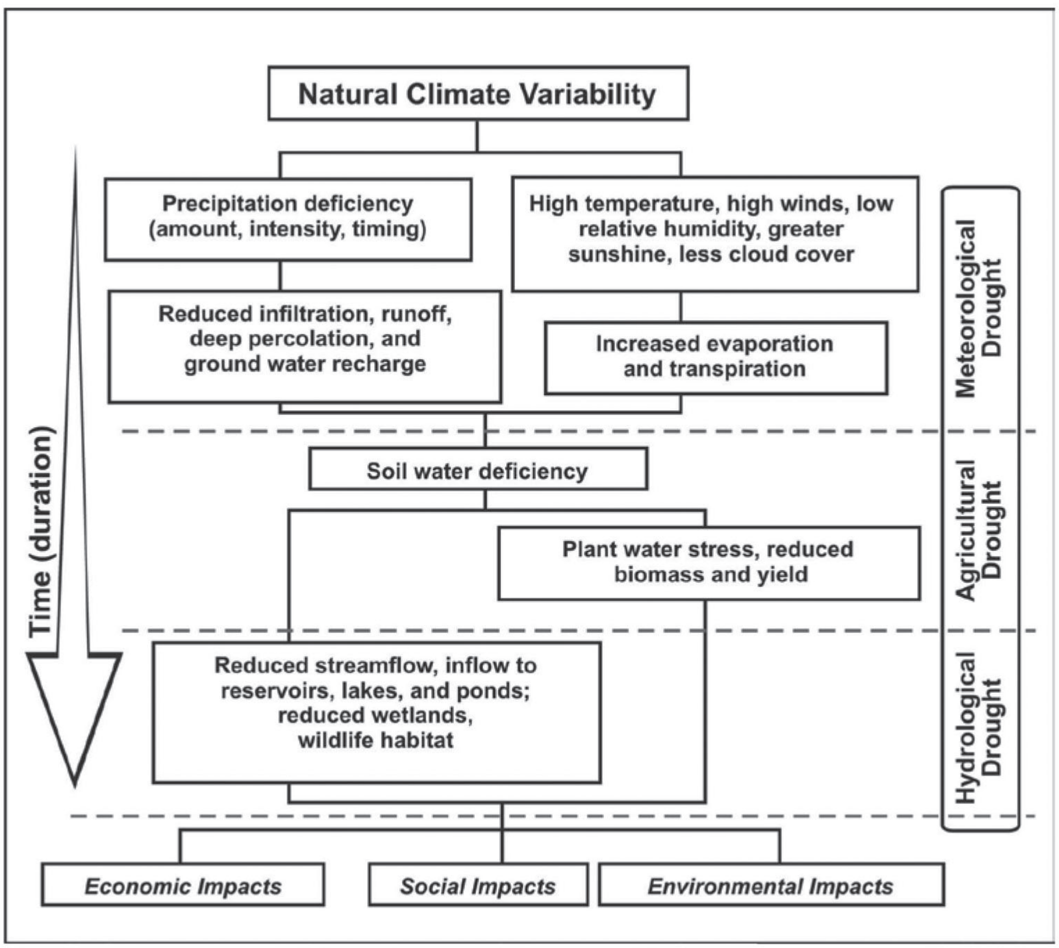

Fig. 1. Sequence of drought occurrence and impacts
Source: National Drought Mitigation Center, 2016.

fined as a function of both exposure and coping capacity (Birkmann, n.d). In this framework, vulnerability is viewed from a specific hazard in all the three sustainable development spheres. The advantage of this model is that once dimension specific risks are identified, an action is activated before (t=0) any disaster strikes hence preparedness measures taken. Mitigation actions do not only end before disasters but also after disasters (t=1). In 2015, the Free State province government declared a state of drought risk disaster which was extended into 2016. Therefore the current study measures the degree to which individual local municipalities could be affected by drought.

Description of the Study Area

Mangaung Metropolitan Municipality is a home to the capital of the Free State province located in Bloenfontein. This municipality embraces Thaba Nchu and Botshabelo towns, the three of which fall within Motheo district (Free State Development Corporation (FDC), 2016).Mangaung Metropolitan Municipality is a Category A municipality. It is situated in the Free State province, in the central interior of South Africa. The Free State is bordered by the Gauteng, Eastern Cape, Northern Cape, KwaZulu-Natal and North West provinces, as well as by the neighbouring country of Lesotho. Mangaung, meaning 'Place of the Cheetahs', accentuates the vibrant, dynamic and energetic character of the tourism industry in the 'At the Heart of it All'(Department of Local Government, 2016). The economy is strongly driven by the government sector, which has seen the fastest growth in the last five years as a result of increased government programmes in livelihoods improvement interventions. The finance sector is the second-fastest growing sector due to very active estate and construction activities(Department of Local Government, 2016). Small businesses have a major role to play in the South African, and especially the Mangaung, economy in terms of employment creation, income generation and output growth. It is estimated that more than 12 million people in South Africa are actively involved in the SMME sector, which accounts for approximately 60% of all employment in the economy and 40% of output(Department of Local Government, 2016). In an area such as Mangaung, with its relatively high levels of unemployment and poverty, it can be expected that the SMME sector plays an even more important role in job creation and poverty alleviation. The informal economy makes an important contribution to the economic and social life of Mangaung. Due to the decline in formal employment and consequent increase in unemployment, many people seek alternative means of earning an income (Department of Local Government, 2016: Stats SA, 2011).Approximately 87% of economic production in Mangaung occurs in Bloemfontein while only 7% and 6% respectively occur in Botshabelo and Thaba Nchu. The dominant economic sector is agriculture in this province (South Africa Local Government Association, 2011). The figure below shows the map of Free State province and location of Bloemfontein where Mangaung municipality is located.

Fig. 2. Map of Free State province and location Mangaung municipality in Bloemfontein Source: Google maps, 2016

Methods and Materials

The study collected online data from census (2011). The researcher selected only relevant data according to the selected indicators that contribute significantly to drought vulnerability. This study included all twenty municipalities from five districts in Free State province. In 1982, Iyengar and Sudarshan developed a method to compute a composite vulnerability index from multivariate data in ranking districts (Kumar *et al*. 2014). Table 1 shows the selected drought vulnerability indicators from StatSa (2011) in accordance with the BBC vulnerability conceptual framework where vulnerability is defined in terms of exposure and coping capacity.

Table 1. Selected drought vulnerability indicators

Selected variable and dimension	Explanation	Functional relationship with vulnerability	Source
Young (0-4) % (exposure)	Children are most vulnerable groups to climate change effects	Increase vulnerability	UNICEF, 2011:Cutter, 2013
Working age (15-64) % (capacity)	This group is moresusceptible to harm	Decreasevulnerability	Cutter, 2013
elderly(65+)% (exposure)	This group is more susceptible to harm	Increase vulnerability	Cutter, 2013
Dependency ratio (exposure)	Families with large number of dependents face difficulty in feeding members during droughts	Increase vulnerability	Belle and Hlalele, 2015
Unemployment rate% (exposure) Youth unemployment rate% (exposure)	Capacity to cope during drought is reduced when people are not working	Increase vulnerability	Belle and Hlalele, 2015
No schooling (20+)%	This is more vulnerable	Increase vulnerability	Adger *et al.*2004
higher education(20+)%	This group has a strong capacity to adapt to changes through knowledge	Decrease vulnerability	Adger *et al.* 2004
Matric aged 20+ % (capacity)	The least and lower educated members aremore vulnerable	Decrease vulnerability	Adger *et al.*2004
No. agric households (exposure)	This indicator increases exposure to drought effects	Increase vulnerability	Belle and Hlalele, 2015
Average household size(exposure)	Families with larger sizes have difficulties in feeding their members	Increase vulnerability	IFAD, 2009
Female headed households (exposure)	Care givers, lower wages	Increase vulnerability	Cutter, 2013
Flush toilets (exposure)	Toilets are larger users of water, communities with high number of flush toilets are most vulnerable to during drought	Increase vulnerability	Author, 2016

Source: StatSA, 2011

Vulnerability index construction methods are developed from two main methods; methods with equal weights and methods with unequal weights (Bhattacharjee and Wang, 2010). Iyengar and Sudarshan's Method is one with unequal weights, which ensures that large variation in any one of the indicators does not unduly dominate the contribution of the rest of the indicators thereby distort regional comparisons (Anon, 2016). The values of computed vulnerability range between 0 and. The values 0 and 1 indicate no and maximum vulnerability respectively.

Drought vulnerability indicators bear various units, and for this reason all indicators' values must be normalised according to the functional relationship each indicator has with vulnerability. For increasing and decreasing functional relationship with vulnerability, normalisation was done using the formulae respectively;

$$Xij = \frac{Xij - Min\{Xij\}}{Max\{Xij\} - Min\{Xij\}} \quad .. (1)$$

and

$$Xij = \frac{Max\{Xij\} - Xij}{Max\{Xij\} - Min\{Xij\}} \quad .. (2)$$

Where Xij is the value of the indicator j, corresponding to region i.

After indicator value normalisation, the Iyengar-Sudarshan vulnerability index equation was applied as;

$$VI = \sum_{j=1}^{k} wjXij \quad .. (3)$$

Where w's (0< w <1 an $\sum_{j=1}^{k} wj = 1$) are weights. These weights are assumed to vary inversely with variance over regions in the respective indicators on vulnerability. The weights are therefore determined as;

$$wj = \frac{c}{\sqrt{variance(xij)}} \quad .. (4)$$

Where c, is the normalising constant such that;

$$c = \frac{1}{\sum_{j=1}^{j=k} \frac{1}{\sqrt{variance(xij)}}} \quad .. (5)$$

$$f(z) = \frac{z^{a-1}(1-z)^{b-1}}{\beta(a,b)},\ 0 < z < 1 \ and \ a,b > 0. \quad .. (6)$$

In this method, suitable probability distribution is needed which takes values in the range [0, 1] and such a distribution is Beta probability distribution which is generally skewed. The density function of this function is given as;

Where $\beta(a,b)$ is a beta function defined by;

$$\beta(a,b) = \int_a^1 x^{a-1}(1-x)^{b-1}\,dx \quad .. (7)$$

Give the skewness of beta distribution, the following fractile intervals can be used in vulnerability stage characterisation;

After vulnerability index computation for each municipality as in equation (3), k-means clustering using IBM Statistics SPSS V.24 was applied to classify municipalities according to their vulnerability indices. A single index was obtained for each cluster to fit into the stages of vulnerability as shown in Table 2.

Table 2. Fractal stages of vulnerability (%)

Less vulnerable	0<VI<20
Moderate Vulnerable	20<VI<40
Vulnerable	40<VI<60
Highly Vulnerable	60<VI<80
Very highly Vulnerable	80<VI<100

Table 3. K-means clustering of Municipalities' vulnerability

Cluster Membership						
Case Number	Municipality	Cluster	Distance index	Vulnerability	Cluster Average Vulnerability index value	Vulnerability index category
1	Tokologo Local	1	.030	0.463	0.51=51% Vulnerable	
2	Moqhaka Local	1	.042	0.564		
3	Ngwathe Local	1	.059	0.545		
4	Masilonyana Local	1	.040	0.475		
5	Mantsopa Local	1	.054	0.452		
6	Nketoana Local	1	.054	0.559		
7	Phumelela Local	1	.021	0.527		
8	Setsoto Local	1	.055	0.561		
9	Kopanong Local	1	.026	0.479		
10	Letsemeng Local	1	.076	0.429		
11	Mafube Local	2	.030	0.595	0.62=62% Highly vulnerable	
12	Nala Local	2	.084	0.708		
13	Maluti-A-Phofung Local	2	.025	0.691		
14	Tswelopele Local	2	.067	0.599		
15	Mohokare Local	2	.050	0.574		
16	Naledi local	2	.045	0.579		
17	Mangaung Metropolitan	3	.058	0.241	0.30=30% Moderately vulnerable	
18	Metsimaholo Local	3	.060	0.238		
19	Dihlabeng Local	3	.075	0.342		
20	Matjhabeng Local	3	.044	0.374		

Table 4. ANOVA Test results

Cluster		Error		F	Sig.
Mean Square	df	Mean Square	df		
.127	2	.003	17	38.978	.000

Results and Discussion

Table shows the results of clustering, where 80% of the municipalities in the Free State are either vulnerable or highly vulnerable. Results also reveal major municipalities in the province having moderate vulnerability levels showing that an attention should be paid smaller rural municipalities. Maluti a phofung local municipality, the highly populated with number of households dependent on agriculture for livelihood (Census, 2011) is one of the highly vulnerable municipalities in the province. This province constitutes 18% of the total population of agriculture households in the whole province. From the results above, an attention must be focused on the most vulnerable municipalities. Table 4 confirms that the clustering results are significant.

Conclusion

In conclusion, the results show major municipalities in the province less vulnerable compared to the rest of other municipalities. The results concur with reality where Mangaung, Metsimaholo and Matjhabeng are some of the largest municipalities in the province. However, about 80% of the municipalities in this province are prone to devastating effects of climate change variability. This implies that an attention should be given to areas with high population such a Maluti a Phofung which harbours the highest number of agriculture households in the province and all other areas in accordance with vulnerability levels.

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