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A multi-dimensional drought risk analysis in the Free State drought-hit municipalities, South Africa

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ABSTRACT

Drought causes about 78% of all natural disasters related deaths in Africa (Disaster Management Training and Education Centre for Africa. Specifically in South Africa, rainfall climate is of great variability with very wide fluctuations in seasonal rainfall deviations since 1960 giving a need for rainfall deficit assessment. Following a drought disaster declaration in some provinces of South Africa, the water and sanitation minister of South Africa, Nomvula Mokonyane signed a memorandum of understanding with the Danish government in combating the challenges of water in South Africa. For better and effective resources allocation mobilization, a risk assessment is vital, therefore this study aimed at assessing drought risk for all municipalities in the Free State drought-hit. Data was collected from Statistics South Africa in quantifying vulnerability. A Patnaik and Narain Method was used in computing the composite vulnerability index. In order to calculate risk level, hazard assessment done by the author was adopted, where each municipality's severity value was computed. Drought hazard analysis was computed from four input parameters namely; precipitation, temperature, wind speed and relative humidity. The results showed the drought risk highest in the northern and eastern parts of Free State province indicating that it is actually imperative that emergency responses consider these parts before any other part of the province. The northern and eastern parts of this province is where most farms are located.

Key words : *Disaster, Risk analysis, Drought, Vulnerability, Patnaik and Narain Method*

Introduction

"Another important lesson is that it is human beings – not nature – that determine whether a hazard poses a threat to the well-being of society. How people view both hazards and mitigation *factors, and how other stakeholders respond to these issues, will determine which preventative measures are taken and which are overlooked. As such, human beings will decide their vulnerability and capacity quotient to accept disaster losses"* (IFRC, 2015). In the 21st century, there is an exponential growing share of devastations triggered by natural disasters that stem from ecological destructive human activities and thereby putting ourselves in the harm's way. These include deforestation which have to date frayed our ecosystems which in turn destabilize climate (Thomas *et al*, 2013). Secondary to the destabilized climate is the evolution of droughts that produce a complex web of impacts which on the other hand ripple through several economic sectors (Wilhite and Svoboda, 2006). These authors continue to say that drought severity and frequencies may be similar over regions as historical events, but the impacts will always vary markedly due to societal changes. For an effective disaster management, disaster risk reduc-

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tion must be juxtaposed with vulnerability assessment. The latter is an important tool for supporting decisions made in relation to disaster preparedness and development of the mitigation programmes (IFRC, 2015). Given the close to homogeneous spatial extent of drought hazard in the Free State Province as shown in the works of Hlalele *et al.*, (2015) the current study seeks to assess municipalities' risk levels drought in order to aid resource allocation throughout the entire province.

Literature review

The following section reviews definitions related to disaster risk management and gives an overview of the current situation in South Africa with regard to drought disaster that is prevailing at the present moment.

Hazard is defined as anything that may pose danger and has a potential to negatively impact on human health, property, activity and or environment (Health Disaster Management, 2002: Department of Home Affairs, 2015). Vulnerability refers to factors ranging from social, economic, environment and physical, which increase the susceptibility of a system to be adversely impacted by a hazard (World Meteorological Organisation, 2015). Similarly, UNISDR, (2009:30) define vulnerability as circumstances and characteristics of a system, asset or community that make it prone to damaging effects of a hazard. Finally, Disaster riskis a potential disaster loss in assets, livelihood, health status, services and lives that takes place in a particular community over specific time period (UNISDR, 2009). On the other hand Disaster Risk (DR) can be defined as a product of Hazard (H) and Vulnerability (V) (Wisner *et al*., 2004).

According to Pelling and Holloway, (2006) (quoted by Department of Environmental Affairs, 2014) South Africa has actually made an emphasis to move from crises management and reactive approaches to proactive approach in managing disasters with strong institutional frameworks which include, the South African Disaster Management Act No. 52 of 2002 and National Disaster Management Framework. Despite the presence of the above mentioned frameworks, in 2015 South Africa was declared to have been hit by drought disaster in its five provinces (Anon, 2015). According to South African Government, (2012) the Free State province is said to be the "bread basket" of South Africa and about 90% of its land is under crop production. This province which produced 44% of the nation's corn in 2014 has declared to be drought hit by the worst drought since 1992 (Mokhema, 2015). In a study undertaken by Hlalele *et al.* (2015) on drought hazard assessment for the Free State province whose aims was aid resources allocation mobilization by disaster mangers and political authorities, all municipalities were found to have felt almost homogenous effects of drought though the northern to eastern parts of the province ranked top.

Materials and Methods

To calculate disaster risk for each municipality in the Free State province, hazard and vulnerability analysis must be done. Hazard analysis from the work of Hlalele *et al*., 2015 on *Bi- hazard assessment for timely and effective disaster management: Free State disaster area 2015* was adopted. This was coupled with vulnerability assessment results whose source of data was Statistics South Africa census in 2011. Firstly, a Patnaik and Narain Method (Patnaik and Narayanan, 2005) was applied where indicators are selected from the sources and dimensions they come from as indicated in Table 1. For this study, only two sources were selected. The two sources of vulnerability that were selected were; demographics and agriculture as shown in table 1 below. All the selected variables were coded and assigned a sign depending on the functional relationships they have with vulnerability as shown in Table 2 below. All the chosen variables were normalised according to their functional relationship with vulnerability.

For all indicators that have an increasing relationship with vulnerability

$$x_{ij} = \frac{X_{ij} - \underset{i}{Min}\{X_{ij}\}}{\underset{i}{Max}\{X_{ij}\} - \underset{i}{Min}\{X_{ij}\}} \quad .. (1)$$

Where Xijis the value of the indicator *j* corresponding to region *i*. Similarly those with a decreasing relationship with vulnerability, the following formular was used

$$y_{ij} = \frac{\underset{i}{Max}\{X_{ij}\} - X_{ij}}{\underset{i}{Max}\{X_{ij}\} - \underset{i}{Min}\{X_{ij}\}} \quad .. (2)$$

After all normalizing all variables from the two sources, a source-wise index was determined and each municipality was ranked accordingly. To determine the overall vulnerability index, a mean

Table 1. A source-wise vulnerability indicator selection

	Source of vulnerability and code			
Dimension	Demographic	Code	Agricultural	code
Exposure	Human population	DE1	Livestock population	AE1
			Households involved in agricultural activities	AE2
			No access to piped water	AE3
Sensitivity	Elderly (65+)	DS1	Agric households (65+)	AS1
	Young (0-14)	DS2		
	Dependency ratio	DS3		
	Household size	DS4		
Adaptive capacity	Number of people employed	DA1	Agric households completed tertiary	AA1
			Water tanks	AA2
			Total Household in production of fodder	AA3

Table 2. Proxy variables and their functional relationship with vulnerability

	Proxy variables	code	Functional relationship with vulnerability
1.	Human population	DE1	(+)
2.	Elderly (65+)	DS1	(+)
3.	Young (0-14)	DS2	(+)
4.	Dependency ratio	DS3	(+)
5.	Household size	DS4	(+)
6.	Number of people employed	DA1	(-)
7.	Livestock population	AE1	(+)
8.	Household involved in agricultural activities	AE2	(+)
9.	No access to piped water	AE3	(-)
10.	Agric households age(65+)	AS1	(+)
11.	Agric households completed (> grade 12)	AA1	(-)
12.	No with rain-water tanks	AA2	(-)
13.	Total Household in production of fodder	AA3	(-)

KEY (+) Increases with increasing vulnerability, (-) Decrease with increasing vulnerability

value from the two sources was determined for municipality. Taking the results of Hlalele *et al.* (2015) (severity values) on drought hazard on the same municipalities, a disaster risk index was computed from equation 3 below. Then all municipalities were ranked on their risk values.

$$DR = H \times V \quad .. (3)$$

Results and Discussion

The table below shows the selection of vulnerability indicators and their dimensions.

From the Tables 4 and 5 above and below respectively, it can be seen that Tswelopele and Nala are the most vulnerable municipalities demographically and both rank in the top ten of all municipalities in the Free State province. These top most vulnerable municipalities are located in the northern and eastern parts of the province. This is where most of the maize production in the Free State is located, places such Cornelia (Agri village) and Delpotrus farm where the Member of the Executive Council (MEC) of Agriculture visited and distributed over 300 bags of animal feed to emerging farmers.

To test for any correction between sources of vulnerability, both Spearman's rho and Kendall's tau were used through the aid of SPSS. A two tailed test was employed at 5% level of significance, however, the hypothesis that the two sources were related was rejected since both 0.650 (Kendall's tau) and 0.574 (Spearman's rho) are greater than 5% level of significance. This shows that more sources of vulnerability should be included to bring about more reliable results.

Tswelopele, Nala, Mafube and Ngwathe, Nketoana and Masilonyane municipalities are the

Table 3. Normalised indicators

		Source of vulnerability														
		Demographic							Agricultural							
	Municipality	DE1	DS1	DS2	DS3	DS4	DA1	Source aver	AE1	AE2	AE3	AS1	AA1	AA2	AA3	Source aver
1	Dihlabeng	0.1444	0.3226	0.4133	0.4510	0.2500	0.8594	0.4068	0.3255	0.1856	0.7442	0.1634	0.8070	0.8383	0.8087	0.5533
2	Kopanong	0.0344	0.7742	0.4533	0.6422	0.0000	0.9681	0.4787	0.1049	0.0375	0.9873	0.0437	0.9590	0.9820	0.9343	0.5784
3	Letsemeng	0.0198	0.3226	0.4533	0.4853	0.3750	0.9786	0.4391	0.0066	0.0162	0.9796	0.0114	0.9876	0.9641	0.9566	0.5603
4	Mafube	0.0464	0.6129	0.7067	0.8235	0.5000	0.9659	0.6092	0.0718	0.0352	0.9582	0.0518	0.9749	0.8623	0.9852	0.5628
5	Maluti a Phofung	0.4307	0.2903	0.8533	0.8284	0.3750	0.7675	0.5909	0.7384	1.0000	0.0000	1.0000	0.0001	0.0000	0.4635	0.4574
6	Mangaung	1.0000	0.2903	0.0800	0.1520	0.1250	0.0000	0.2745	1.0000	0.8886	0.3262	0.7509	0.0000	0.6467	0.0000	0.5160
7	Mantsopa	0.0370	0.3226	0.7333	0.7304	0.3750	0.9657	0.5273	0.0718	0.0423	0.9631	0.0391	0.9628	1.0000	0.9785	0.5797
8	Masilonyana	0.0540	0.4516	0.4667	0.5392	0.3750	0.9677	0.4757	0.0450	0.0522	0.9697	0.0491	0.9582	0.9701	0.9421	0.5695
9	Matjhabeng	0.5285	0.0968	0.1333	0.1275	0.1250	0.5415	0.2588	0.3015	0.3003	0.8438	0.2121	0.6864	0.9222	0.6636	0.5614
10	Metsimaholo	0.1726	0.0000	0.0000	0.0000	0.1250	0.8090	0.1844	0.0087	0.0771	0.9851	0.0502	0.9046	0.9880	0.9160	0.5614
11	Mohokare	0.0136	0.6452	0.7867	0.9118	0.1250	0.9858	0.5780	0.0545	0.0120	1.0000	0.0164	0.9935	0.7725	1.0000	0.5498
12	Moqhaka	0.1884	0.6774	0.0933	0.2892	0.2500	0.8488	0.3912	0.2052	0.1081	0.9362	0.1005	0.8736	0.8922	0.7822	0.5569
13	Nala	0.0787	0.4516	0.8533	0.8873	0.8750	0.9466	0.6821	0.0866	0.0663	0.9862	0.0767	0.9555	0.9940	0.8641	0.5757
14	Naledi-FS	0.0000	0.7742	0.8267	1.0000	0.1250	1.0000	0.6210	0.0000	0.0223	0.9802	0.0300	0.9905	0.9581	0.9831	0.5663
15	Ngwathe	0.1330	1.0000	0.5067	0.7794	0.2500	0.8990	0.5947	0.2035	0.1419	0.9659	0.1549	0.8602	0.8802	0.7744	0.5687
16	Nketoana	0.0498	0.4516	0.8000	0.8480	0.5000	0.9581	0.6013	0.2031	0.0735	0.6986	0.0786	0.9455	0.8683	0.9425	0.5443
17	Phumelela	0.0324	0.5161	0.7200	0.7941	0.7500	0.9712	0.6307	0.2711	0.0589	0.8168	0.0602	0.9618	0.7006	0.9156	0.5407
18	Setsoto	0.1221	0.4516	0.7733	0.8245	0.3750	0.9190	0.5776	0.3066	0.1602	0.9032	0.1496	0.8552	0.8144	0.8228	0.5731
19	Tokologo	0.0065	0.4839	0.6533	0.7157	0.2500	0.9909	0.5167	0.0166	0.0000	0.9785	0.0000	1.0000	1.0000	0.9855	0.5687
20	Tswelopele	0.0322	0.3226	1.0000	0.9902	1.0000	0.9760	0.7202	0.0138	0.0240	0.9780	0.0240	0.9879	0.9760	0.9541	0.5654

Table 4. Vulnerability source-wise ranking of municipalities

	Source of vulnerability				
	Municipality	Demographic	Rank	Agricultural	Rank
1	Dihlabeng	0.4068	16	0.5533	15
2	Kopanong	0.4787	13	0.5784	2
3	Letsemeng	0.4391	15	0.5603	13
4	Mafube	0.6092	5	0.5628	10
5	Maluti a Phofung	0.5909	8	0.4574	20
6	Mangaung	0.2745	18	0.5160	19
7	Mantsopa	0.5273	11	0.5797	1
8	Masilonyana	0.4757	14	0.5695	5
9	Matjhabeng	0.2588	19	0.5614	11
10	Metsimaholo	0.1844	20	0.5614	12
11	Mohokare	0.5780	9	0.5498	16
12	Moqhaka	0.3912	17	0.5569	14
13	Nala	0.6821	2	0.5757	3
14	Naledi-FS	0.6210	4	0.5663	8
15	Ngwathe	0.5947	7	0.5687	6
16	Nketoana	0.6013	6	0.5443	17
17	Phumelela	0.6307	3	0.5407	18
18	Setsoto	0.5776	10	0.5731	4
19	Tokologo	0.5167	12	0.5687	7
20	Tswelopele	0.7202	1	0.5654	9

most at risks of drought however it can also be deduced that these municipalities are located from central to the northern parts of the province towards the eastern parts.Mangaung Metropolitan Municipality ranks the last in terms of the overall risk level, this is probably because it is located in the capital city of the province. The figure shows the location of each municipality in the Free State province.

Fig. 1. Study area, Free state province showing municipalities.
Source: http://bgis.sanbi.org/municipalities/choose-muni.asp?prov=FS

Table 5. Municipality ranking in terms of vulnerability

	Municipality	Final vulnerability index	Rank
1	Dihlabeng	0.4800	16
2	Kopanong	0.5286	12
3	Letsemeng	0.4997	15
4	Mafube	0.5860	4
5	Maluti a Phofung	0.5242	13
6	Mangaung	0.3953	19
7	Mantsopa	0.5535	10
8	Masilonyana	0.5226	14
9	Matjhabeng	0.4101	18
10	Metsimaholo	0.3729	20
11	Mohokare	0.5639	9
12	Moqhaka	0.4740	17
13	Nala	0.6289	2
14	Naledi-FS	0.5936	3
15	Ngwathe	0.5817	6
16	Nketoana	0.5728	8
17	Phumelela	0.5857	5
18	Setsoto	0.5754	7
19	Tokologo	0.5427	11
20	Tswelopele	0.6428	1

Conclusion

In conclusion, most of the municipalities are homogenous in terms of the agricultural vulnerability,

Table 6. Correlations

			Demographic	Agricultural
Kendall's tau_b	Demographic	Correlation Coefficient	1.000	.074
		Sig. (2-tailed)	.	.650
		N	20	20
	Agricultural	Correlation Coefficient	.074	1.000
		Sig. (2-tailed)	.650	.
		N	20	20
Spearman's rho	Demographic	Correlation Coefficient	1.000	.134
		Sig. (2-tailed)	.	.574
		N	20	20
	Agricultural	Correlation Coefficient	.134	1.000
		Sig. (2-tailed)	.574	.
		N	20	20

Table 7. Drought risk ranking in the Free State municipalities

Municipality	Vulnerability (V)	Hazard (H)	Risk= VxH	Rank
Tswelopele	0.6428	12.96830775	8.3	1
Nala	0.6289	12.96830775	8.2	2
Mafube	0.5860	13.09263333	7.7	3
Ngwathe	0.5817	13.09263333	7.6	4
Tokologo	0.5427	12.96830775	7.0	5
Masilonyana	0.5226	12.96830775	6.8	6
Phumelela	0.5857	11.43368047	6.7	7
Setsoto	0.5754	11.43368047	6.6	8
Nketoana	0.5728	11.43368047	6.5	9
Mantsopa	0.5535	11.43368047	6.3	10
Moqhaka	0.4740	13.09263333	6.2	11
Naledi-FS	0.5936	10.23044146	6.1	12
Maluti a Phofung	0.5242	11.43368047	6.0	13
Mohokare	0.5639	10.23044146	5.8	14
Dihlabeng	0.4800	11.43368047	5.5	15
Kopanong	0.5286	10.23044146	5.4	16
Matjhabeng	0.4101	12.96830775	5.3	17
Letsemeng	0.4997	10.23044146	5.1	18
Metsimaholo	0.3729	13.09263333	4.9	19
Mangaung	0.3953	12.16679277	4.8	20

Source: Hlalele *et al.*, 2015

however a significant difference was seen in demographic source. There was also a vast difference in the drought severity as shown from Hlalele *et al.* (2015) work. One advantage of this study was that precipitation and temperature were used as observed data and as input parameters in the computation of the drought severity. These two form part of the climatic variables. However,it is therefore recommended that a further study is conducted whereby several other sources of vulnerability are considered in quantifying disaster risk levels. These results therefore serve as base for effective drought management in the future where areas of high vulnerability are identified and emanate mainly from demographic sources.

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