USING MULTI CRITERIA DECISION MAKING FOR HUMANITARIAN PLANNING DURING A LAST MILES RELIEF SUPPLY IN SADC

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ABSTRACT

Southern African Development Community (SADC) has seen an increase in drought disasters in the past decades causing thousands livestock's death, and triggering major foods, water shortages with related impacts on livelihood and businesses. With future prediction pointing toward aggravation of climate variability, this research intends to provide SADC and the world with a practical decision making mechanism capable of enhancing the effectiveness and efficiency of the regional relief operations. The study aims to optimize the pre-positioned relief supplies and demands in facility locations across SADC. The objective is to upgrade the regional humanitarian disaster planning and the drought disaster response capacities. The multi-criteria decision making (MCDM) and location criteria for site selection are utilized to minimize the multiple relief items, response times, capacity restrictions while maximizing the satisfied relief demand to the pre-positioned destinations.

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1 INTRODUCTION

A surge on natural disaster cases was encountered worldwide between 2002 and 2011, with 394 natural disasters recorded per annual average having killed 107 000 people, affecting 268 million people others, while causing an estimated US$ 143 billion's worth of damage [1]. A world Disasters report published in 2014 by the International Federation of Red Cross (IFRC) [2] showed the year 2013 as being the worst in recent time with a registered 337 natural disasters in 2013. According to [3], poor countries and areas are more vulnerable to disaster and are most severely affected than richer one. It is further estimated that 90% of all those affected by natural disasters are in countries of medium human development [4], and that two thirds of those killed are from countries of low human development [5].

FAO/WFP report presents Swaziland statistically as one of the most vulnerable country to climate variability in the SADC region [6]. This land locked country, with high poverty rate (63% in 2010/11), high unemployment levels and low Human Development Index, has a history of severe droughts that have affected over 80% of its rural-based population, which depend largely on subsistence farming and/or livestock rearing [7]. The 2015/2016 drought events alone have seen 5.5% of Swazi population in severe food and water insecurity and in urgent need of assistance, while another 18% with moderate food insecurity [6].

Although most African countries are in dire need of logistical support from the humanitarian community, [8] noted an absence of disaster planning in Africa. To mitigate such lack, this research provides SADC countries with both decision making and a methodological approach to disaster relief supply chain. A decision model is proposed for the optimization of decision making during a humanitarian planning of distribution centers. This study aims to optimize the pre-positioned relief supplies and demands decisions in facility locations across SADC in order to upgrade the regional drought disaster response capacities. This study outcome will likely guarantee an efficient and effective decision making during the inventory management for disaster response.

In order to accomplish the above aim, the following objectives will be addressed:

- The identification and quantification of drought impacts in SADC.
- The identification of the most appropriate locations for creating an efficient emergency response facility in the region.
- Determination of a multi-criteria decision making process with location criteria for site selection.
- Outline the results and ways to increase SADC drought disaster response with efficiency and effectiveness.

2 LITERATURE REVIEW

According to [9], 642 drought events were reported across the world between 1900-2013, causing about 12 million deaths, US$ 135 billion economic damages and affecting 2 billion more [10]; [11]. It is estimated that SADC region have seen over 100 disastrous droughts over thirty years period [12]. The current conditions in SADC are likely to worsen due to the slow progress in drought risk management in comparison to the growing population [7].

2.1 Drought's history in SADC

SADC covers an area of approximately 7 million square kilometres ranging from desert, through temperate, savannah and equatorial climates. Average annual precipitation ranges from 100 to 2000 mm/annum. About 75% of the SADC region is classified as arid to semiarid. Mean annual runoff is 650 cu.km in 16 main river basins of which 85% are shared [13]. Drought is a common SADC's disaster and ground fact shows that it is increasingly unusual for drought not to occur in the region each year. The 1991–92 drought events alone ravaged more than 80% of the region and affected thousands. Table 1 lists the number drought events, number killed, total affected, damage (US$ 000) as well as the population number per country and the proportion per population that has affected the Southern African region from 1900 to 2016.

Table 1: Drought events, number killed, numbers affected and cost of damages SADC from 1900 to 2016 [9]

Drought	Events count	Total deaths	Total affected	Total damage ('000 US$)	population number (million)	Proportion per population
Angola	7	58	4443900	0	25.83	17.2%
Botswana	7	0	1344900	47000	2.3	58.47%
DRC	2	0	800000	0	79.7	0.01%
Lesotho	6	0	2736015	1000	2.2	124%
Madagascar	7	200	3535290	0	25	14.14%
Malawi	8	500	24378702	0	17.75	13.7%
Mauritius	1	0	0	175000	1.28	0
Mozambique	12	100068	17757500	50000	28.76	67.70%
Namibia	8	0	1125700	115000	2.5	45%
Tanzania	10	0	12737483	0	55.16	23.09%
Seychelles	0	0	0	0	0.97	0
South Africa	9	0	20175000	3000000	55	36.7%
Swaziland	5	500	1630000	1739	1.3	125%
Zambia	5	0	4173204	0	16.7	24.9%
Zimbabwe	8	0	18512642	51000	16	116%

According to records EM-DAT [9] as per Table 1, SADC countries have had nearly 63 million people affected by droughts disaster from 1900 to 2016. Seychelles and Mauritius however have no population affected recorded although the later had encounter a substantial financial damages [9].

Figure 2 shows the proportion of affected countries to the country population revealing that Swaziland, Lesotho and Zimbabwe are respectively the most affected nations of drought in SADC. DRC, Mauritius and Seychelles have shown little threat to drought disaster in comparison the other twelve. It should be noted that the proportion per population calculation depicts the severity of the impact of the drought disasters to SADC population.

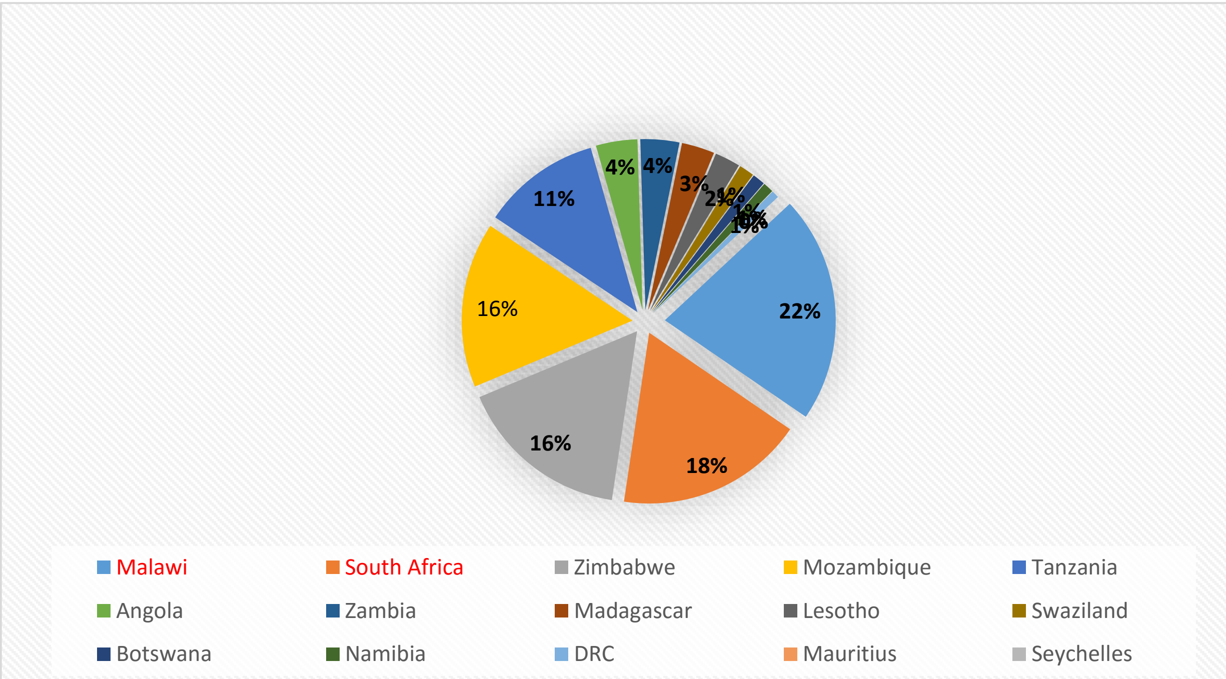

Figure 1: Ranking of SADC Countries affected by droughts from 1900 to 2016 [9].

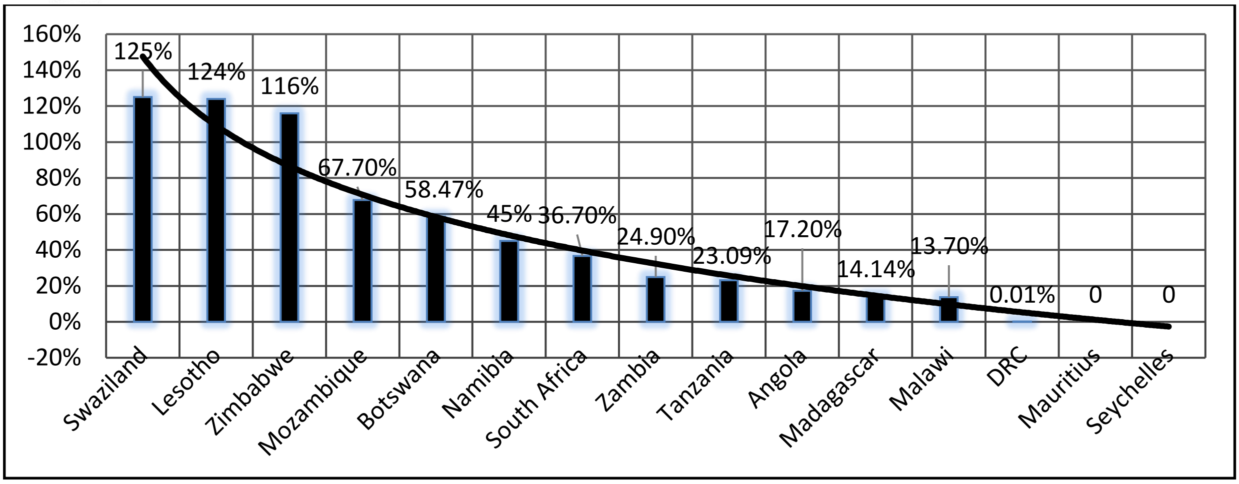

Figure 2: Proportion of population/number affected to droughts in SADC from 1900 to 2016 [9].

2.2 Models history

In the past years, prepositioning location facility emerges as one of the most effective tools in humanitarian disaster planning. The first research contributors [14] and [15], are among on the topic, using mathematical models to determine numbers and locations of Distribution Center (DC) to be included in a network of emergency facilities, including inventory management at the established facilities. A quantitative approach was introduced to multi-objectives prepositioning by maximizing the total expected relief demand of disaster areas covered by existing distribution centers through four objectives: (1) maximum response time limit, (2) budget availability, (3) multiple item types, and (4) capacity restrictions [16]. Then, [17] solved a multi-objective facility location problem in emergency logistics by integrating business 'best practices' such as just-in-time and campaign system in disaster relief chain, addressing therefore facility location problem in terms of material flow. The findings also include an escalation of orders from local DC to regional, continental as far as the main warehouse, to replenish the initial relief items that were distributed to affected area.

Multi-Criteria Decision Making (MCDM) is both a quantitative and qualitative way of optimizing the pre-positioning locations facility. The MCDM was first represented in the perspective of facility location problem by designing a framework and ranking them in terms of importance [18], then application of multi-criteria decision making in a small scale to a real life scenario in Bangladesh, helped bring more transparency in results [19]. MCDM was employed to provide a decision support framework for locations identification to address network design in Indonesia disaster relief supply chains [20].

MCDM is defined as a discipline of operations research that considers decision problems in a context of a number of decision criteria [21]. For [19], the benefits of applying MCDM are its ability to highlight the structure of the decision problem and therefore results are in a high transparency. The obtained model helps relief organizations make a well planned warehouse location decision instead of an often ineffective ad-hoc decision. In term of MCDM technique, two approaches are worth mentioning: 1) Analytic Hierarchy Process (AHP), and 2) Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE). Author [22] and [18] proposed to address the MCDM problem using Analytic Hierarchy Process (AHP) although each differ on the number of attributes (seven vs. five) as well as the application (traditional/manufacturing vs. humanitarian). AHP and PROMETHEE I+II frameworks include considerations on criteria (attribute) such as delivery time, costs, spatial distance, infrastructure, climate, economic aspects, personnel related aspects. Each of the frameworks' attribute, unlike in business setting, may not be applicable to SADC drought supply chain. Cost and available infrastructure, among others, play a crucial attribute role in humanitarian supply chain decision during a drought; unlike the climate attribute. From the SADC drought preparedness, Table 2 lists seven criteria:

Table 2: Definition of each location criteria for site selection

Series No	CRITERIA		DESCRIPTION
C1	Delivery time	DT	Time to reach a humanitarian Response Facility (HRF) with a loaded disaster transport
C2	Security	S	Concerning the risk factor, especially during the last mile distribution of HRF.
C3	Access to affected areas	AAA	Looking at the accessibility of reliefs to the most affected HRF.
C4	Population Coverage	PC	The number of population exposed to a natural disaster to cover in a HRF.
C5	Available infrastructures	AI	Availability of required infrastructure to access in a HRF decision.
C6	Cost	C	Implication of cost into the HRF decision
C7	Capacity of relief to be transported	CRD	Contribution of capacity of relief to be transported into a HRF

3 RESEARCH METHODOLOGY

Aside from the reviewed literature, the study has utilized disaster management databases such as: EM-DAT: The OFDA CRED International Disaster Database, SADC Meteorology Centre, SADC National Disaster Agency, World Bank, USAID, FAO/WFP, SADC REGIONAL EARLY WARNING UNIT, NOAA, NASA, US agency for developments, Famine Early WARNING Systems (FEWS) and other collaborating institutions.

3.1 Data Analysis

The research first identifies suitable locations for creating efficient emergency response facility in SADC region. Then, based on the generic multi-criteria decision making (MCDM) model with location criteria for site selection using Analytical Hierarchy Process (AHP) problems as developed by [23], the study followed the following sequence:

- Defines a set of location criteria for site selection in comparison to alternatives using available resources.
- Then, use cross-comparison of location criteria and AHP, the study determines of criteria weightage (score).
- Finally, with cross-comparison between cities and score of location criteria, defines the optimized configuration.

3.2 Fuzzy Analytical Hierarchy Process (f-AHP)

MCDM could be deterministic, stochastic, or fuzzy. Fuzzy logic deals with situations which are vague or ill-defined and gives a quantifiable value [24], which is appropriate in a humanitarian response [25]. Multi Criteria decision making involves alternatives, goals or decision criteria which are placed in hierarchical structure [21]. Two key elements of MCDM are the decision weight (based on importance) and the matrix (Evaluate decision criterion). And, f-AHP's role is to compute the criteria weightage (score), and criteria will be crossed to a linguistic term (Triangular Fuzzy Number) for pairwise comparison matrices as shown in Table 3.

1. Triangular fuzzy numbers (TFNs)

TFNs are convenient to use in applications due to their computational simplicity [26]. [27] defines TFN "A" by a triplet (l, m, u) and equation (1) defines its membership function μ_A(x):

$$\mu_A(\mathrm{x}) = \begin{cases} \frac{x-l}{m-l}, & l \leq x \leq m \\ \frac{u-x}{u-m}, & m \leq x \leq u \\ 0 & otherwise \end{cases} \quad (1)$$

Where "x" is the mean value of "A" and (l, m, u) are real numbers. Two TFNs "A" and "B" are defined by the triplets $A = (l_1, m_1, u_1)$ and $B = (l_2, m_2, u_2)$ [28].

2. Construction of f-AHP comparison matrices

This study utilizes modified synthetic extent f-AHP, which was originally introduced by [27] and developed by [29].The incompleteness of the synthetic extent f-AHP reflects its suitability in decision problems where uncertainty exists in the decision-making process [28]. Table 3 shows the standard 9-unit scale linguistic variables used to make the pairwise comparisons [30]. The values deriving from a pre-defined set of ratio scale values as presented in Table 3 serves to describe the pairwise comparisons [28].

Table 3: Linguistic terms and corresponding TFN

Numerical values	Definition	Fuzzy triangular Scale
1	Equally Important (Eq. Imp)	(1,1,3)
3	Weakly Important (W. Imp)	(1,3,5)
5	Fairly Important (F. Imp)	(3,5,7)
7	Strongly Important (S. Imp)	(5,7,9)
9	Absolutely Important (A. Imp)	(7,9,11)

3. Value of fuzzy synthetic extent

Let $C = \{C_1, C_2, \ldots, C_n\}$ be a N decision criteria set, where n represents the number of criteria and $A = \{A_1, A_2, \ldots, A_m\}$ be a M decision alternative set, where m is the number of decision alternatives. LetM^1C_i, M^2C_i, $M^mC_i, i = 1, 2, \ldots, n$ where all the M^jC_i $(j = 1, 2, \ldots, m)$ are TFNs. In line with the equation in the point on the TFNs, the value of fuzzy synthetic extent S_i in regard to the ith criteria is defined:

$$S_i = \sum_{j=1}^{m} M^j C_i \left[\sum_{i=1}^{n} \cdot \prod_{j=1}^{m} M^j C_i\right]^{-1} \quad (2)$$

Where (.) represents fuzzy multiplication and the superscript (-1) represents the fuzzy inverse [28].

4. Calculating sets of weighted values of f-AHP

For sets of weight values under each criterion to be determined, a principle of comparison for fuzzy numbers must be considered [27]. As demonstration, for two fuzzy numbers, M_1 and M_2, the degree of possibility that $M_1 \geq M_2$ is defined as:

$$V(M_1 \geq M_2) = \underset{x \geq y}{\mathrm{SUP}}[\min(\mu M_1(x), \mu M_2(y))] \quad (3)$$

Where sup represents Supremum, with $V(M_1 \geq M_2) = 1$. Since M_1 and M_2 is defined by the TFNs (l_1, m_1, u_1) and(l_2, m_2, u_2), respectively, it follows:

$$V(M_1 \geq M_2) = 1 \; iff \; m_1 \geq m_2$$

$$V(M_1 \geq M_2) = hgt(M_1 \cap M_2) = \mu M_1(X_d) \quad (4)$$

Where iff signifies 'if and only if', while d is the ordinate of the highest intersection point between the μM_1 and μM_2 TFNs, and x_d is the point in the domain of μM_1 and μM_2 where the ordinate d is found. The term hgt is the height of fuzzy numbers on the intersection of M_1 andM_2. For $M_1 = (l_1, m_1, u_1)$ and$M_2 = (l_2, m_2, u_2)$, the possible ordinate of their intersection is given by Equation (5). This Equation determines the degree of possibility for a fuzzy number:

$$V(M_1 \geq M_2) = hgt(M_1 \cap M_2) = \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} = d \quad (5)$$

To obtain the degree of possibility for a convex fuzzy number *M* to be greater than the number of k fuzzy numbersM_i $(i = 1, 2, \ldots, k)$, the use of the operations max and min is needed [31] and is defined by:

$$V(M \geq M_1, M_2, \ldots, M_k = V[(M \geq M_1)\ and\ (M \geq M_2) and \ldots and\ (M \geq M_k)] = \min V\,(M \geq M_i).\, i = 1,2, \ldots, k \quad (6)$$

Assuming $d'(A_1) = \min V(S_1 \geq S_k)$, where $k = 1,2, \ldots, n, k \neq i$ and n is the number of criteria. A weight vector is given by:

$$W' = [d'(A_1), d'(A_2), \ldots, d'(A_m)] \quad (7)$$

Where A_i $(i = 1, 2, \ldots, m)$ are the m decision alternatives. Each $d'(A_1)$ as illustrated in equation (8) represents the perference of each decision candidate and W' as vector is nomalised as follows:

$$W' = [d(A_1), d(A_2), \ldots, d(A_m)] \quad (8)$$

If two fuzzy numbers, $M_1 = (l_1, m_1, u_1)$ and$M_2 = (l_2, m_2, u_2)$, in a fuzzy comparison matrix satisfy$l_1 - u_2 > 0$, then $V(M_2 \geq M_1) = hgt\,(M_1 \cap M_2) = \mu_{M_2}(x_d)$, where $\mu_{M_2}(x_d)$ is illustrated by [29]:

$$\mu_{M_2}(x_d) = \begin{cases} \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, l_1 \leq u_2 \\ 0, \quad otherwise \end{cases} \quad (9)$$

4 RESULTS

4.1 Definition of location criteria for site selection

A qualitative approach was used to identify the extent to which each SADC country is affected by drought disaster and the prevailing decision criteria's in each of those listed countries. A list of high risk locations as well as the types of criteria's customary to SADC countries being study for Drought events from Table 4 derived from literatures reviews and various agencies operating in the region. The high risk locations were determined based on the population density and the drought history.

Table 4: Risk criteria for the SADC countries

	Countries	Capital City	High Risk Locations	Type Of Criteria
1	**ANGOLA**	Luanda	Luanda, Uige and Benguela	Security, Infrastructure, Cost and population to cover
2	**BOTSWANA**	Gaborone	Central, Kweneng and Ngamiland	Cost, Access to affected Zone and delivery time
3	**LESOTHO**	Maseru	Berea, Maseru and Mafeteng	Security, Cost and delivery time

4	**MADAGASCAR**	Antananarivo	Analamanga, Vakinankaratra and Vatovavy Fitovinany	Security, Cost, Infrastructures, Access to affected zone, capacity to be delivered and population to cover
5	**MALAWI**	Lilongwe	Zomba, Blantyre District and Lilongwe	Cost, Infrastructures, capacity to be delivered, access to affected zone
6	**MOZAMBIQUE**	Maputo	Maputo, Nampula, Zambezia, Sofala	Delivery time, infrastructures, security, cost, capacity to be delivered and population to cover
7	**NAMIBIA**	Windhoek	Omusati, Ohangwena and Khomas	Cost, population to cover, access to affected zone and deliver time
8	**SOUTH AFRICA**	Johannesburg	Limpopo, Kwazulu Natal and Gauteng	Cost, population to cover, access to affected zone
9	**SWAZILAND**	Mbabane	Lubombo, Manzini and Hhohho	Cost, population to cover and access to affected zone
10	**TANZANIA**	Dar es Salaam	Dar es Salaam, Mwanza and Kagera	Cost, Infrastructures, capacity to be delivered, access to affected zone and population to be cover
11	**ZAMBIA**	Lusaka	Lusaka, Copper belt and Southern	Cost, Infrastructure, population to cover, access to affected zone
12	**ZIMBABWE**	Harare	Matabeleland north, Matabeleland South and Manicaland	Cost, Infrastructure, population to cover, access to affected zone

4.2 Weightage of location criteria

After identifying the potential humanitarian relief locations, a cross-comparison of location criteria and f-AHP is needed. To the weighted values of f-AHP under each criterion; a survey was conducted targeting relief agencies mentioned at the research methodology. In total, 60 questionnaires were dispatched, 48 were returned (80% response rate) [32]. The data collected from the survey responses were analysed using with SPSS version 21.0 [32]. The research reliability score computed exceeds the recommended value of 0.700 [32]. The survey outcomes displayed in Table 5 (in Weight % and rank) reveal drought response decision priorities using f-AHP calculation.

Table 5: Weightage of Location criteria ranking

S/n	**Criterion**	**Weight (%)**	**Rank**
C6	Cost (C)	25	1
C3	Access to affected areas (AAA)	17	2
C5	Available infrastructures (AI)	16	3
C7	Capacity of relief to be transported (CRT)	14	4
C4	Population Coverage (PC)	12	5
C1	Delivery Time (DT)	8	6
C2	Security (S)	8	7

Results show that criteria Cost (C6) and the Access to affected areas (C3) have priority ranking in drought disaster response unlike delivery time (C1) or Security (C2).

4.3 Determination of scores for Locations performance on criteria

Scores for locations expected performance on the criteria are generated from geographical and historical data. Thereafter, each criterion is analysed and the results are interpreted per country. The index value "1.00" as per Table 6 represents the best performing case (region, city or province) in term of criteria's scores within the geographic area of reference.

4.3.1 Delivery Time (C1-DT)

Delivery time (C1-CT) is one of the least priorities for decision makers in the SADC region (the sixth with only 8% of weight criterion). Unlike other natural disasters, drought have no direct impacts on transportation infrastructures, therefore, unless existing planning issues, the delivery time should not be directly affected. Table 6 shows the transportation time from the Central Distribution Center (main entry port) to affected areas Distribution Centres (DC).

4.3.2 Security (C2-S)

According to [33], nearly 29 million people were under food insecurity in SADC region in 2015 due to delayed and decreased rainfalls. Drought disrupts rain and temperature cycle which in turn affects farming and water reserve. Drought however, assuming that it is the only embattled disaster, causes minimal risks to humanitarian relief deliveries, facilities or personnel.

4.3.3 Access to Affected Areas (C3-AAA)

Access to affected areas is considered one of the most important humanitarian responses planning decision. This criterion is defined as the distance between the candidate location and the demand points. With the candidate location, also call central distribution Center (CDC), refer to a safe zone that is used for planning, procurement and supply to affected areas. Each demand point represents the distribution point (DC) of the affected areas. Table 6 shows that affected areas in the regions are accessed by air, road, by train even by sea.

Table 6: Deliver Time and Access to Affected Areas

	COUNTRIES	CENTRAL DISTRIBUTION CENTRE	HIGH RISK LOCATION	DEMAND POINT	DISTANCE FROM MAIN DEPOT (km)	AIR TIME FROM MAIN DEPOT (Hour)	ROAD TIME FROM MAIN DEPOT (Hour)	ACCESS TO AFFECTED ZONES INDEX
1	ANGOLA	**Luanda** (Fevereiro Int Airport)	Luanda	Luanda	11	0.0	0.3	**1.00**
			Uige	Carmona	290	0.3	4.4	0.98
			Benguela	Benguela	540	1.0	7.7	0.64
2	BOTSWANA	**Gaborone** (Sir Seretse Khama Int Airport)	central	serowe	314	0.5	3.4	0.95
			Kweneng	Molepolole	62	0.1	1.3	**1.00**
			Ngamiland	Maun	855	1.3	8.8	0.69
3	LESOTHO	**Maseru** (Moshoeshoe Int Airport)	Berea	Berea hill	37	0.0	1.0	0.85
			Maseru	Maseru	19	0.0	0.4	**1.00**
			Mafeteng	Mafeteng	65	0.1	0.9	0.54
4	MADAGASCAR	**Antananarivo** (Ivato Int Airport)	Analamanga	Antananarivo	13	0.0	0.6	**1.00**
			Vakinankaratra	Antsirabe	182	0.2	3.6	0.98
			Vatovavy Fitovinany	Manakara	583	1.0	10.9	0.75
5	MALAWI	**Lilongwe** (Lilongwe Int Airport)	Zomba	Zomba	325	0.8	4.4	0.97
			Blantyre	Blantyre	352	0.8	4.7	0.51
			Lilongwe	Lilongwe	26	0.0	0.6	**1.00**
6	MOZAMBIQUE	**Maputo** (Maputo Int Airport)	Nampula	Nampula	2035	2.2	26.2	0.42
			Maputo	Matola	6	0.0	0.3	**1.00**
			Zambezia	Quelimane	1559	1.8	18.3	0.74
			Sofala	Beira	1210	1.4	15.6	0.99
7	NAMIBIA	**Windhoeck** (Hosea Kutako Int Airport)	Khomas	Windhoeck	46	0.0	0.6	1.00
			Ohangwena	Eenhana	742	1.2	7.2	0.97
			Omusati	Outapi	808	1.3	9.4	0.51
8	SOUTH AFRICA	**Johannesburg** (O.R.Tambo Int Airport)	Kwazulu Natal	Durban	576	1.5	5.8	0.63
			Gauteng	Johannesburg	28	0.0	0.4	**1.00**
			Limpopo	Polokwane	307	0.7	3.7	0.97
9	SWAZILAND	**Sikupe** (King Mswati III Int Airport)	Lubombo	Siteki	34	0.0	0.5	**1.00**
			Manzini	Manzini	56	0.1	1.0	0.74
			Hhohho	Mbabane	92	0.0	1.5	0.45
10	TANZANIA	**Dar es Salaam** (Julius Nyerere Int Airport)	Dar es Salaam	Dar es Salaam	13	0.0	0.6	**1.00**
			Mwanza	Mwanza	1117	1.8	18.6	0.99
			Kagera	Bukoba	1377	7.8	22.4	0.55
11	ZAMBIA	**Lusaka** (Kenneth Kaunda Int Airport)	Lusaka	Lusaka	15	0.0	0.4	**1.00**
			Copperbelt	Ndola	335	2.8	4.9	0.51
			Southern	Choma	310	0.4	4.3	0.97
12	ZIMBABWE	**Harare** (Harare Int Airport)	Matabeleland South	Gwanda	568	1.0	6.5	0.44
			Matabeleland North	Lupane	457	1.0	6.2	0.79
			Manicaland	Mutare	272	0.5	3.4	**1.00**

The access to affected zones index was calculated by the means of the distance from main depot (km) with the shortest distance representing the index value (1.00).

4.3.4 Population Coverage (C4-PC)

This criterion defines the population exposed to drought per the potential locations and country. Local DC is selected based on historical data on drought disasters, on the number of population coverage and on easy accessibility to victims via transportation modes. The population coverage index is determined by dividing the exposed population to the area superficies. And the areas with higher population density signify higher disaster risk and vulnerability; for such, the coverage index used is (1.00). The coverage index on the table is determined from the population/m^2density with the value (1.00) representing the biggest population density. Table 7 shows the vulnerable population in each region per country as well as their densities.

Table 7: Population coverage in high risk location (Region, province or district)

	COUNTRIES	POTENTIAL LOCATIONS	EXPOSED POPULATION	AREA SIZE (mi^2)	DENSITY (population/m^2)	COVERAGE INDEX
1	ANGOLA	Luanda	6945386	933	**7444**	**1.00**
		Uige	1483118	22663	65	0.008
		Benguela	2231385	12273	182	0.032
2	BOTSWANA	central	585595	57039	10	0.21
		Kweneng	304549	13857	**22**	**1.00**
		Ngamiland	175631	11583	15	0.53
3	LESOTHO	Berea	300000	767	**391**	**1.00**
		Maseru	170000	1686	101	0.13
		Mafeteng	253000	818	309	0.52
4	MADAGASCAR	Analamanga	3439600	6736	**511**	**1.00**
		Vakinankaratra	1852200	6409	289	0.48
		Vatovavy Fitovinany	1454900	7569	192	0.19
5	MALAWI	Zomba	583167	1027	568	0.52
		Blantyre	809397	807	**1003**	**1.00**
		Lilongwe	1346360	2754	489	0.24
6	MOZAMBIQUE	Nampula	3985613	30506	131	0.68
		Maputo	1205709	8762	**138**	**1.00**
		Zambezia	3850000	39953	96	0.37
		Sofala	1642920	26262	63	0.15
7	NAMIBIA	Khomas	415800	14272	29	0.47
		Ohangwena	245446	4134	**59**	**1.00**
		Omusati	249900	10251	24	0.21
8	SOUTH AFRICA	Kwazulu Natal	10456900	36433	287	0.18
		Gauteng	12728400	7018	**1814**	**1.00**
		Limpopo	5518000	48554	114	0.05
9	SWAZILAND	Lubombo	207731	2258	92	0.19
		Manzini	319530	1581	**202**	**1.00**
		Hhohho	282734	1400	202	0.60
10	TANZANIA	Dar es Salaam	4364541	538	**8113**	**1.00**
		Mwanza	2772509	3655	759	0.113
		Kagera	2458023	9755	252	0.03
11	ZAMBIA	Lusaka	2888600	8454	**342**	**1.00**
		Copperbelt	242700	12096	20	0.05
		Southern	1907800	33136	58	0.18
12	ZIMBABWE	Matabeleland South	683893	20916	33	0.31
		Matabeleland North	749017	28967	26	0.14
		Manicaland	1753000	14077	**125**	**1.00**

4.3.5 Available Infrastructures (C5-AI)

Available Infrastructure criteria define suitable location with key infrastructure to support rapid humanitarian response. Infrastructure targeted includes air airports for relief cargo, good roads condition for connectivity, railways and seaports. Other key infrastructure includes railways and seaports.

Table 8 shows the existing infrastructures and computed the available infrastructure index for every potential location per country with 0.25 points representing every infrastructure type.

Table 8: Available Infrastructure Index

	COUNTRIES	POTENTIAL LOCATIONS	TYPE OF INFRASTRUCTURE	INFRASTRUCTURE INDEX
1	ANGOLA	**Luanda**	**Marine, Railway, Airport,**	**1.00**
		Uige	Road, Railway, Airport	0.75
		Benguela	Marine, Railway, Airport,	1.00
2	BOTSWANA	central	Airport, Road, Railway	0.75
		Kweneng	Road, Airport, Raiway	**0.75**
		Ngamiland	Airport, Road, Railway	0.75
3	LESOTHO	Berea	Railway, Airport, Road	**0.75**
		Maseru	**Railway, Airport, Road**	**0.75**
		Mafeteng	Railway, Airport, Road	0.75
4	MADAGASCAR	**Analamanga**	**Railway, Airport, Road**	**0.75**
		Vakinankaratra	Railway, Airport, Road	0.75
		Vatovavy	Railway, Airport, Road	0.75
5	MALAWI	**Zomba**	**Railway, Road, Airport**	**0.75**
		Blantyre	Railway, Road, Airport	**0.75**
		Lilongwe	Railway, Road, Airport	0.75
6	MOZAMBIQUE	Nampula	Railway, Airport, Road	0.75
		Maputo	Marine, Railway, Airport,	**1.00**
		Zambezia	**Marine, Railway, Airport,**	**1.00**
		Sofala	Marine, Railway, Airport,	1.00
7	NAMIBIA	**Khomas**	**Road, Railway, Airport**	**0.75**
		Ohangwena	Road, Railway	0.50
		Omusati	Road, Airport, Railway	0.75
8	SOUTH AFRICA	**Kwazulu Natal**	**Marine, Railway, Airport,**	**1.00**
		Gauteng	Railway, Airport, Road	0.75
		Limpopo	Railway, Airport, Road	0.75
9	SWAZILAND	**Lubombo**	**Airport, Road, Railway**	**0.50**
		Manzini	Railway, Airport, Road	**0.75**
		Hhohho	Road	0.25
10	TANZANIA	**Dar es Salaam**	**Marine, Road, Airport,**	**1.00**
		Mwanza	Marine, Road, Airport,	1.00
		Kagera	Airport, Road	0.50
11	ZAMBIA	**Lusaka**	**Railway, Airport, Road**	**0.75**
		Copperbelt	Railway, Airport, Road	0.75
		Southern	Road, Raiway, Airport	0.75
12	ZIMBABWE	Matabeleland	Road, airport, Raiway	0.75
		Matabeleland North	Road, airport, Raiway	0.75
		Manicaland	**Road, Railway, Airport**	**0.75**

4.3.6 Cost (C6-C)

Criteria cost defines value related to the costs of supply chain. According to [34], key findings useful for humanitarian supply chain cost in SADC region:

- Transportation of goods by road in Southern Africa move at velocity of 18.6 kilometers per hour. Meanwhile road freight cost in SADC around US$5 cents per tonne-km [35].
- The average regional costs per tonne is between US$100 and US$320 for rail, between US$120 and US$280 for road, and US$110 for container-cargo-handling, air transportation cost is between US$4000 and US$6000.

With Table 8 confirming "availability of infrastructures", Table 9 and Table 10 have computed two decision making scenarios: 1) Scenario 1 from Table 9 describes the supply chain decision prioritizing each SADC country's air transportation as 'main entry', then both road and train transportation used for last miles distribution to local DC. 2) Scenario 2 from Table 10 describes the supply chain decision prioritizing the enormous access to the sea most countries possesses while using road and train transportation for last miles. 9 of the 15 SADC countries are coastal countries possessing one or more seaports. The demand quantity from Table 9 and Table 10 was estimated based on historical data and the projected number exposed population (Table 7).

Next, the study calculated each candidate location transportation cost based on the demand quantity, the average regional cost per tonne (as mentioned above) as well as the distance to the local DC. The cost index is estimated from the sum of the estimated transportation modes, meaning that the estimated transportation mode with the lowest cost is the best decision making option with the index value (1.00).

Table 9: Estimate Cost decision index from Air, Road, and Rail using scenario 1

	COUNTRIES	CENTRAL DISTRIBUTION CENTRE 1	POTENTIAL LOCATIONS	ESTIMATED DEMAND QUANTITY (T)	DISTANCE FROM MAIN DEPOT (km)	ESTIMATED AIR COST FROM MAIN DC ($)	AIR COST INDEX	ESTIMATED ROAD COST FROM MAIN DC ($)	ROAD COST INDEX	ESTIMATED TRAIN COST FROM MAIN DC ($)	TRAIN COST INDEX	OPTIMIZE DECISION
1	ANGOLA	**Luanda** (Fevereiro Int Airport)	Luanda	90	11	$ -	0.85	$ 10,988.00	0.96	$ -	1.00	$ 10,988.00
			Uige	17	290	$ 72,930.00		$ 2,978.00		$ 3,230.00		$ 2,978.00
			Benguela	13	540	$ 59,020.00		$ 2,896.00		$ 3,250.00		$ 2,896.00
			Total	**120**	**841**	**$ 131,950.00**		**$ 16,862.00**		**$ 6,480.00**		**$ 16,862.00**
2	BOTSWANA	**Gaborone** (Sir Seretse Khama Int Airport)	central	15	314	$ 64,710.00	0.93	$ 2,412.00	1.00	$ 3,900.00	0.97	$ 2,412.00
			Kweneng	25	62	$ 101,550.00		$ 3,201.00		$ 2,500.00		$ 2,500.00
			Ngamiland	10	855	$ 48,550.00		$ 2,311.00		$ 2,850.00		$ 2,850.00
			Total	**50**	**1231**	**$ 214,810.00**		**$ 7,924.00**		**$ 9,250.00**		**$ 7,762.00**
3	LESOTHO	**Maseru** (Moshoeshoe Int Airport)	Berea	9	37	$ -	0.81	$ 1,520.00	0.95	$ 900.00	1.00	$ 900.00
			Maseru	14	19	$ -		$ 2,032.00		$ -		$ 2,032.00
			Mafeteng	7	65	$ 28,455.00		$ 1,442.00		$ 770.00		$ 770.00
			Total	**30**	**121**	**$ 28,455.00**		**$ 4,994.00**		**$ 1,670.00**		**$ 3,702.00**
4	MADAGASCAR	**Antananarivo** (Ivato Int Airport)	Analamanga	100	13	$ -	0.90	$ 12,267.00	0.97	$ -	1.00	$ 12,267.00
			Vakinankaratra	50	182	$ 209,100.00		$ 7,871.00		$ 6,500.00		$ 6,500.00
			Vatovavy Fitovinany	40	583	$ 183,320.00		$ 9,596.00		$ 7,400.00		$ 7,400.00
			Total	**190**	**778**	**$ 392,420.00**		**$ 29,734.00**		**$ 13,900.00**		**$ 26,167.00**
5	MALAWI	**Lilongwe** (Lilongwe Int Airport)	Zomba	17	325	$ 73,525.00	0.94	$ 3,297.00	0.98	$ 2,720.00	1.00	$ 2,720.00
			Blantyre	13	352	$ 56,576.00		$ 2,601.00		$ 2,470.00		$ 2,470.00
			Lilongwe	20	26	$ 80,520.00		$ 2,518.00		$ -		$ 2,518.00
			Total	**50**	**703**	**$ 210,621.00**		**$ 8,416.00**		**$ 5,190.00**		**$ 7,708.00**
6	MOZAMBIQUE	**Maputo** (Maputo Int Airport)	Nampula	30	2035	$ 180,000.00	0.91	$ 5,631.00	1.00	$ 9,600.00	0.96	$ 5,631.00
			Maputo	80	6	$ -		$ 9,616.00		$ -		$ 9,616.00
			Zambezia	35	1559	$ 194,565.00		$ 6,015.00		$ 10,850.00		$ 6,015.00
			Sofala	55	1210	$ 286,550.00		$ 8,814.00		$ 16,500.00		$ 8,814.00
			Total	**200**	**4810**	**$ 661,115.00**		**$ 30,076.00**		**$ 36,950.00**		**$ 30,076.00**
7	NAMIBIA	**Windhoeck** (Hosea Kutako Int Airport)	Khomas	35	46	$ -	0.90	$ 4,361.00	0.96	$ -	1.00	$ 4,361.00
			Ohangwena	20	742	$ 94,840.00		$ 3,888.00		$ 4,200.00		$ 3,888.00
			Omusati	25	808	$ 120,200.00		$ 5,025.00		$ 5,500.00		$ 5,025.00
			Total	**80**	**1596**	**$ 215,040.00**		**$ 13,274.00**		**$ 9,700.00**		**$ 13,274.00**
8	SOUTH AFRICA	**Johannesburg** (O.R.Tambo Int Airport)	Kwazulu Natal	40	576	$ 183,040.00	0.90	$ 8,847.00	0.97	$ 6,000.00	1.00	**$ 6,000.00**
			Gauteng	50	28	$ -		$ 6,246.00		$ -		$ 6,246.00
			Limpopo	10	307	$ 43,070.00		$ 1,739.00		$ 1,400.00		$ 1,400.00
			Total	**100**	**911**	**$ 226,110.00**		**$ 16,832.00**		**$ 7,400.00**		**$ 13,646.00**
9	SWAZILAND	**Sikupe** (King Mswati III Int Airport)	Lubombo	11	34	$ -	0	$ 1,649.00	1.00	**$ -**	0	$ 1,649.00
			Manzini	12	56	$ -		$ 2,031.00		$ -		$ 2,031.00
			Hhohho	12	92	$ -		$ 2,411.00		$ -		$ 2,411.00
			Total	**35**	**182**	**$ -**		**$ 6,091.00**		**$ -**		**$ 6,091.00**
10	TANZANIA	**Dar es Salaam** (Julius Nyerere Int Airport)	Dar es Salaam	100	13	$ -	0.93	$ 1,208.00	0.97	$ -	1.00	$ 1,208.00
			Mwanza	65	1117	$ 332,605.00		$ 12,434.00		$ 17,550.00		$ 12,434.00
			Kagera	35	1377	$ 188,195.00		$ 7,276.00		$ -		$ 7,276.00
			Total	**200**	**2507**	**$ 520,800.00**		**$ 20,918.00**		**$ 17,550.00**		**$ 20,918.00**
11	ZAMBIA	**Lusaka** (Kenneth Kaunda Int Airport)	Lusaka	38	15	$ -	0.91	$ 4,698.00	0.97	$ -	1.00	$ 4,698.00
			Copperbelt	29	335	$ 125,715.00		$ 5,835.00		$ 4,060.00		$ 4,060.00
			Southern	28	310	$ 120,680.00		$ 5,464.00		$ 3,640.00		$ 3,640.00
			Total	**95**	**660**	**$ 246,395.00**		**$ 15,997.00**		**$ 7,700.00**		**$ 12,398.00**
12	ZIMBABWE	**Harare** (Harare Int Airport)	Matabeleland South	30	568	$ 137,040.00	0.93	$ 5,702.00	0.97	$ 5,100.00	1.00	$ 5,100.00
			Matabeleland North	37	457	$ 164,909.00		$ 6,526.00		$ 5,550.00		$ 5,550.00
			Manicaland	68	272	$ 290,496.00		$ 10,442.00		$ 8,840.00		$ 8,840.00
			Total	**135**	**1297**	**$ 592,445.00**		**$ 22,670.00**		**$ 19,490.00**		**$ 19,490.00**
					TOTAL	$ 6,287,877.00	0.91	$ 364,906.00	0.96	$251,070.00	1.00	$336,698.00

Scenario 1 on Table 9 shows the calculated estimation of air, train and road transportation cost from the Main distribution center (DC) to the demand point (potential location considering the distance and the estimated demand quantity. The results of this scenario shows that

Airlifting relief supply increase accessibility and speed of delivery as most potential locations have airports. However, it cost between US$4000 and US$6000 per tonne to transport goods in the region, leading to an increase in overall transportation of relief in during a disaster response. Further air cost could occur if airlifting is used for last miles shipment. The study has revealed however that using road and train from the main airport "country entry point" to the high risk areas amid road and railway availability are the most cost effective way of connecting in the country. For instance, OR Tambo international airport is the main entry point for reliefs in South Africa; finding the best decision to supply goods from OR Tambo to Limpopo is to select the cheapest transportation options available to reach the destination. The environmental friendly nature of drought disaster allows decision makers to select using trains to transport 50 tonnes at the cost of only US$8847.

Applying scenario 2 (Table 10) decision making however, although the response time is lengthier and the connectivity reduced (especially with land lock and island countries), using the sea transportation is cheaper and appears the most suited for drought disaster. With 95% of SADC trade being done via the sea, maximizing the sea route, although increases the time, but reduces one of the key elements which are the transportation cost. With more than 60 available ports operating in SADC [34], coastal and landlocked countries have sufficient port options to choose from based on the distance, security, quantity of relief as well as the availability of the road or train transportation.

Table 10: Estimate Cost decision index for Road, Rail from Seaport using Scenario 2

	COUNTRIES	CENTRAL DISTRIBUTION CENTRE 2	POTENTIAL LOCATIONS	CAPITAL CITY	ESTIMATED DEMAND QUANTITY (T)	DISTANCE FROM MAIN DEPOT (km)	ESTIMATED ROAD COST FROM MAIN DC ($)	ROAD COST INDEX	ESTIMATED TRAIN COST FROM MAIN DC ($)	TRAIN COST INDEX	OPTIMIZE DECISION
		Luanda Port	Luanda	Luanda	90	11	$ 11 340,00		$ -		$ 11 340,00
1	**ANGOLA**	Walvis Bay	Uige	Carmona	17	290	$ 4 556,00	0.84	$ 3 230,00	**1.00**	$ 3 230,00
		Lobito port	Benguela	Benguela	13	12	$ 1 638,00		$ -		$ 1 638,00
		Durban	central	serowe	15	1229	$ 2 655,00		$ 2 550,00		$ 2 550,00
2	**BOTSWANA**	Maputo	Kweneng	Molepolole	25	1350	$ 4 575,00	0.58	$ 2 500,00	**1.00**	$ 2 500,00
		Walvis Bay	Ngamiland	Maun	10	855	$ 1 600,00		$ 1 400,00		$ 1 400,00
		Durban	Berea	Berea hill	9	660	$ 1 584,00		$ 900,00		$ 900,00
3	**LESOTHO**	Port Elizabeth	Maseru	Maseru	14	642	$ 2 450,00	0.59	$ 1 960,00	**1.00**	$ 1 960,00
		Richards Bay	Mafeteng	Mafeteng	7	574	$ 1 183,00		$ 770,00		$ 770,00
			Analamanga	Antananarivo	100	579	$ 15 700,00		$ 12 000,00		$ 12 000,00
4	**MADAGASCAR**	Toamasima	Vakinankaratra	Antsirabe	50	761	$ 8 450,00	0.55	$ 6 500,00	**1.00**	$ 6 500,00
			Vatovavy Fitovinany	Manakara	40	1162	$ 7 760,00		$ 7 400,00		$ 7 400,00
		Maputo	Zomba	Zomba	17	674	$ 2 839,00		$ 2 720,00		$ 2 720,00
5	**MALAWI**	Walvis Bay	Blantyre	Blantyre	13	856	$ 2 340,00	**1.00**	$ 2 470,00	0.504	$ 2 340,00
		Durban	Lilongwe	Lilongwe	20	754	$ 3 460,00		$ 3 600,00		$ 3 460,00
			Nampula	Nampula	30	765	$ 6 360,00		$ 9 600,00		$ 6 360,00
6	**MOZAMBIQUE**	Maputo	Maputo	Matola	80	25	$ 9 840,00	0.66	$ -	**1.00**	$ 9 840,00
		Nacala	Zambezia	Quelimane	35	518	$ 6 405,00		$ 5 250,00		$ 5 250,00
		Beira	Sofala	Beira	55	17	$ 6 710,00		$ -		$ 6 710,00
		Walvis Bay	Khomas	Windhoeck	35	56	$ 4 410,00		$ 3 500,00		$ 3 500,00
7	**NAMIBIA**	Cape Town	Ohangwena	Eenhana	20	742	$ 3 880,00	0.501	$ 4 200,00	**1.00**	$ 3 880,00
		Luderitz	Omusati	Outapi	25	808	$ 5 000,00		$ 5 500,00		$ 5 000,00
		Durban	Kwazulu Natal	Durban	40	14	$ 4 880,00		$ -		$ 4 880,00
8	**SOUTH AFRICA**	Richards Bay	Gauteng	Johannesburg	50	575	$ 9 100,00	0.68	$ 6 000,00	**1.00**	$ 6 000,00
		Port Elizabeth	Limpopo	Polokwane	10	876	$ 2 140,00		$ 1 500,00		$ 1 500,00
		Durban	Lubombo	Siteki	11	410	$ 1 936,00		$ 2 200,00		$ 1 936,00
9	**SWAZILAND**	Richards Bay	Manzini	Manzini	12	394	$ 2 076,00	0.56	$ 2 520,00	**1.00**	$ 2 076,00
		Maputo	Hhohho	Mbabane	12	376	$ 2 052,00		$ -		$ 2 052,00
		Dar es Salaam	Dar es Salaam	Dar es Salaam	100	10	$ 12 100,00		$ -		$ 12 100,00
10	**TANZANIA**	Mwanza	Mwanza	Mwanza	65	13	$ 7 865,00	0.89	$ -	**1.00**	$ 7 865,00
			Kagera	Bukoba	35	1377	$ 9 695,00		$ 3 500,00		$ 3 500,00
		Walvis Bay	Lusaka	Lusaka	38	1671	$ 6 688,00		$ 3 800,00		$ 3 800,00
11	**ZAMBIA**	Maputo	Copperbelt	Ndola	29	1200	$ 4 640,00	0.59	$ 4 060,00	**1.00**	$ 4 060,00
		Lobito	Southern	Choma	28	1927	$ 5 152,00		$ 3 640,00		$ 3 640,00
		Durban	Matabeleland South	Gwanda	30	1140	$ 5 520,00		$ 5 100,00		$ 5 100,00
12	**ZIMBABWE**	Walvis Bay	Matabeleland North	Lupane	37	950	$ 6 401,00	0.54	$ 5 550,00	**1.00**	$ 5 550,00
		Walvis Bay	Manicaland	Mutare	68	760	$ 11 084,00		$ 8 840,00		$ 8 840,00
						TOTAL	**$ 206 064,00**	0.62	**$ 122 760,00**	**0.37**	**$174 147,00**

Looking at Table 9 and Table 10 outcomes, Figure 3 reveals optimizing both decision shows that using scenario 2, although it takes longer to deliver reliefs is cheaper with US$174,147 than Scenario 1 (US$178,094).

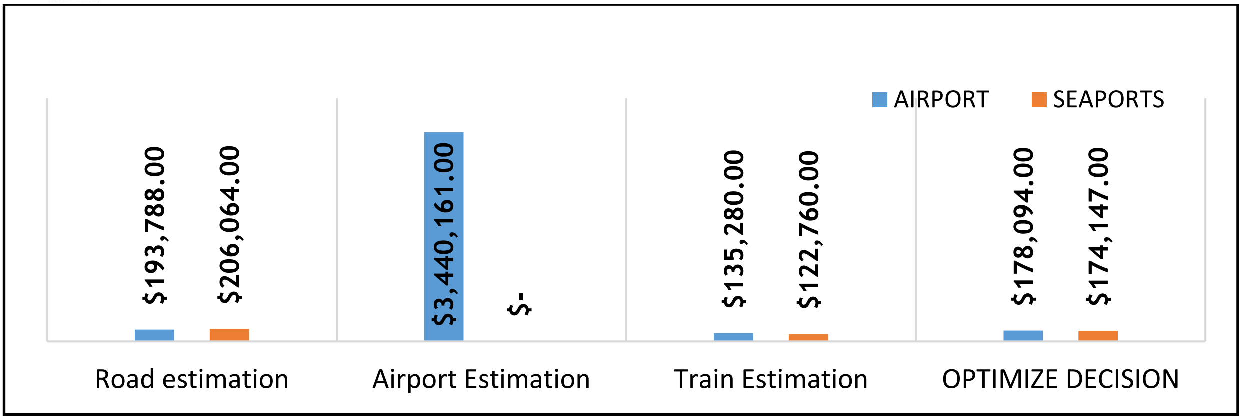

Figure 3: Cost comparison between the Airport and Seaports scenario

It should be noted that the difference is only $3947, future works will incorporate financial damages causes by the length of the delivery the affected zones.

4.3.7 Capacity of relief to be transported (C7-CRT)

Capacity of relief to be transported defines value related to the costs of transportation and coverage per affected area. This criteria index specifies the amount of goods to be transported to the candidate locations, then to the affected. Unlike previously described criteria, this criterion requires a thoughtful planning and evaluation of resources at affected areas. To ensure that resources are not either wasted or lacking, a thorough assessment with partners on the affected region is needed. The capacity was assumed to be based on each area past drought history as well as available historical data on drought disaster as shown in Table 7.

5 CONCLUSION

This paper has reviewed drought disaster impacts in SADC countries and listed ways the region could minimize the transportation cost during humanitarian relief response. A series of models were proposed among which a Multi-Criteria decision Making (MCDM) was selected based on it Analytic Hierarchy Process (AHP) approach. This approach defines, weighs and ranks seven location criteria's for site selection. The model provides a detailed decision support framework for the various organizations already active in the region. Drought disaster, based on its properties offers decision makers a planning advantage, therefore the developed scenarios permits decision makers to manage drought planning and response with cost effectiveness. Findings from both scenarios revealed that by excluding air transportation in drought disasters, countries even landlocked stand to gain on operational and delivery cost. To cope with these new global climate challenges, the region vast sea routes and many Seaports should be developed further and maximized in order to be included even into the last miles transportations efforts.

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