Optimising the de Martonne aridity index using adjustment values

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Abstract

In 1926, Emmanuel de Martonne designed an aridity index to enable quantification and classification of climate conditions. It was originally best optimised for areas with temperatures greater than -10 degrees Celsius (Maliva & Missimer 2012). Given that temperatures could be negative, de Martonne (1926) proposed to adjust the index by adding 10 to temperature. However, due to differences in local climates from region to region, estimation of aridity was poor since the index was adjusted using a constant. As a result, there was a need to identify a method to determine the best suited adjustment value to optimise the index, heedless of an area's temperature range. In this paper, the chi-square (χ^2) goodness of fit test, and the Root Mean Square Error (RMSE) are used to identify the best-suited climate adjustment value between 10 and zero that optimises the de Martonne index. Results showed that it is possible that more than one value may be a suitable adjuster. However, the best optimising adjuster should have the lowest $\chi^2$and RMSE statistics. The findings also revealed that 10 may not always be an adequate adjustment value as this would lead to a misclassification of the climate.

***Key words**: de Martonne aridity index; Chi-square test; Root mean square error*

Introduction

Modern research has conclusively established that climate is rapidly changing due to global warming, such that the need to pen the most suited description of the level of dryness is rising (Lungu *et al.* 2011; Alam & Iskander 2013). A variety of methods are available to quantify climatic dryness. One such aridity index is the de Martonne index (MA). The MA is computed as a ratio between annual rainfalls (Pa) to annual mean temperature (Tam) as shown in Equation 1.

$$MA = \frac{Pa}{Tam+10} \qquad (1)$$

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Initially, the index could not be used in areas where temperatures are below zero. To resolve this, de Martonne (1926) proposed to adjust temperature with 10. This made the index useful only in areas where temperatures are greater than -10 degrees Celsius (de Martonne 1926; Paltineanu *et al.* 2006; Maliva & Missimer 2012; Quan *et al.* 2013; Barbara *et al.* 2014; Haider & Adnon 2014). However, this method of adjusting the temperature with 10 has never been proven to be universal. It is important to correctly classify climatic regions in order to respond adequately to issues surrounding climate variability within the context of the individual climatic regions. Arid regions stand a greater chance of experiencing extreme drought events than humid regions (Maliva & Missimer 2012). Therefore, it can be anticipated that in these regions farmers, water resources, and the overall ecosystem would frequently be at risk of extreme drought (Mniki 2009; Collins *et al.* 2009; Maliva & Missimer 2012; Kumar *et al.* 2015). The objective of this paper was to optimise the MA to better identify different climatic zones. Within the context of water security, food security, or adaptive capacity of farmers to a changing climate, it is important to identify areas vulnerable to intensive dryness (Verchot *et al.* 2007). A method that can describe climate conditions at a higher scale for specific regions could empower decision makers in monitoring climate change moving from a general or global scale to a site-specific scale.

Methodology

Given that this paper aims to improve the MA to be able to differentiate between small climate differences, it was important to use areas with nearly similar climate conditions. The climate of Cape Town varies between Mediterranean to semi-humid, with annual rainfall ranging between 400 mm to 600mm. Buffelsfontein is the coldest area in South Africa with the lowest mean temperature recorded is 2.8 degrees Celsius (SAWS 2017). Alice has semi-humid to humid climate with rainfall occurring all year through (Boumis 2017). After computing the index on the three towns based on Equation 1, the three towns were classified as semi-dry, Mediterranean, and humid as shown in **Table 1**.

Table 1: Classification of the climate of Cape Town, Alice and Buffelsfontain by the original de Martonne Index (Source: authors own)

Town	rain(mm)	T (c)	Index	Class
Cape Town	528.46	17.12	19.48	Semi-Dry
Alice	599.22	17.84	21.51	Mediterranean
Buffelsfontain	622.96	11.39	29.11	Humid

This shows that, if temperature is adjusted using 10, some areas might not be appropriately classified. Hence, the need to identify an optimising value to improve the MA. This paper explores the application of the Chi-Squared test and the Root Mean Square Error (RMSE) to identify the best-suited adjustment value.

Results and discussion

Results from a comparison of chi-square tests at different adjustment values from 10 to zero confirmed that the MA can be optimised using different values in each area apart from the theoretical 10 proposed by de Martonne (1926). The MA will be optimised if temperature is adjusted using 10 or nine for Buffelsfontein, between six and three for Cape Town, and between four and one for Alice. In cases where multiple values are found suitable to optimise the MA, the RMSE and the test statistic should be used as an indicator to identify the best adjuster (**Table 2**). Results presented in **Table 2** revealed that the three towns where suitably classified using all optimising values.

Table 2: Classification of the climate of Cape Town, Alice and Buffelsfontain using the max, min, and best adjustment value (A V) (Source: Authors own)

Town	Rain	T(c)	AV	Index	χ^2	RMSE	Class
Cape Town	528.47	17.12	6	22.85	5.70	0.67	Mediterranean
	528.47	17.12	5	23.89	5.29	0.58	Mediterranean
	528.47	17.12	4	25.02	1.37	0.25	Semi-Humid
	528.47	17.12	3	26.26	2.76	0.39	Semi-Humid
Alice	599.22	17.85	4	27.43	6.53	0.58	Semi-Humid
	599.22	17.85	3	28.74	4.53	0.43	Humid
	599.22	17.85	2	30.19	5.83	0.46	Humid
	599.22	17.85	1	31.79	10.97	0.67	Humid
Buffelsfontain	622.96	11.40	10	29.12	10.17	0.49	Humid
	622.96	11.40	9	30.54	5.48	0.35	Humid

This proves that even though it is optimal to use the best adjustment value, all suitable adjustment values would still adequately optimise the MA in most cases. **Table 1** presented a classification of the three areas using 10 as the AV. The results showed that Alice and CT were misclassified following the classification method proposed by Baltas (2007). Based on the classification proposed by Baltas (2007), an area receiving about 600 mm of rainfall is said to be a humid region. Therefore, Buffelsfontein is rightfully classified following this logic. An arid region is measured by the balance between the amount of rainfall and evapotranspiration (Tilahun 2016). This means, regions with high temperatures will likely evaporate the rainfall and leave the area dry. However, in the case of Buffelsfontain, the low temperature causes less evapotranspiration, making it a relatively humid region. This justifies that the test effectively identifies the best AV and should be used in any study.

Conclusion

Climate variability plays a considerable role in farming practices, water resources management or even public health. It is important to be able to understand climate conditions more precisely than approximately in order to plan adaptive measures. This is valid especially for projected long-term adaptation scenarios such as the one implemented by the South African Department of Environmental Affairs (DEA) (Ziervogel *et al.* 2014). So far, they are aiming to develop national and sub-national adaption measures based on different possible future climate scenarios. However, it is still important that the method used to classify climate condition is optimal and does not excessively generalise information. The MA as proposed in this paper is able to identify climate conditions more precisely, which will permit the implementation appropriate adaptation measure. In a global equation of water balance, differentiating arid regions from humid regions becomes very important. This permits decision makers to tackle dynamics related to the different regions more appropriately. The report from the economic research services sponsored by the United States Department of Agriculture stated that, according to their findings, farmers in drought prone areas are likely to enroll in the conservation program as arid region are prone to drought (Wallander *et al.* 2013). This shows the importance of classifying climatic regions more precisely.

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