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ANALYSES OF TRENDS IN THE FIRE LOSSES AND THE FIRE-BRIGADE CALL-OUTS IN SOUTH AFRICA BETWEEN 2004 AND 2017

Rennifer MADONDO[1], Nhamo MUTINGWENDE[1], Siviwe SHWABABA[1], Robyn J. BAYNE[2], Ágoston RESTÁS[3] and Roman TANDLICH[1,4*]

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ABSTRACT:

The current study aimed at performing correlation analyses to gain a more detailed systems understanding of the temporal trends in financial losses from fires (disaster impacts) and the fire brigade call-outs (disaster response) in South Africa from the 2004 to 2017 period. The analysis is performed using data on the fire disaster impacts at the national level and the local level (Makana Local Municipality). The data on disaster impacts was extracted from databases and reports published by the Fire Protection Association of Southern Africa and Statistics South Africa. The total number of fire brigade call-outs/fires for the entire territory of South Africa ranged from 26574 in 2010 to 49567 in 2017. There was a direct correlation between the total number of fires and the losses from fires in residential settings in South Africa with time for the studied period. The losses from fire disasters in residential settings accounted for between 21.84 % and 74.06 % of all financial losses in South Africa between 2004 and 2017. On the other hand, call-outs to fire brigades with a residential cause or related to rubbish/bush/grass accounted for an average of 81.7 ± 2.7 % between 2004 and 2007, while it reached 88.5 ± 4.9 % in Makana Local Municipality. This indicates that fires in residential settings or related to rubbish or plant-based fuel account for a significant majority of the time fire brigades spent fighting fires in South Africa between 2004 and 2017. Fuel and waste management, and increasing fire human resilience at the household level, will play a significant role in the fire disaster risk management in South Africa. Vegetation cover and management will play a key role in the fire DRM in South Africa and local municipalities such as Makana.

Key-words: *Brigade, Damage assessment, Financial losses, Fire causes, Fire statistics*

1. INTRODUCTION

Understanding disasters, managing the related risk(s), and decreasing the impacts of the disasters on the affected population is a complex process. It requires the system's understanding to be applied to the disasters under study and the related risks/impacts. Dealing with disaster risks must consider the triggers of a disaster, i.e., hazards and the links to the vulnerability of the human population, assets, or environmental components of the socio-ecological systems to the effects of the disaster in question. At the same time, it is necessary to understand the adaptive capacity of the socio-ecological system to cope with the disaster disruptions through internal perturbations and the human resilience, assets, and environment to the disruptions.

[1] *Disaster Management and Ethics Research Group (DMERG), Faculty of Pharmacy, Rhodes University, Grahamstown 6140, South Africa, r.tandlich@ru.ac.za, nmutingwende@gmail.com, siviwe.shwababa@ru.ac.za*

[2] *School of Disaster Management, Stenden South Africa, 1 Grand Street, Port Alfred 6170, South Africa, robynjbayne@gmail.com*

[3] *Institute of Disaster Management, National University of Public Service, Ludovíka tér. 3, 1441 Budapest Pf. 60, Hungary, Restas.Agoston@uni-nke.hu*

[4] *Faculty of Health Sciences, Technical University of Liberec, Studentská 2, 461 17 Liberec, Czech Republic, *corresponding author's email: roman.tandlich@gmail.com*

This is a short but holistic picture which many authors have reflected upon, analysed, and developed as part of a theoretical framework in the academic field of Disaster Risk Management (DRM) science. Many of these authors studied the components of this system, i.e., hazards, vulnerability and coping/adaptive capacity, as well as resilience. As pointed out by Becker (2009), understanding the components of disaster risk is not enough to achieve comprehensive DRM. Their interdependencies or links and interplays between the DRM system's components are just as important and must be understood in detail to avoid a 'suboptimisation problem' (Becker, 2009). The suboptimisation problem is the misunderstanding about the cause and effect, i.e., how does the change in the value of one parameter impact the whole system of DRM. This perspective has some aspects in common with the time-person-place perspective from the public health and disease progression, i.e., the interplay of a specific person's (physical) presence at the place where a pathogen can come into contact with them at a time when the pathogen is most virulent/infectious and/or when the individual human can be most susceptible to disease from the pathogen (Boston University School of Public Health, 2020). The complexity of the DRM space and the related considerations will be demonstrated in the example of drought and the links to fires in South Africa and its implications on other disasters, as well as impacts on human wellbeing.

Climate change in South Africa has been linked as the cause/contributing factor to the 2015-2022 El-Niño related drought, which in turn caused the 2018 water delivery problems in the City of Cape Town (Archer et al., 2022). The impacts have extended into the Eastern Cape Province, where agriculture, as one of the primary sources of population income/economic activity, has been impacted (Archer et al., 2022). In addition, the 2015-2022 El-Niño related drought has been causing significant problems in providing safe drinking water to the population (Iheanetu and Tandlich, 2022). Problems in the WASH service delivery by local government have resulted in Natechs occurring (similar to the findings of Hoossein et al., 2016). Natechs or complex disasters here will be those human actions has led to climate change and that in turn has a negative feedback effect on the proliferation of novel disaster hazards, e.g. increases in the intensity of fires under drought conditions…conditions where component of the system is linked and affected bidirectionally by another (based on the authors' application of the work by Coetzee and van Niekerk, 2012). In this DRM landscape, climate change will thus have cascading effects on resource management and how disaster risk is minimised or managed. In the complex and drought-related DRM space, one of the important considerations will be fires. This will be the result of a combination of the increased availability of dry and combustible fuel, and the decreased volumes of water to fight the fires. Therefore the WASH angle could be extended to other disasters, as a reference viewpoint or a way to interpret the DRM space.

The fuel angle can be demonstrated by the conditions of the fynbos and the invasive pine plantations, as reported for the Knysna fires in 2017 by Kraaij et al. (2018). The decreased water volumes and the fire DRM issues will be similar to the severity to the data reported for the fire-fighting challenges in the California fires during ongoing and severe drought (Wang et al., 2017). Simply put, the decreasing precipitation will contribute to decreased volumes of water being available for human consumption and agriculture. Those uses will (have to) be prioritised in terms of allocation in the use of the existing water resources over fire-fighting and fire DRM, i.e. unless fires happen planning decisions and political will are likely to prefer activities with proven links to human existence over potential disasters. As a result, the water volumes for fire-fighting will likely be negatively impacted by the drought and climate change. Drought has been a contributing factor to the recent fire disasters in South Africa and there has therefore been an ongoing interest and research into the fire DRM, under drought conditions (Kraaij et al., 2018; COGTA, 2020). Similar studies on fire DRM have been conducted in Australia (Haque et al., 2021) and the European Union countries (European Environment Agency, 2021). In more detail for South Africa, several studies in recent years have looked at some of the fire impacts and disaster outcomes.

Strydom and Savage (2016) reported that fires could lead to the release of CO, CO_2 and deposit of black carbon on the surface of the snow, which can, in turn, result in a feedback loop in increasing climate change effects. By the same token, fires can have cascading disaster impacts that increase soil erosion rates, lower ground infiltration and escalate hazards from flash flooding in areas such as the

Eastern Cape Province, South Africa (Strydom and Savage, 2016). The monthly number of fires, as determined based on satellite imagery analysis for the entire territory of South Africa, was reported to range from just under 100 in April to the maximum of just over 700 in August and September in a single calendar year (Strydom and Savage, 2016). Considering the individual provinces in South Africa, Mpumalanga and KwaZulu-Natal were reported to experience most fires in August, while the Western Cape with the City of Cape Town suffered most fires in February between 2003 and 2013 (Strydom and Savage, 2016). The detrimental impacts of veld fires in Mpumalanga and KwaZulu-Natal, according to (Forsyth et al., 2010), can be summarized as follows:

"two South African provinces, i.e. KwaZulu Natal and Mpumalanga lost over 60 000 hectares at some point. Loss of timber worth billions was recorded in South Africa in one veld fire incident. Many people have lost jobs and property, and land damages have been recorded due to veld fires"

At the same time, the three agricultural and more rural provinces of North West Province, Free State and Eastern Cape, along with the economic hub of South Africa…the Gauteng Province, have the peak fire seasons in September (Strydom and Savage, 2016). Finally, the sparsely populated Northern Cape Province was reported to experience the most fires in November (Strydom and Savage, 2016). The threat of fires is also ongoing, and this is demonstrated by the current fire map for some of the Southern African countries in **Fig. 1** below.

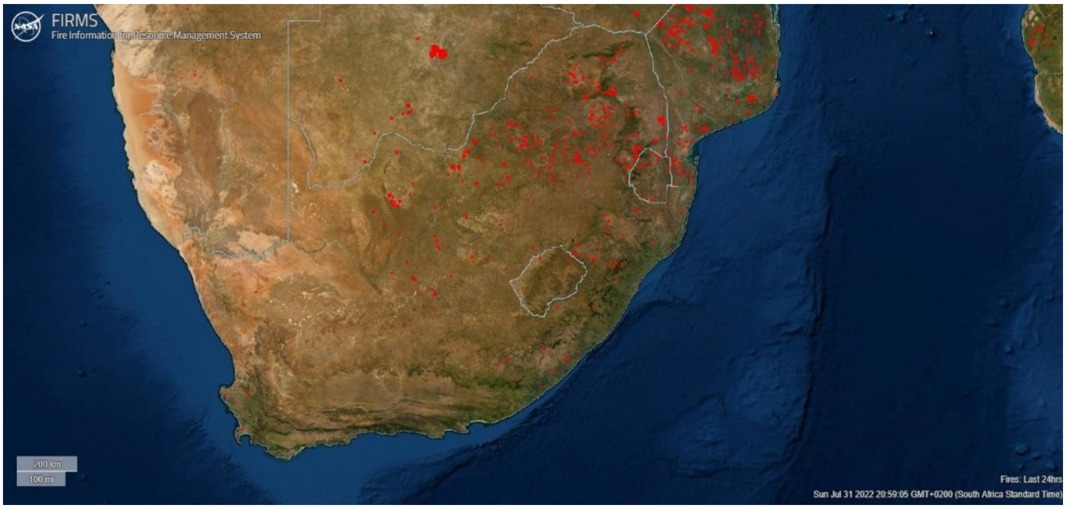

Fig. 1. Geographical distribution of fires in South Africa on 31st July 2022 (figure was adapted from https://firms.modaps.eosdis.nasa.gov/map/#d:2022-07-30..2022-07-31,2022-07-30;@27.9,-28.8,6z; no copyright applies; website accessed on 31st July 2022). Red dots represent active fires.

In 2021, a total of 126169 fires were reported countrywide in South Africa and the most affected provinces were the Eastern Cape, the North-West and Mpumalanga (Sgqolana, 2021). Efforts to tackle disaster hazards, vulnerability and manage disaster risk have also been ongoing. Academic examples of such efforts include the study by Ishola et al. (2020), who proposed a quantitative risk assessment for the fires in commercial complexes in South Africa that provides some tools to help manage the fire disaster risk in the country. Xulu et al. (2021) used open-source data from Google and satellite imagery to determine that 37.4% of the area in the Western Cape Province of South Africa was severely burned during the 2018 fires. In the same study, fires contribute to elevated atmospheric concentrations of carbon mono-oxide and black carbon (Xulu et al., 2021).

Based on the text so far, it is clear that the frequency and geographical distribution of fires in South Africa have been studied prior to the current study. To avoid the occurrence of the 'suboptimisation' problem with fires in the DRM space, it is necessary to conduct further studies on the impact of fires in South Africa. The impact of fires will be analysed in terms of financial losses from the destruction of assets, e.g., housing and industrial infrastructure. In South Africa, losses in those assets, changes in the quality of life due to injuries in the aftermath of fires, and the displacement of populations due to loss of housing stock can result in significant disruptions to the functioning of society. More examination of the local data from South African databases is necessary regarding the residential impacts of fires and the potential sources of fuel/fuel load in residential areas, e.g. significance of vegetation and rubbish not collected by local municipalities. A complete and recently updated databases for fire impacts in South Africa should be used as data sources for the analysis.

The authors follow up with the current analysis on the review paper by Madondo et al. (2022). The aim here is to perform a set of corelation analyses and calculations to understand the structure of fire losses and response measures to fires in South Africa. Analyses were performed at the national level and on the example of a small local municipality in the rural Eastern Cape from 2004 until 2017. This local municipality was Makana Local Municipality is rural and has been impacted by problems in service delivery such as provision of drinking water. The authors have experience and ongoing interest in the DRM profile of the municipality and the paper could be looked as a continuation of those efforts. Due to the ongoing drought in South Africa and the breakdown in municipal service delivery, it is the working hypothesis of the current paper that the majority of the fire-fighting resources will be required to fight fires in residential settings. In addition, the authors hypothesise that municipal waste and its rates of its collection will have an impact on the fuel load and the fire-fighting resources that must be committed to fighting the fires in South Africa and in local municipal settings

2. METHODOLOGY

2.1. Evaluation of the temporal trends in fire statistics in South Africa 2004-2017

The first interest of the authors was to gain an understanding about the recent temporal trends in the fire numbers and their impacts/causes in South Africa. Interdependencies between the fire occurrence and the triggers of the fires should be linked to the fire triangle (Madondo et al., 2022). In other words, the monitoring and evaluation of fire statistics should focus on identifying the main type(s) of fuel that drive(s) fires in South Africa.

By the same token, the major assets impacted by the fires should also be identified and impacts quantified to avoid the 'suboptimisation' problem in the fire DRM in South Africa. The relevant data was extracted from the statistics published by the Fire Protection Association of Southern Africa (FPASA; see www.fpasa.co.za for details; website accessed on 4th May 2022). In particular, the authors extracted the total number of fires in a given calendar year in South Africa. Further, the data on the total financial and residential property losses due to fires were also extracted for the 2004-2017 study period. The residential property losses are reported as the sum of the losses from formal and informal dwellings, flats, and the hotel/hostel/boarding accommodation. In addition, the total call-outs for a fire brigade to assist with fire-related issues, i.e. the total number of fires in South Africa, were extracted with the FPASA database for the 2004-2017 time period. As with the fire losses, the number of calls were analysed for those originating from formal dwellings, flats, informal dwellings, and the hotel/hostel/boarding accommodation. At the same time, the fire brigade call-outs for rubbish, bush or grass related fire issues were correlated with time in the 2004-2017 period.

After data extraction, the first step in the quantitative analyses was to calculate the correlation coefficients, namely the Spearman correlation coefficient (see https://www.socscistatistics.com/tests/spearman/default2.aspx for details; website accessed on 28th April 2022 and 4th May 2022) and the Pearson correlation coefficient (see https://www.socscistatistics.com/tests/pearson/default2.aspx and https://www.socscistatistics.com/pvalues/pearsondistribution.aspx for more information; website accessed on 28th April 2022 and 4th May 2022). Calculations of the Spearman and Pearson correlation coefficients were aimed at establishing if there was a direct or indirect proportionality or a lack thereof, between the calendar year as an independent variable and the measure of fire disaster impacts as the dependent variable. In other words, the correlation evaluations were to establish whether the disaster/fire impacts (financial losses), as well as the fire brigade call-outs (disaster response), were showing a significantly monotonous and/or linear trend in South Africa with time. Such trends could provide insight into the increasing or decreasing fire disaster risk and the South African DRM systems' ability to mobilise, respond and to some extent to cope or not to cope with fires between 2004 and 2017. The correlation coefficients for fire brigade call-outs were calculated for the entire territory of South Africa and for Makana Local Municipality. The reason for the two scales of analysis was two-fold. Firstly, the need to ascertain whether there was a correspondence between the national and local trends in the selected fire statistics or not. This is important to avoid the ecological fallacy of transposing the national trends on the local conditions in a specific area, if not appropriate, in South Africa. In addition, the evaluations of both trends at the national and local levels should also provide more insight into the cause and effect of fires (as disasters), i.e. help avoid the 'suboptimisation' problem in the fire DRM in South Africa.

2.2. Residential losses and the fuels controlling the fire brigade call-outs in South Africa for the 2004-2017 study period

Percentage of financial losses from fires in the residential settings in South Africa were calculated in relation to the total losses from fires in the country. This calculation assessed the fire disaster hazard/risk to the housing stock/residential properties in South Africa. The fraction/percentage of the total financial losses accounted for by the residential fire losses (X) were then calculated on an annual basis using Equation (1).

$$X = 100 \times \frac{Z}{Y} \tag{1}$$

where

Z represents the total financial losses from fires in formal and informal dwellings, flats, hostels and boarding houses extracted from the FPASA database and summed up to represent the residential property in South Africa (see the Results and Discussion section below for details)

Y represents the total financial losses from fires in South Africa in a given calendar year (see the Results and Discussion section below for details).

Finally, the percentage of call-outs for fire brigades in South Africa was recorded for the residential fires and/or by fires related to rubbish/bush/grass. These were calculated as a percentage of the total fire call-outs in South Africa and Makana Local Municipality (*designated as A in further text*). The percentages were calculated as shown in Equation (2).

$$A = 100 \times \frac{B}{C} \tag{2}$$

The terms in Equation (2) are analogical to the terms in Equation (1), except those financial losses were replaced by the number of the fire brigade call-outs in South Africa or Makana Local Municipality. Analysing the call-outs trends can indicate the type of assets most at risk from fires, as well as the potential of fuel control in the management of fires during droughts, and the fires which will require the allocation/use of most of the fire DRM resources in the country. The analyses of that data provide a better understanding of the burden of South African fires, which occur in residential settings. This might, in turn, indicate the potential optimisation of the DRM resource allocation to fires in South Africa, required to decrease the potential disaster impact of fires on the country's population.

If the domestic waste was not collected by local municipalities regularly for the 2004-2017 period, then that could increase the fuel load for the fires across South Africa. A correlation analysis was performed to investigate that point in more detail for the number of fire brigade call-outs due to rubbish/bush/grass and the percentage of South African/Makana households with regular refuse collection. The raw data for the latter variable was extracted from the General Household Survey by Statistics South Africa, or the Integrated Development Plans of Makana Local Municipality (see the Results and Discussion section for details). The correlation was examined using the Spearman correlation coefficient at a 5 % level of significance, just as with the above-mentioned correlations. The vegetation in the study is looked at as a fuel source and it is not the aim of this study to specifically link the causes of the fire to the vegetation type in a particular part of the country. The vegetation types and classification can be found at the South African National Biodiversity Institute (SANBI, 2022). Briefly, the following biomes are commonly found across South Africa: thicket biome, fynbos biome, grassland savanna biome, desert, Nama-Karoo, and succulent Karoo Biomes (SANBI, 2022). Thicket and fynbos types have also been reported to be present in Makana Local Municipality (Palmer, 2004). Local government services are not only necessary to protect wellbeing of the residents in an area, but the lack of waste collection can increase the fire hazards through the potential for fires spreading through the combustion of loose rubbish. This element will also be investigated in the current paper.

2.3. Prediction of the fire numbers for the 2018-2022 period

Data from the FPASA was used in this paper, as the authors found it to be the most complete and most fit for purpose from the data sources available on fire statistics in South Africa. Other data sources could be used if the level of data disaggregation would be similar to the FPASA database. An example of such data could the VIIRS system, but the damages and financial information is not the same, as reported in the FPASA database for the 2004-2017 period (Global Forest Watch, 2022). However, the level of detail and the information diversity is limited to a specific aspect of the fires, e.g. the burn intensity and area (Xulu et al., 2021). The FPASA data allows for the evaluation of the resource allocation and potential optimisation at the national and local level across South Africa. That was the main reason that the FPASA fire statistics database was selected by the authors of the current study. However it is clear that the data must be extended beyond 2017. Therefore, the authors attempted to model some aspects of the FPASA data for extrapolation beyond 2017. The total number of fires in South Africa was correlated as an independent, using the multiple linear regression analysis (Past 3.0, Hammer et al., 2001), with the human development index (HDI; Countryeconomy.com, undated; Human Development Report, 2020), the gross national product per capita based on purchasing power parity (GDP_{PPP} in USD; World Bank, 2022) and the interest of the South African public in fires/veld fires/veldfires by extracting total number of yearly searches on Google for the keyword fire through Keywordseverywhere.com (GSKEF in number of searches; Burivalová et al., 2018; Pretorius et al., 2022 and https://keywordseverywhere.com/; website accessed on 29th June 2022).

3. RESULTS AND DISCUSSION

3.1. Evaluation of the temporal trends in fires and fire losses/damages in South Africa for the 2004-2017 study period

Data from the FPASA in **Table 1** shows the total number of fire call-outs/fires and fire losses in South Africa from 2004 to 2017. The numbers indicate that the total number of fire brigade call-outs for the entire territory of South Africa ranged from 26574 in 2010 to 49567 in 2017. These are equal to the total number of fires in the given calendar year, with only one insignificant exception that did not have any effect on the results of the correlation analyses (data not shown). There was a direct and statistically significant increase in the total number of fire brigade call-outs/fires with time in South Africa between 2004 and 2017. That conclusion was supported by the value of the Spearman correlation coefficient, which was equal to 0.65385, and that value was statistically significant at 5 % of significance (*p*-value = 0.01535). At the same time, the directly proportional relationship was likely linear in nature, as indicated by the value of the Pearson correlation coefficient, which was equal to 0.58440, and that value was statistically significant at 5 % of significance (*p*-value = 0.03595).

Table 1.

Fire statistics and fire losses in South Africa, as based on the Fire Protection Association of South Africa between 2004 and 2017.

Year	Total losses from fires (ZAR)	*TFC*[a] (#)	Total residential losses from fires (ZAR)	Residential losses as percentage total (%)	Pages in data source	Website for source document
2004	1211926334	36591	492120909	40.61	Page 15, 17, 19	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2004.pdf
2005	1321494810	42863	350056269	26.49	Page 21	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2005.pdf
2006	2732970948	33499	2023916105	74.06	Pages 12, 18, 21	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2006.pdf
2008	2312573487	35434	504966938	21.84	Pages 28-30	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2008.pdf
2009	2013698822	40481	667102742	33.13	Pages 26-27	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2009.pdf
2010	1323019072	26574	613802753	46.39	Page 20	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2010.pdf
2011	2085522959	37721	728144691	34.91	Page 48	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2011.pdf
2012	3162240443	41481	744278394	23.54	Page 32	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2012.pdf
2013	2158223582	42343	1008867283	46.75	Page 34	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2013.pdf
2014	1847497349	46187	680486831	36.83	Pages 48 and 50	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2014.pdf
2015	2732024282	45784	1186434833	43.43	Pages 30-31 and 36	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2015.pdf
2016	3144851768	41873	1843930163	58.63	Pages 22, 23 and 28	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2016.pdf
2017	5481548883	49567	2773495906	50.60	Pages 18, 19 and 24	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2017.pdf

[a] *Total number of fires/fire brigade callouts in South Africa between 2004 and 2017. The unit for this parameter is dimensionless or number, marked with # in Table 1.*

For the 2004-2017 period, the total financial losses due to fires in South Africa ranged from 1.321 billion ZAR in 2005 to 5.482 billion ZAR in 2017 per year (exchange rate 1 USD = 6.1851-14.8171 ZAR: SARS, 2003-present). At the same time, the financial losses from fires in residential settings ranged, for the 2004-2017 period, from 350.056 million ZAR in 2005 to 2.773 billion ZAR in 2017. There was a direct and statistically significant increase in the financial losses from fires with time in South Africa for the analysed period. For the total financial losses, that conclusion was indicated by the value of the Spearman correlation coefficient, which was equal to 0.62637, and that value was statistically significant at 5 % of significance (*p*-value = 0.02199).

The directly proportional relationship was likely linear in nature, as indicated by the value of the Pearson correlation coefficient, which was equal to 0.65660, and that value was statistically significant at 5 % of significance (*p*-value = 0.01478). A similar correlation performed for the residential setting fire losses showed that the Spearman correlation coefficient was equal to 0.70879, and that value was statistically significant at 5 % of significance (*p*-value = 0.00668). This relationship was monotonous but likely not linear, as indicated by the Pearson correlation coefficient, which was equal to 0.52710, but was not statistically significant at 5 % of significance (*p*-value = 0.06382). Based on the correlation analysis of the fire loss data from the FPASA, it is clear that the financial losses from fires have been increasing in absolute terms in South Africa with time between 2004 and 2017. That increase was linear with time. There was an increase in fire losses in housing stock, and it was directly correlated with time, but not in a linear fashion. Losses from fire disasters in residential settings accounted for a significant portion of the financial fire disaster losses, as they accounted for between 21.84 and 74.06 % of all financial losses from fires in South Africa between 2004 and 2017.

3.2. Evaluation of the temporal trends in fire brigade call-outs in South Africa for the 2004-2017 study period

The FPASA data in **Table 2** indicate that the number of fire brigade call-outs for the entire territory of South Africa ranged from 26574 in 2010 to 49567 in 2017. In more detail, the number of fire brigade call-outs, which were related to fires in residential settings, ranged from 7170 in 2006 to 13123 in 2017. Finally, the number of fire brigade call-outs due to rubbish/bush/grass ranged from 16909 in 2010 to 28482 in 2017. For the number of fire brigade call-outs to residential fires, the Spearman correlation coefficient was equal to 0.85165, and that value was statistically significant at 5 % of significance (p-value = 0.00022). This relationship was monotonous and likely linear, as the value of the Pearson correlation coefficient which was equal to 0.82190 and that correlation was statistically significant at 5 % of significance (p-value = 0.00057).

Table 2.

Fire brigade call-outs in South Africa, as based on the Fire Protection Association of South Africa between 2004 and 2017.

Year	***TFC***[a] (dimen-sionless)	***RFC***[b] (dimen-sionless)	***RBGFC***[c] (dimen-sionsless)	***PRRBGFC***[d] (%)	Pages in data source	Website for source document
2004	36591	7505	23367	84.37	Pages 26,27	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2004.pdf
2005	42863	7423	28165	83.03	Pages 22,23	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2005.pdf
2006	33499	7170	19271	78.93	Page 26	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2006pdf
2008	35434	7207	22228	83.07	Pages 32-33	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2008.pdf
2009	40481	8496	24683	81.96	Page 32-33	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2009.pdf
2010	26574	5391	16909	83.92	Page 22	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2010.pdf
2011	37721	8330	22646	82.12	Page 39	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2011.pdf
2012	41481	9491	23977	80.68	Page 28-29	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2012.pdf
2013	42343	10199	24989	83.10	Page 26-27	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2013.pdf
2014	46187	10514	28482	84.43	Pages 42-43	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2014.pdf
2015	45784	11326	25882	81.27	Pages 26-27	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2015.pdf
2016	41873	10555	20684	74.60	Pages 16-17	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2016.pdf
2017	49567	13123	26866	80.68	Pages 14-15	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2017.pdf

[a] *Total number of fires/fire brigade callouts in South Africa between 2004 and 2017.*
[b] *Dwellings, informal dwellings, flats and hotels/boarding houses in South Africa between 2004 and 2017.*
[c] *Rubbish, grass and bush fire brigade call-outs in South Africa between 2004 and 2017.*
[d] *Dwellings and rubbish call-outs as percentage of all total call-outs in South Africa between 2004 and 2017.*

The correlation analyses were repeated for the number of fire brigade call-outs to fires linked to the rubbish/bush/grass. The relevant Spearman correlation coefficient was equal to 0.28571, and that value was not statistically significant at 5 % of significance (*p*-value = 0.34400). The respective relationship was not monotonous and likely not linear, as the Pearson correlation coefficient was equal to 0.21350 and, therefore, not statistically significant at 5 % of significance (*p*-value = 0.48370). Based on the data from the FPASA, it is clear that the number of fire brigade call-outs increased overall in South Africa between 2004 and 2017. An analogical trend was observed for the call-outs to residential fires, but not for fires related to rubbish/bush/grass. For the 2004-2017 study period, the call-outs to fire brigades, which had a residential cause or related to rubbish/bush/grass, accounted for an average of 81.7 ± 2.7 %. This indicates that fires in residential settings, or fires related to rubbish/bush/grass, accounted for a significant majority of the time fire brigades spent fighting fires in South Africa between 2004 and 2017. Fuel and waste management, as well as increasing the fire human resilience at the household level, will play a significant role in the fire DRM in South Africa. This is based on the likelihood that fire DRM resources might become insufficient o fight fires during drought related conditions. The number of fire brigade call-outs between 2004 and 2017 were correlated with the household percentage in South Africa with regular refuse collection. The raw data is shown in **Table 3** below.

Table 3.

Fire brigade call-outs in South Africa due to rubbish/bush/grass, as based on the Fire Protection Association of South Africa, and correlation with the percentage of the South African households with regular municipal refuse collection between 2004 and 2017.

Year	*RBGFC*[a] (dimensionless)	*PHRRR*[a] (dimensionless)	General Household survey raw data location	Website for source document
2004	23367	57.1	Figure 28 on page xxxi	https://www.statssa.gov.za/publications/P0318/P03182004.pdf
2005	28165	60.1	Figure 20 on page xxvii	https://www.statssa.gov.za/publications/P0318/P03182005.pdf
2006	19271	60.6	Figure 20 on page xxx	https://www.statssa.gov.za/publications/P0318/P03182006.pdf
2008	22228	60.5	Figure 21 on page 31	https://www.statssa.gov.za/publications/P0318/P03182008.pdf
2009	24683	55.1	Figure 25 on page 32	https://www.statssa.gov.za/publications/P0318/P03182009.pdf
2010	16909	59.1	Figure 26 on page 32	https://www.statssa.gov.za/publications/P0318/P03182010.pdf
2011	22646	61.0	Figure 31 on page 34	https://www.statssa.gov.za/publications/P0318/P03182011.pdf
2012	23977	64.0	Figure 33 on page 35	https://www.statssa.gov.za/publications/P0318/P03182012.pdf
2013	24989	63.5	Table 13 on page 50	https://www.statssa.gov.za/publications/P0318/P03182013.pdf
2014	28482	63.8	Table 13 on page 51	https://www.statssa.gov.za/publications/P0318/P03182014.pdf
2015	25882	63.5	Table 13 on page 48	https://www.statssa.gov.za/publications/P0318/P03182015.pdf
2016	20684	64.9	Table 12 on page 47	https://www.statssa.gov.za/publications/P0318/P03182016.pdf
2017	26866	65.9	Table 13 on page 45	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2017.pdf

[a] *Rubbish, grass and bush fire brigade call-outs in South Africa between 2004 and 2017.*
[b] *The percentage of households with regular municipal refuse removal in South Africa between 2004 and 2017.*

There was no statistically significant relationship at a 5 % level of significance, as indicated by the value of the Spearman correlation coefficient and the *p*-value (0.26685; *p*-values = 0.37814). Therefore, rubbish uncollected by local government is not the only controlling factor, in determining the number of fires/fire brigade call-outs, due to rubbish/bush/grass. As a result, the plant fuel might play a more significant role in the fire triangle relevant to the fire-prone and drought-stricken areas in South Africa between 2004 and 2017 (Madondo et al., 2022).

To avoid the ecological fallacy of applying national data to the local level, the South African conclusions were compared to those for Makana Local Municipality as an example. Rhodes University is based in Makana Local Municipality, and the area has been impacted by drought since about 2015 (as indicated, for example, by Iheanetu and Tandlich, 2022). Drought will require alteration of the existing fire-fighting approaches, as the volumes of water available for such purpose might not be sufficient or might be decreased to pre-drought status. Therefore, it is necessary to evaluate whether the resources of fire brigades are required for similar or different activities compared to the entire South Africa. Therefore, the FPASA data in **Table 4** show the number of fire brigade call-outs in Makana Local Municipality for the 2004-2017 study period. The number of call-outs, or the total number of fires in the municipality, ranged from 99 in 2015 to 280 in 2016. The number of fire brigade call-outs related to fires in residential settings ranged from 26 in 2014 to 70 in 2016. Finally, the number of fire brigade call-outs between 2004 and 2017, which were related to fires by rubbish/bush/grass in Makana Local Municipality, ranged from 62 in 2015 to 153 in 2005. There was no statistically significant relationship between the number of the total fire brigade call-outs, nor the call-outs to residential fires or fires related to rubbish/bush/grass and time between 2004 and 2017.

Table 4.

Fire brigade call-outs in Makana Local Municipality, as based on the Fire Protection Association of South Africa between 2004 and 2017.

Year	*TFC*[a] (dimen-sionless)	*RFC*[b] (dimen-sionless)	*RBGFC*[c] (dimen-sionless)	*PRRBGFC*[d] (%)	Pages in data source	Website for source document
2004	159	36	112	93.08	Pages 26,27	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2004.pdf
2005	194	27	153	92.78	Pages 22,23	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2005.pdf
2006	135	42	72	84.44	Page 26	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2006pdf
2008	218	45	149	88.99	Pages 32-33	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2008.pdf
2009	144	36	82	81.94	Page 32-33	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2009.pdf
2010	145	42	88	89.66	Page 22	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2010.pdf
2011	172	54	98	88.37	Page 39	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2011.pdf
2012	152	36	108	94.74	Page 28-29	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2012.pdf
2013	146	30	86	79.45	Page 26-27	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2013.pdf
2014	144	26	108	93.06	Pages 42-43	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2014.pdf
2015	99	29	62	91.92	Pages 26-27	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2015.pdf
2016	280	70	182	90.00	Pages 16-17	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2016.pdf
2017	136	41	71	82.35	Pages 14-15	https://www.fpasa.co.za/images/FireStats/Fire_Stats_2017.pdf

[a] *Total number of fires/fire brigade callouts in Makana Local Municipality between 2004 and 2017.*
[b] *Dwellings, informal dwellings, flats and hotels/boarding houses in Makana Local Municipality between 2004 and 2017.*
[c] *Rubbish, grass and bush fire brigade call-outs in Makana Local Municipality between 2004 and 2017.*
[d] *Dwellings and rubbish call-outs as percentage of all total call-outs in Makana Local Municipality between 2004 and 2017.*

That conclusion was supported by the value of the Spearman correlation coefficients, which ranged from -0.29711 to 0.01936, for the Makana data. None of the correlations were statistically significant at 5 % of significance (*p*-values = 0.40941- 0.94994). For the 2004-2017 time period, the call-outs to fire brigades, which had a residential cause or were caused by rubbish/bush/grass, accounted for an average of 88.5 ± 4.9 % of all fire brigade call-outs in Makana Local Municipality. That proportion was statistically significantly different from the analogical proportion for the entire territory of South Africa (*t*-test at 5 % level of significance, *p*-value = 0.0001). Therefore, just like for the entire territory of South Africa, fuel/waste management and increasing the fire human resilience at the household level will play a significant role in the fire DRM in Makana Local Municipality. This will be based on the drought and the potential insufficient fire-fighting resources available to fight such fires in South Africa and in Makana Local Municipality. The Integrated Development Plans (IDPs) for Makana Local Municipality could only be found from 2011 until 2017 (see http://www.makana.gov.za/wp-content/uploads/2013/06/Final-Document-IDP-2016-2017.pdf for details; website accessed on 19th May 2022). Only the 2001-2011 census figure for the access to regular municipal refuse removal could be found; more specifically the 2011 figure was equal to 89.6 % of all Makana households. Based on this point estimate, vegetation management will, therefore, likely play a significant role in the fire DRM under the conditions of drought in Makana, just like concluded for South Africa. In addition, littering or illegal dumping is non-designated landfills/areas by Makana residents might provide another plausible explanation.

3.3. Prediction of the fire numbers for the 2018-2022 period

The fire call-out were equal to the number of fires in South Africa for the given calendar year between 2004 and 2017. Data on the HDI, GDP_{ppp} and the GSKEF were compiled for the 2004-2017 period, and they are listed in **Table 5** below.

The 2018-2022 period was modelled based on the following reasoning. The number of fires can be expected to be correlated to the level of development of the given country. In other words, the value and number assets at risk from fire disasters can reasonably be expected to be linked to the level of development of the country and wealth/economic value or status in a given country. In addition, the level of education and health/wellbeing of the country's population will be linked to the and the interest of the population in a type of disaster, i.e. fire. Therefore, the authors of the current study attempted to develop an equation that could be used to predict the fire statistics, namely the *TFC* in relation to HDI, GDP_{ppp} and the GSKEF. For this, data from **Table 5** was used and the correlations were performed as the multiple linear regression analysis as shown in Equation (3).

$$TFC = -70815(\pm 24997) + 2.109 \times 10^5(\pm 66527) \times HDI + 3.8151(\pm 1.6507) \times GDP_{\mathrm{PPP}} + 0.1513(\pm 0.1013) \times GSKEF; R^2 = 0.7580 \quad (3)$$

For Equation (3), 12 points in the correlation yielded the following statistical data for ANOVA: *F*-statistic 8.354, *df1* = 3 and *df2* = 8 and *p*-value = 0.0075735. At the same time, the adjusted R^2 value was equal to 0.66729. The *TFC* value for 2010 was removed to increase the R^2 value from around 0.57 to 0.7580.

The Graphpad online outlier calculator (see https://www.graphpad.com/quickcalcs/grubbs2/ for details; website accessed on 2nd August 2022) was used to assess whether the 2010 value of *TFC* is a statistically significant outlier or not. The *Z* value for the 2010 value of *TFC*, namely 26574, was equal to 2.21. The critical *Z* value was equal to 2.462 and *p*-value was higher than 0.05. Therefore the 2010 value of *TFC* was not statistically significantly an outlier at 5 % level of significance. However, the value was removed to improve the quality of the fit in the multiple linear regression and the justification for this step is based on the following reasons: increase in the R^2 value, the standard deviation of the optimised values of adjustable parameters were mostly below 50 % of the parameter value and the recalculated *TFC* values from Equation (3) were 100 ± 6 % of the actual FPASA values. Therefore, the predictions in the 2004-2017 interval were reliable based on Equation (3). It is, however, also true that the adjusted R^2 values indicated that the used independent variables were only able cumulatively to account for around 66 % of the variance in the dependent variable. Therefore, other parameters could influence the number of fire brigade call-outs in South Africa. The values of the fire brigade call-outs were extrapolated to the 2018-2022 period and the assumptions made are shown in **Table 5**. The predicted number of fire brigade call-outs ranged from 43064 to 46997. In 2021, a total of 126169 fires were reported countrywide in South Africa and the most affected provinces were the Eastern Cape, the North-West and Mpumalanga (Sgqolana, 2021). Therefore, the prediction from Equation (3) should be multiplied by 2.862 to get the extrapolation close to the real-life data. However, the difference in the data collation methodology might also have to be examined, as a potential source of discrepancy.

Table 5.

Fire brigade call-outs as a function of the level of human development, gross domestic product per capita and the total number of Google searches for fire in South Africa between 2004 and 2017.

Year	*HDI*[a] (dimensionless)	GDP_{PPP}[b] (USD)	*GSKEF*[c] (dimensionless)	*TFC*[d]
2004	0.619	10061.5974	120100	36591
2005	0.622	10790.3306	128370	42863
2006	0.626	11599.1032	115300	33499
2008	0.646	12857.9865	121440	35434
2009	0.655	12565.2928	130690	40481
2010	0.664	12913.5405	126110	26574
2011	0.665	13393.7669	142860	37721
2012	0.675	13215.7087	146965	41481
2013	0.685	13606.9429	138926	42343
2014	0.693	13602.1026	129226	46187
2015	0.701	13701.9454	143326	45784
2016	0.703	13748.4614	127266	41873
2017	0.705	13860.2702	147312	49567
2018	0.707	14207.4329[f]	125411	43064
2019	0.709	14288.5899[f]	138404	45143
2020	0.709[e]	13359.4843[f]	127236	46997
2021	0.709[e]	14420.1743[f]	134663	44075
2022	0.709[e]	14420.1743[f]	151266	46587

[a] *Human Development Index in the given calendar year between 2004 and 2017.*
[b] *Gross domestic product per capita based on purchasing power parity between 2004 and 2017.*
[c] *Total yearly Google searches for the search term 'fire' in South Africa between 2004 and 2017.*
[d] *Total number of fires/fire brigade callouts in South Africa between 2004 and 2017.*
[e] *The HDI values for 2020-2022 were assumed to be constant and equal to the 2019 value. This is based on the likely decline and recovery from the COIVD19 pandemic*

3.4. Integrating remarks on the data analysis and comparison with literature

The World Meteorological Organisation reported that the number of wildfires will go up by 14 % between the present and 2030 (WMO, 2022). There will also be a further increase of 50 % by 2050 compared to the current fire numbers (WMO, 2022). For Botswana, Maabong and Mphale (2021) reported that the El-Niño/La-Niña oscillation in Southern Africa can lead to the growth of plants and thus an increase in fuel. That would be followed shortly by the occurrence of wildfires, which ranged from 37 to 938 between 2006 and 2017 in Botswana (Maabong and Mphale, 2021). On a broader time scale, the number of wildfires in Botswana ranged from about 20 to about 350 between 1994 and 2009, with most of them being of human origin (Maabong and Mphale, 2021). In 2017, a mega-fire hit the area in the Southern Cape and, more specifically the area around the City of Knysna (Kraaij et al., 2018). The triggers for the fire were multi-fold, but the commercial forestry plantations of alien vegetation (namely pine trees) and the fire-prone atmospheric conditions contributed to the severity of the fire losses (Kraaij et al., 2018). Therefore data from this study could indicate that vegetation cover and management will play a key role in the fire DRM in South Africa, as well as in local municipalities such as Makana. The current paper is based on open-source data that is freely available and that can be used to investigate the trends in the fires in South Africa. This is the case in terms of overall number of fires and the factors driving them. The FPASA data base was deemed the most complete in South Africa and was therefore used.

4. CONCLUSIONS

The number of fires and the losses from fires increased between 2004 and 2017. Fires in residential settings, or fires related to rubbish or plant-based fuel, account for a significant majority of the time that fire brigades spent fighting fires in South Africa between 2004 and 2017. Therefore, fuel and waste management, as well as increasing the fire human resilience at the household level, will play a significant role in the fire DRM in South Africa. This will apply to national, as well as local context in local municipalities such as Makana.

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