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Research article

Investigating the trend of road traffic fatalities in Malawi using Mann-Kendall statistic

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ABSTRACT

Fatalities due to road accidents remain a major challenge worldwide. In the recent years, Malawi, one of the developing African countries with a total population of about 19 million has also been witnessing a very high fatality rate [of about 31 crash deaths per 100,000 population in 2016] compared to most of its neighbours in the region. This seems to be continuously increasing even with several intervention measures, such as, speed and alcohol impairment laws, and laws for mandatory seatbelt and helmet use. In view of this, the study attempted to investigate the trend of road fatalities in Malawi, such that effectiveness of the existing measures can be established. For this, archived crash data of road fatalities between years 2000–2021 were used to undertake intervention and trend analyses. The method of Cumulative Summation was used to identify intervention points in the series, followed by the Mann-Kendall statistic (τ) to determine the trend during the intervened period using the non-parametric Rank-Sum test to support the findings. The results showed that the trend has been decreasing in the early years of legislating policy measures [2000–2012] and, thereafter [2013–2021], increased significantly [$\tau = 0.8333$]. This suggests that there was acceptance of the measures by the motorists/public in the early years of implementation [2000–2012], which might have been overshadowed by vehicle population growth and weak enforcement mechanism that have seen the trend increasing lately. The study therefore suggests that there is still a scope to review the intervention measures in their effective implementation as well as regular monitoring.

1. Introduction

Road traffic accidents therefrom have been seen to have significant social ramifications due to a large number of deaths, disabilities and injuries. It is estimated that, as high as 1.35 million lives annually are lost globally with more than 50% of them belonging to the slow moving categories such as: pedestrians, cyclists and motorcyclists [1,2]. Typically, pedestrians, cyclists and motorcyclists representing 54% of all deaths are possibly the hardest hit compared to the numbers from motorised four wheelers comprising 29% [1]. Disproportionately, 93% of all road traffic deaths occur in developing countries [2,3], even though these countries have approximately

Abbreviations: CUSUM, Cummulative Summation; DRTSS, Directorate of Road Traffic and Safety Services; Eq., Equation; GDP, Gross Domestic Product; SADC, Southern African Development Community; US, United States; WHO, World Health Organisation.

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60% of the world's vehicles [3]. The scale of response not matching the scale of the problem has been highlighted in the WHO Global report of 2018 as the basis for the number of road traffic deaths on the world's roads to remain unacceptably high [1]. The report has also stated that the global impact of road traffic accidents on families, communities, countries and health systems is extreme [1], which clearly shows that significantly more action is needed to make the world's roads safer [4].

Malawi, a developing country located in the southern African region, has equally been affected by the impact of road traffic fatalities as witnessed elsewhere across the world. For example, as per the WHO Global report [1], the fatality rate in 2016 was estimated at 31 crash deaths per a 100,000 population against the country's vehicle ownership of less than half a million. This fatality rate, compared to the global and regional data [1], is possibly one of the highest in the world and the African region respectively. The country's fatality rate is also estimated to be the third highest in the Southern African Development Community (SADC) after the Democratic Republic of the Congo (33.7 deaths per 100,000) and Zimbabwe (34.7 deaths per 100,000) [1]. This may be attributed to limited understanding of the factors that lead to road crashes and their influence on road fatalities and in turn might have resulted in implementation of inappropriate and/or ineffective mitigation measures for reduction of the noticed high fatality rates in Malawi.

The cost associated with road crashes in Malawi being one of the highest in the world, adds another dimension to its economic growth. It is estimated that Malawi loses up to 10.8% of her gross domestic product (GDP) annually [3] compared to a global average of 3% [3]. Thus, Malawi lost about 588 million US dollars (i.e., 10.8% of 5.43 billion US dollars) in road crashes in 2016 [5], which represented almost 47% of the national budget in that year. Malawi's national budget 2016/2017 was pegged at 965.2 billion Kwacha (or 1.262 billion US dollars) [6]. The losses from road crashes, according to WHO, arise from the cost of treatment as well as loss of productivity for those killed or disabled by their injuries, and for family members who need to take time off work or school to care of the injured [3].

While road traffic injuries are world's leading killer of children and young adults aged 5–29 years [1,3], in Malawi, economically productive age groups [15–64 years] are among the most vulnerable road users, accounting for 62% of all the road traffic fatalities and injuries [5]. This could explain the intensity of impact road crashes have on the well-being of the Malawian society as these people [the productive age groups] are the ones that drive the economy at household and national levels [7].

Based on the facts given above, it can be highlighted that Malawi pays a very high price for mobility, regardless that intervention measures exist. For example, Malawi has enacted and enforcing speed limits, alcohol impairment laws, and laws for mandatory seatbelt and helmet use [1,8,9] as a strategy to reduce the risks of the critical factors of road traffic fatalities [1,10]. Therefore, speedy action, such as trend analysis of the road traffic fatalities, is needed to evaluate the effectiveness of the intervention measures. The aim of this study is therefore to investigate the current trend of road traffic fatalities in Malawi. The trend will also help Malawi to project future fatalities and plan future intervention measures and enforcement mechanism.

A number of studies have been undergoing in many countries of the world to investigate on the trend in road traffic fatalities and the effectiveness of the intervention measures implemented to mitigate the fatalities. It has been noted that time series models have been commonly used in these investigations. For example, Abdulkabir, Tunde [11] used time series analysis in their studies to determine the direction of the trend of the number of road accidents in Ibadan, Oyo state, Nigeria and found that there will be an increase in the number of accident occurring in the near future. Parvareh, karimi [12] also made use of time series models to assess and predict the road accident trend in Kurdistan Province, Iran and findings indicated increasing trends of the car occupants' and motorcyclists' injuries during the period 2009–2017. The analysis of road traffic crashes in the state of Qatar [13] also used time series

Table 1
Computed CUSUM (Y_t values).

Year	Fatalities (X_i)	X_{mean}	CUSUM [$Y_t = \sum_{i=1}^{t}(X_i - X_{mean})$]
2000	342	895.72	−553.7
2001	321		−1128.4
2002	453		−1571.1
2003	432		−2034.9
2004	283		−2647.6
2005	1027		−2516.3
2006	930		−2482.0
2007	841		−2536.8
2008	942		−2490.5
2009	863		−2523.2
2010	976		−2443
2011	784		−2554.7
2012	880		−2570.4
2013	1058		−2408.1
2014	1062		−2241.9
2015	1068		−2069.6
2016	1121		−1844.3
2017	1142		−1598.0
2018	1275		−1218.8
2019	1241		−873.5
2020	1221		−548.2
2021	1444		0

Source: National Crash Database (Malawi) models to evaluate the trend of the crash rate over time and the results revealed that the total number of the crashes leading to severe injuries showed an increasing trend from 2010 to 2016 and were to continue increasing until 2018.

Time series models may have been seen sometimes as providing precise estimates of the trends and predict accurate estimates of road traffic accidents as its outcome [14] hence preferred by many researchers. However, research has shown that the time series should be congregated over long period of time if these results were to be achieved [15–17]. For example, the study of Raeside and White [18] suffered less reliable projections as they used eight years' worth of data to forecast for 10 years. Thus, conditions of parsimony were greatly violated [19]. The present study could suffer a similar problem because the data for analysis covers a shorter period of time [$n = 22$]. Thus, time series model may not provide the most precise estimates for Malawi. Therefore, there is need to apply a different inferential statistic such as intervention and trend analysis to obtain reliable projections.

2. Methodology

The following sections discuss the methods used for collecting and analysing data for investigating the trend of road fatalities in Malawi using them for determining the effectiveness of the intervention measures implemented to mitigate the fatalities.

2.1. Data type and sources

Archived crash data for road fatalities for the period 2000–2021 [see Table 1] were used to obtain inferential statistics. Inferential statistics such as intervention and trend analyses were used to identify step changes in the fatalities and determine their trend. The data used were also for the same period [2000–2021] and these data [see Table 1] were retrieved from the national crash database kept and managed by the Malawi Directorate of Road Traffic and Safety Services (DRTSS). The DRTSS data were collected at the scene by police officers in the Traffic Section. In Malawi, a death is considered a result of a road accident if the victim dies instantly or within 30 days of the crash [1,8,20].

2.2. Data analysis

For the trend analysis of time series, there are three key steps that are performed sequentially. The first step is to subject the data to intervention analysis. If interventions are present, a statistical test is undertaken to confirm the existence of interventions in the series. When confirmed of an intervention, trend analysis is performed on time series after the year of intervention. If the statistical test rejects assumption of intervention, trend analysis is undertaken on the whole time series. In this study, the three analyses are the (i) identification of likely year of intervention, (ii) step change analysis for confirmation of the identified year of intervention and (iii) trend analysis. These analyses are presented below.

2.2.1. Identification of likely year of intervention

Intervention analysis can be performed using the Cumulative Sum [CUSUM] method given in Hipel and McLeod [21] to determine the likely date/time of intervention in a given time series, or changes in environmental regime [22], if any. Razali, Abdullah [23] also used CUSUM methodology in examining conformance of the quality of the fertilizer production and even the method has been used in psychometric research to detect aberrant responses in a response sequence, e.g., test speediness, inattentiveness, or cheating [24]. On the whole, CUSUM is a well-established statistical process control method to detect changes in a sequence [24], hence has been used for determining the impact of intervention measures such as on road fatalities, if any.

The CUSUM were calculated from Ref. [25]:

$$Y_t = \sum_{i=1}^{t} (X_i - X_{mean}) \qquad [1]$$

where $X_{mean} = \sum_{i=1}^{n} \left(X_i/_n \right)$ and n is the number of observations.

The CUSUM computed using Eq. (1) are then plotted against years of observation (t_i). When observations in the plot [Y_t versus t_i] [22] appear to wave across a horizontal line of zero Y_t value, it suggests that the time series is not subjected to any interventions. But a steady decline or rise from winding pattern would suggest an intervention in the corresponding year, t_i [22]. A positive slope of the plot shall indicate the step change is increasing while the reverse is true for a decreasing step change [25,26].

Changes in a time series could either be gradual, or sudden (step change), or a combination of the two [27]. The test undertaken to confirm the existence of intervention in the series was rank-sum test. The choice of rank-sum test was based on consideration that the sample size is small [$n = 22$]. The rank-sum test is based on a non-parametric procedure to overcome the problems of small sample sizes [28,29]. The two series split by the year of change due to possible intervention [22] is then subjected to a step change analysis as given in the section below.

2.2.2. Step change analysis for confirmation of the identified time of intervention

The rank-sum test, a non-parametric test for difference in medians of two series split representing before and after intervention period used to test for any sudden changes or step changes [22,30,31]. The test is sometimes referred to as Wilcoxon rank-sum test, or Mann-Whitney test or a combination of the two [Wilcoxon-Mann-Whitney rank-sum test] [31,32].

The standard outline in computing the rank-sum test statistic [22,29,33,34] is given below.

(i) Rank all the data from 1 (smallest) to N (largest). In the case of ties (equal data values) the average of the ranks is used.
(ii) Compute a statistic 'S_m' as the sum of the ranks of the observations in the smaller group (the count or number of observations in the smaller group (i.e., series before intervention) is denoted as k, and the count or number of observations in the larger group (i.e. series after intervention) is denoted as m, and
(iii) Compute the theoretical mean (μ) and standard deviation of (σ) for the entire sample, given as [33–35]:

$$\mu = k(k+m+1)/2 \quad [2]$$

$$\sigma = \left\{ \left[km(k+m+1)/12 \right]^{0.5} \right\} \quad [3]$$

The test statistic Z_{rs} is computed as [33–35]:

$$\left.\begin{aligned} Z_{rs} &= (S_m - 0.5 - \mu)/_{\sigma} \quad \text{if } S_m > \mu \\ &= 0 \quad \text{if } S_m = \mu \\ &= (S_m + 0.5 - \mu)/_{\sigma} \quad \text{if } S_m < \mu \end{aligned}\right\} \quad [4]$$

The null hypothesis H_0 is that no change has occurred in the time series or that the two samples come from the same population [i.e. have the same median] and is accepted when the computed Z_{rs} is less than the critical tabulated Z-value (1.96) obtained from a normal distribution table at 5% significance level [33–35].

2.2.3. Trend analysis

Suppose intervention exists in the series and has been confirmed, the next step would be to analyse trends in the series after intervention. The trend could be analyzed by using Mann- Kendall method and this method was developed by two scientists, Mann and Kendall [36,37]. A number of studies have also used this method in determining the trend of their data [26,38–41]. The Mann-Kendall technique [τ] is given as follows [26,42]:

$$\tau = 2S/_{[n_3(n_3-1)]} \quad [5]$$

where Tau [τ] is the trend characteristic, S is the sum of differences between observations ($x_j - x_i$), as per Equation (6) and n_3 is the total sample size of the observations under trend analysis or after intervention.

The value of S [22,26,42] is given by:

$$S = \sum_{i-1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i) \quad [6]$$

where

$$\operatorname{sgn}(x_j - x_i) = 1 \text{ if } (x_j - x_i) > 0$$

$$= 0\text{if } (x_j - x_i) = 0$$

$$= -1 \text{ if } (x_j - x_i) < 0$$

Then, the matrix of $i * j$ is constructed to obtain the value of S.

Substituting the value of S in Eq. (5), the Mann- Kendall-Tau [τ] is calculated and the value of τ [22,26,42] will define the trend as: where $\tau > 0$ Indicates an increasing trend, $\tau = 0$ Indicates trend is steady or homogeneous, $\tau < 0$ Indicates decreasing trend

The results of this analysis (i.e. the value) notified the status of road traffic fatalities in Malawi in the context of trend i.e. whether the trend was on an increase or decreasing or steady/homogeneous. Through the observed trend, the study determined the effectiveness of the policy measures presented in the introduction and recommended review of these measures if there was a need.

3. Results

The trend analysis was conducted in two stages namely.

(i) Intervention analysis that determined the impact of intervening measures on the road fatalities and on their trends, and
(ii) Trend analysis that established the trend of the fatalities in Malawi.

3.1. Intervention analysis

The intervention analysis was performed using CUSUM approach. Using Equation [1], the CUSUM were constructed such that a plot of Y_t values against the years can be done to identify the possible year(s) of intervention(s), if any. The computed CUSUM (Y_t values) are presented in Table 1.

A plot of CUSUM [Y_t values] against the years is illustrated in Fig. 1. The plot has steady negative slope in the period 2000–2004 and, thereafter, waves along a horizontal line [2005–2012] and in a positive grade [2013–2021]. This suggests that the fatalities were subjected to possible interventions [22,25] at 2004 and 2012, which need to be confirmed by using Equation (4).

3.2. Rank-sum test

The total number of observations (sample size) being small [$n = 22$] a non-parametric rank-sum test was performed on the split samples to confirm the existence of an intervention in the series at 2004 and 2012. For this, the approach of rank-sum test [28,29] was taken. The parameters and their values used for computing rank-sum test statistics are presented in Table 2.

Using m = 17[2004]/9[2012], k = 5[2004]/13[2012] and N = k + m = [5 + 17 or 9 + 13] = 22, the values of μ and σ were computed using Equation [2] and Equation [3] respectively and were found to be 57.5[2004]/149.5[2012] and 12.76 [2004]/14.97 [2012].

The sum of the ranks, computed for the series before intervention at 2004 [2000–2004] was found to be 15 and 91 for the series before intervention at 2012 [2005–2012].

Since [15]/[91] $< \mu$ [57.5]/[149.5] [see Table 2], the test statistics for the two intervention tests [2004 and 2012] were determined from

$$Z_{rs} = \left(\frac{S_m + 0.5 - \mu}{\sigma}\right), \text{If } S_m < \mu$$

Thus,

$$Z_{rs}\ (2004) = \left(\frac{15 + 0.5 - 57.5}{12.76}\right) = -3.29$$

and

$$Z_{rs}\ (2012) = \left(\frac{91 + 0.5 - 149.5}{14.97}\right) = -3.87$$

The null hypotheses H_0 for the two intervention tests at 2004 and 2012 were thus rejected as the statistic values [Z_{rs} (2004) = − 3.29/Z_{rs} (2012) = − 3.87] were found to be insignificant [$Z_{rs} = -3.29/-3.87 < -1.96$ or $Z_{rs} = 3.29/3.87 > 1.96$, p-value = 0.05], suggesting the existence of interventions at 2004 and 2012.

3.3. Trend analysis

Since interventions exist in the time series [observed fatalities] and have been confirmed, the next step was to analyse the trend in series [1] before intervention at 2004 [2000–2004], [2] after intervention at 2004 and before intervention at 2012 [2005–2012], and

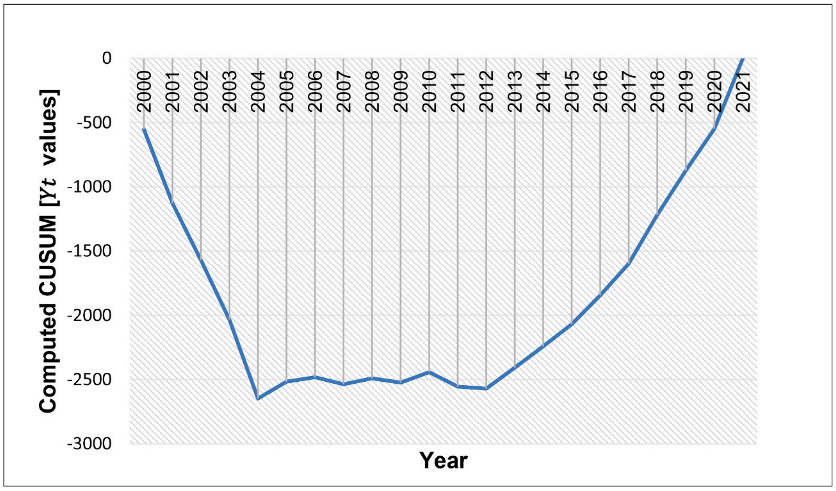

Fig. 1. Plots of CUSUM [Y_t] against years of data collection.

Table 2
Rank-Sum test statistics.

Ranked values	Rank	Fatalities before intervention		Rank		Fatalities after intervention		Rank		μ		σ	
		2004	2012	2004	2012	2004	2012	2004	2012	2004	2012	2004	2012
283	1	342	342	3	3	1027	1058	13	14	57.5	149.5	12.76	14.97
321	2	321	321	2	2	930	1062	10	15				
342	3	453	453	5	5	841	1068	7	16				
432	4	432	432	4	4	942	1121	11	17				
453	5	283	283	1	1	863	1142	8	18				
784	6	**k = 5**	1027	**S_m = 15**	13	976	1275	12	21				
841	7		930		10	784	1241	6	20				
863	8		841		7	880	1221	9	19				
880	9		942		11	1058	1444		22				
930	10		863		8	1062	**m = 9**						
942	11		976		12	1068							
976	12		784		6	1121							
1027	13		880		9	1142							
1058	14		**k =13**		**S_m=91**	1275							
1062	15					1241							
1068	16					1221							
1121	17					1444							
1142	18					**m = 17**							
1221	19												
1241	20												
1275	21												
1444	22												

[3] after intervention at 2012 [2013–2021]. However, [3], rather than [1] and [2], could be supportive to law enforcement agencies and decision makers in road safety for determining the current and near future status of road traffic fatalities in Malawi. It could also be used for investigating the effectiveness of intervening policies put in place by the Government, which might call for their possible review.

Using Equation (6) and (5), the values of S and Mann-Kendal-Tau [τ] were computed and are presented in Table 3. The results [Table 3] show that the trend was decreasing [$\tau = -0.2$] in the years before intervention at 2004 [2000–2004] and continued to decrease [$\tau = -0.2857$] up to 2012. But, thereafter [2013–2021], the trend increased significantly [$\tau = 0.8333$]. Factors such as [1,43] weak enforcement of policies and regulations, inadequate funding for road safety activities and poor emergency medical services [EMS] should be some of the major factors for the increasing trend. For example, according to the Global Status Report 2018 [1], speed limit enforcement is at 40%, drink-driving law enforcement, at 40%, motorcycle helmet law enforcement, at 20% and seatbelt law enforcement, at 30%, which clearly influences high number of road crashes and fatalities.

4. Discussion

The study applied the intervention and trend analysis respectively to determine the trend on road fatalities in Malawi and evaluate the effectiveness of the impact of mitigation measures on the fatalities. The Mann-Kendal-Tau value [$\tau = 0.8333$] indicates that the trend of road fatalities in Malawi is of late [2013–2021] on the increase. Oreko, Nwobi-Okoye [14] attribute the increase in the rate of fatalities from road crashes in many developing nations primarily to human, technical/vehicular and environmental factors as well as urbanization, industrialization, population growth and increase in the number of motor vehicles on the roads. Urbanization [44,45], industrialization [45,46], population growth [45,47,48] and growth in vehicle ownership [44,49,50] are shown to have cost implication on public health as an increase in levels of these factors have also showed increases in the road traffic fatalities. Thus, concerted efforts to mitigate the impact of these factors on the fatalities could be the possible solution.

5. Conclusions

The trend on road fatalities has been assessed and the outcome shows that it has been substantially decreasing in the early years of legislating policy intervention measures [2000–2012] and, thereafter, increased significantly [$\tau = 0.8333$]. This suggests that there was acceptance of the measures of intervention by the motorists/public in the early years of implementation [2000–2012], which

Table 3
Computed S and Mann-Kendal-Tau (τ) values.

Series	N	S-value	Mann-Kendal-Tau [τ]
2000–2004	5	−2	−0.2
2005–2012	8	−8	−0.2857
2013–2021	9	30	0.8333

might have been overshadowed by vehicle population growth and weak enforcement mechanism that have seen the trend increasing lately.

Unless drastic measures are taken to reduce the trend, it is likely that Malawi will considerably fail to meet fatality reduction targets set in its road safety strategy [1] and, most importantly, the goals of the UN Decade of Action for Road Safety 2021 to 2030 [i.e. to prevent at least 50% of road traffic deaths and injuries by 2030] [51].

In view of the above and keeping the country's road safety in view, there is a need to review the existing intervention measures and formulate strict policies/guidelines such as: further reduction in speed limits [separately for the settlement zones, bad roads, highways]; in the allowable limits for driving under the influence of alcohol and high penalties for non-use of seatbelts together with increase in frequency of monitoring and strict law enforcement such that the fatality reduction targets can effectively be achieved.

Author contribution statement

Gibson Mpokonyoka Ngwira: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Benjamin Bolaane, Bhagabat P. Parida: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

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