Measuring System Change: Shifts in the Health Landscape under the Tigray Siege

Joëlle Stocker & Araya Abrha Medhanyie

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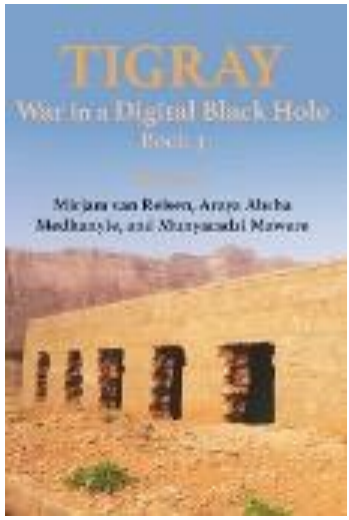

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Chapter 11

Measuring System Change: Shifts in the Health Landscape under the Tigray Siege

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System brings coexistence while reconciliation brings love.

Abstract

In this chapter, the nature of the change in Tigray's health system is studied, looking at how the war of 2020–2022 influenced shifts in the health landscape. This Fisher information model was used to analyse the stability of Tigray's health system during the war. The study identifies how the health system responded to various events that took place during the war. The research uses data on the prevalence of diseases and mortality, together with data on critical events in the war. The results show that the health system trends align with war events, especially when all zones were analysed together. Mekelle and North Western zones were the most stable, while the East, South, and South Eastern zones were the least stable, with many missing data points indicating instability. The Central Zone showed a gradual decline in Fisher information, reflecting the war's toll. Temporary increases in Fisher information suggest resilience, although the study could not conclude a significant bounce-back effect post-war. The findings highlight the utility of the Fisher information model in analysing the stability of health systems in war situations, but underscored the need for comprehensive data to understand long-term impacts.

Keywords: Tigray war, health system, Fisher information, critical shifts, resilience, hysteresis, Ethiopia

Introduction

Wars are defined by tipping points, specific events that instigate a transition from 'what was' to 'what is': peace, war, siege, famine, and, eventually, peace again. These definite moments in time may be critical points in the narrative we see and understand, but when looking at the transitions that complex systems undergo from one state to another, for instance, a state of peace to a state of war, these 'tipping points' are not straightforward. In health systems, for example, the tipping points related to war-caused disruptions may occur months after the onset of the war, when the effects on health facilities, medical supplies, hygiene, and disease control lead to a new state, defined by a very different health landscape.

Garry and Checchi (2020) studied the health effects of armed conflict, looking up to 20 years after the onset of the war. Their research shows how long-lasting the effects are, due to the large-scale changes, including those to the fabric of communities and societies. Important changes include problems with childhood development and lasting reproductive issues, disruption of disease control and increases in the burden of endemic infectious diseases, lack of vaccinations leading to epidemics, treatment interruptions leading to worse outcomes, and overall worse health due to limited education and employment (Garry & Checchi, 2020; Bendavid *et al.*, 2021).

The process in which systems move from one state to another after resilience has been eroded and a tipping point is reached is described by critical transitions (Scheffer *et al.*, 2012). The study by Garry and Checchi (2020) presents a clear alternative health state brought forth by conflict and war. Importantly, they show that it is difficult to return to the pre-war state once the shift to an alternative state is reached. In the theory of critical transitions, this is called hysteresis: once the transition to another state has occurred, it is difficult (and sometimes near impossible) to revert to the previous state (Scheffer, 2009). Thus, the system state defined and brought forth by war often outlasts that war by years, decennia, and sometimes entire lifetimes.

In this chapter, we study the nature of the change caused by the war with the health system in Tigray as a case study. We look at how the

war of 2020–2022 influenced changes in the health landscape through the prevalence of disease and mortality, when the transitions occurred, and how the system responded to various events that took place during the war.

Conceptual framework

Measuring the resilience of systems can be complicated, as measurements used within and across fields can vary wildly (Stocker, 2024). Many assessments have been created for different kinds of data and approaches. Qualitative research designs evaluating resilience fundamentally differ from quantitative designs, with different sets of limitations. Studies have found that combining qualitative and quantitative data provides more robust assessments of data, as they can constrain the respective limitations of the different approaches (Biddle *et al.*, 2020; Ungar, 2003).

One way of considering the resilience of a system is through the theory of critical transitions. These outline the process by which a system moves from one state to another, as the conditions in which the system exists, change (Scheffer *et al.*, 2012). This transition occurs as a system gradually loses resilience, due to disturbances or changes in conditions, until it reaches a tipping point. Past this point, the characteristics of the systems have changed to a degree that it is deemed to exist in an alternative state. However, it is notoriously difficult to pinpoint exactly when these tipping points occur. While there have been studies on assessing early warning signs for these critical transition, no robust assessment methods currently exist (Hewitt & Thrush, 2019).

In this study, we focus on Fisher information to analyse the stability of the Tigray health system during the war. In simple terms, Fisher information describes the measure of order and disorder within a system (Mayer *et al.*, 2006). Each system consists of several states in which it can exist, based on the conditions in which it is, defined by n variables. The n measurable variables define the system at any point in time, thus all variables have a value for a specific point in time. The states are characterised in two ways: a data point around which the states have centred, and a level of uncertainty for each dimension

which describes the breadth of the states (Eason & Cabezas, 2010). With these parameters, the probability of observing the system in any particular state is estimated.

A system is said to be orderly when it does not change from one state to another, thus staying within the levels of uncertainty around a specific point. In that case, the probability of observing the system in a particular state is high, and the Fisher information value will be high (Eason & Cabezas, 2010). Low Fisher information values on the other hand would indicate more disorder, as the probability of observing the system in a particular state would be low.

When using Fisher information to identify tipping points or critical transitions, we are looking at how steep the change is in the order and disorder of a system. To calculate how significant the deviation is from the usual behaviour of the system, the standard deviation and mean of the Fisher information over the total period of time can be calculated. A critical transition is deemed to occur when a variation exceeds two standard deviations above or below the mean (Gonzalez-Mejia, 2012; Vance *et al.*, 2017).

Problem statement

This study aims to accomplish two things. The first is to test whether Fisher information is reliable in measuring health system stability in times of conflict. The second is to look at the behaviour of the health system in Tigray during the war, and whether or not one can speak of a system collapse. In other words, can we identify catastrophic shifts or critical transitions in the system, and if so to what extent are they related to the events that took place?

Our research question is, therefore: *What was the impact of the events in the Tigray war on the stability of the health system?*

Two hypotheses were formulated on the behaviour of the system, reflected in the Fisher information values:

- Significant events in the war are noticeable through an increase or decrease in Fisher information.
- The collapse of the health system in Tigray is visible in a gradual, but significant, decrease in Fisher information.

Methodology

This study uses an explorative research design in looking at whether Fisher information is useful for evaluating the stability of the health system in times of war and identifying potential critical transitions. This is studied by triangulating the results with entries from the Europe External Programme with Africa (EEPA) Situation Reports, which recorded the events of the war systematically. The study was conducted with limited data available. Fisher information requires very regular longitudinal data, which is difficult to obtain in times of war.

The study is primarily quantitative, condensing large datasets into an index indicating a particular aspect of the system it describes. This study, therefore, aims at supporting results from qualitative and in-depth assessments that have been made in other studies on the resilience of the health system during the Tigray war.

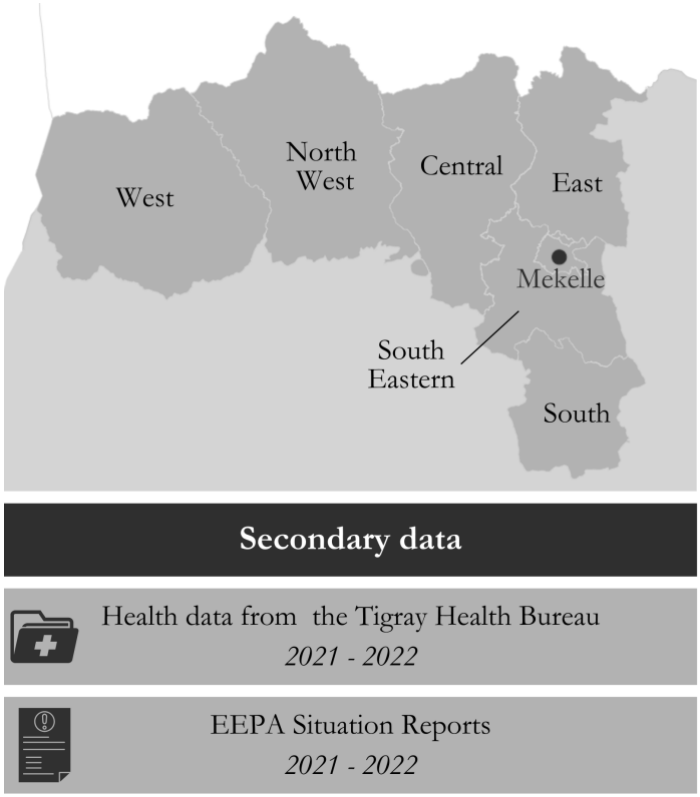

Figure 11.1. Study location and overview of data used in the study

Data collection

Secondary data was obtained from the Tigray Health Bureau on the prevalence of diseases and maternal and perinatal mortality rates spanning 2021 and 2022. The operational procedures for patient data collection were stopped as a consequence of their reliance on the central government, which was the main party to the war (Taye *et al.*, 2024). This data was thus collected by international non-governmental organisations (INGOs), in a limited capacity. The data was divided into the zones in Tigray: Mekelle, Central, North Western, West, South, South Eastern, and East. The variables that were used in the study were: malaria cases, microscope/Rapid Diagnostic Test, pulmonary fibrosis cases, polycythaemia vera (PV) cases, meningitis cases, meningitis deaths, dysentery cases, typhoid fever cases, rheumatic fever cases, typhus cases, severe acute malnutrition (SAM) cases, SAM deaths, acute flaccid paralysis cases, measles cases, anthrax cases, anthrax deaths, number needed to treat deaths, acute water diarrhoea cases, rabies cases, rabies deaths, maternal deaths, pre-natal deaths, hepatic veno-occlusive disease (HVOD) cases, HVOD deaths, scabies cases, and antibiotic use for acute respiratory tract infections (ARTI).

Data was also extracted from the EEPA Situation Reports. The Situation Report on the Horn of Africa was published daily during the Tigray war and published what was deemed credible information, which included published sources as well as information from the ground obtained through credible channels. During the Tigray war, the region was held under an information blockade and siege during much of the time. It was difficult, if not impossible, for journalists to enter or stay in the region. The Internet was down and the use of Internet through international organisations that remained during the conflict was extremely limited. Consequently, the information on the situation in Tigray was restricted within and outside the region. The EEPA Situation Report earned a position where it was well-informed and to date the most comprehensive overview of the events that took place in the region during the war. The EEPA Situation Reports provide a granular overview of information on the situation in Tigray during the war period. Entries from the reports of 2021 and 2022 were coded and labelled. 182 entries between 1 January 2021 and 1

November 2022 were used. In addition, the critical points in the war, as described by Melicherova *et al.* (2024)[1] were used to compare to the Fisher information trends.

Data analysis

Fisher information was calculated using the method outlined by Cabezas and Eason (2010). Values for Fisher information were measured for the zones separately, as well as together. The data were first binned into windows of 8 points, with the space between windows being 1 (each new window started at x_1+1). The uncertainty was found by calculating 2 standard deviations from the first 5 data points for each variable. Once Fisher information was calculated, an average of 3 data points was calculated to smoothen the trend line.

An important note to consider is that the data collected by the Tigray Health Bureau was not collected from a fixed number of health facilities, but rather from those that were able to report the number of cases. Thus, the number of health facilities that the data was collected from, altered over the 2 years (see Figure 11.2).

[1] The critical points were identified by Melicherova and Van Reisen (2024) by coding and labelling 8,171 entries from the EEPA Situation Reports and 522 from EEPA's weekly news highlights. This analysis was supported by a literature search.

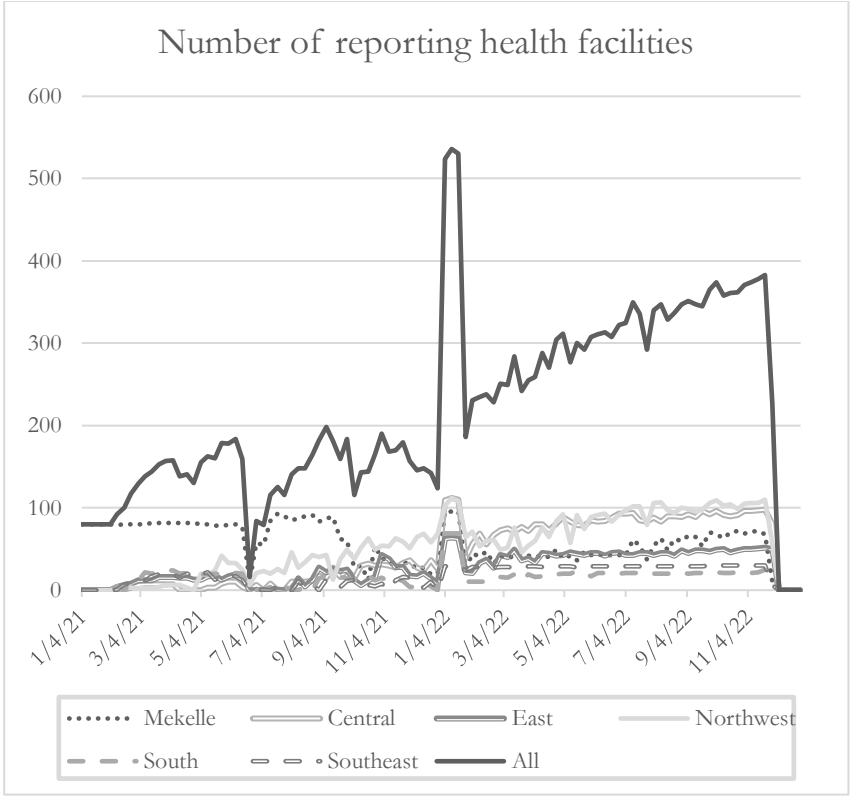

Figure 11.2. Number of reporting health facilities per week and zone

To understand the effect of this on the data, the Pearson Correlation on the variables and number of reporting health facilities was calculated. The majority of variables have a significant correlation. Based on this, a second Fisher information analysis was done on the dataset using the rate of cases, by dividing the number of cases by the number of reporting health facilities.

Missing data points were interpolated in Excel, considering 8 points before and after rather than the entire dataset, as this provided more accurate estimates. The Western Zone had almost no data for the second half of 2021 and 2022 and was, therefore, not included in the analysis. This zone is still under the occupation of Amhara forces and has not accessible to the Tigray Health Bureau since November 2020.

Two more statistical analyses were performed. First, a Kruskal-Wallis test and a Dunn test using the Bonferroni method was conducted to

compare the Fisher information results between zones. Second, to see whether specific variables strongly influenced the results, the Fisher information was calculated again (per zone and for all zones together) omitting one variable each time. The original Fisher information results were then compared to each result with a missing variable using a Pearson correlation test.

Results

Before looking into the Fisher information results, a background of the effect of the war on the health system is provided. It is important to provide context to support the interpretation of the quantitative analysis. This can help in the understanding of the results and indicate the trustworthiness of the analysis conducted.

Tigrayan healthcare system during the war

An idea of the conditions surrounding access to healthcare in Tigray during the war, can be obtained from the Situation Reports that were published by EEPA from the end of 2020 to the end of 2022. Tigray, a region in the federal democratic state of Ethiopia, governed by the Tigray People's Liberation Front (TPLF), was invaded by the Ethiopian National Defence Force (ENDF) of the federal government, together the with neighbouring country's military, the Eritrean Defence Forces (EDF).

Table 11.1 shows the number of operational health facilities reported at different points in time. Throughout the 2 years, the reported number of functional health facilities remained around 10%, with a spike in August 2021 when it was reported that 36% of health facilities were operational. The number of operational hospitals was generally higher, although it was reported on less frequently.

Table 11.1. Status of healthcare system in Tigray 2021–2022

Status of healthcare system	Date	SR No.
5 out of the 40 hospitals were physically accessible	11/01/2021	52
17 out of 224 health facilities (7.59%) were operational	09/02/2021	80
5-10% of health facilities were operational	23/02/2021	90
13% of health facilities were functioning normally	16/03/2021	104
55 out of 153 health facilities (35.95%) and 8 out of 17 hospitals (47.06%) were operational	16/08/2021	200
9.7% of health centres, 43.8% of general hospitals, and 21.7% of primary hospitals were fully functional.	31/05/2022	213
3.3% of health facilities in Western, 3.3% in South Eastern, 6.5 in North Western, 8% in Central, 14.6% in Southern, 16% in Eastern, and 78.6% in Mekelle were fully functional.	31/05/2022	213
9% of health facilities were functioning.	28/10/2022	300

The strain on the health system was caused by several factors. One of the common ways in which the healthcare system was undermined, was through the looting of medical supplies by armed forces and the destruction of health facilities and hospitals (EEPA, 2021, SR 48; EEPA, 2021, SR 62; EEPA, 2021, SR 72; EEPA, 2021, SR 103; EEPA, 2021, SR 105, 109; EEPA, 2021, SR 150). Armed troops also inhibited medical supplies from reaching facilities by blocking roads

and stopping envoys (EEPA, 2021, SR 76; EEPA, 2021, SR 132; EEPA, 2021, SR 183; EEPA, 2022, SR 208). Transport issues and seizing of ambulances led to patients not being able to access health facilities (EEPA, 2021, SR 76; EEPA, 2021, SR 104; EEPA, 2021, SR 173). In addition, hospitals were occupied by troops, restricting access to the general population (EEPA, 2021, SR 89; EEPA, 2021, SR 104; EEPA, 2021, SR 109). Humanitarian aid into the region was limited, with supplies being blocked and humanitarian workers killed (EEPA, 2021, SR 144; EEPA, 2021, SR 158; EEPA, 2021, SR 174; EEPA, 2021, SR 175; EEPA, 2021, SR 183; EEPA, 2022, SR 208; EEPA, 2022, SR 218). This led to the Médecins sans Frontières (MSF) suspending its activities in Adi-Abi, Adigrat, and Aksum (EEPA, 2021, SR 183). Finally, fuel shortage and the Internet blockade further restricted the accessibility of healthcare (EEPA, 2022, SR 209; EEPA, 2022, SR 225).

An increase in the prevalence of diseases was observed. An important factor in this was the decrease in vaccination levels in the region, falling to 10% towards the end of 2022 compared with pre-war vaccination levels being above 90% (EEPA, 2022, SR 272). On 30 June 2022, it was said that "the extremely limited availability of humanitarian aid and medical services caused epidemic-like diseases in the camps, including loss of lives" (EEPA, 2022, SR 231). On 17 October 2022, the Tigray Health Bureau stated concern for the increasing cases of malaria and insufficient health infrastructure to prevent needless deaths (EEPA, 2022, SR 291).

Several significant events took place during the war that further influenced the health system in Tigray. These are outlined in Table 11.2.

Table 11.2. Significant events in the Tigray war

#	Event	Date	Relevant zones	Description of event
0	Start of the law enforcement operation by the allied Federal Ethiopian forces	3–4 Nov 2020	All zones	Forces invade the Tigray region from the West, South, and North, and access to neighbouring countries and regions is blocked
1	Start of Operation Alula Abanega	18 Jun 2021	Central, South Eastern, and Southern	Recapturing of Mekelle (and several other towns) and unilateral cease-fire.
2	Mekelle is recaptured by the Tigray Defence Forces (TDF)	28 Jun 2021	Mekelle	The end of the *Alula Abanega* operation.
3	Start of Operation Tigrayan Mothers	12 Jul 2021	Southern	Recapturing of several towns in the Southern and South-Western fronts. Fighting expands beyond Tigray. The operation ends on 27 July with the TDF confirming the dismantling of some ENDF forces outside of Tigray.

4	ENDF and allies recapture several towns	23 Aug 2021	Eastern and Western	ENDF and Eritrean troops managed to recapture several towns and advance on Tigray.
5	The new chief of the interim administration	5 Oct 2021	All	Abiy is sworn into office for a second term, the cabinet is reorganised and a new chief of the Tigray interim administration is appointed.
6	The new offensive launched by the ENDF	15 Oct 2021	Inside and outside Tigray	Major offensives are launched across all important fronts in the Tigray, Amhara, and Afar regions. TDF launches a counter-offensive in the Amhara region.
7	The ENDF bombards the Tigray region	18 Oct 2021	Outside Tigray	Bombing focuses on dismantling telecommunication stations and other important infrastructure. Residential areas are also hit by airstrikes.
8	A formal agreement is signed between the TDF and	5 Nov 2021	Outside Tigray	A formal agreement is signed to work together towards a transitional

	Oromo Liberation Army (OLA)			government to replace Prime Minister Abiy. The TDF makes rapid advancements on the war front.
9	Announcement of the withdrawal of TDF troops from regions outside Tigray	20 Dec 2021	Outside Tigray	By 30 November, ENDF had recaptured significant towns in the Afar region, and progress is also made in the Amhara front. In December, the withdrawal of TDF troops outside of Tigray is announced to prioritise peace and humanitarian aid to the region.
9	A series of aerial strikes, also hitting residential areas	20 Dec 2021	All	The withdrawal of TDF troops is met with aerial bomb strikes in December and throughout January.
10	A ceasefire is announced	24 Mar 2022	*All*	A truce is agreed upon between the TPLF and the Federal Government. However, Eritrean troops remain active in the region. The ceasefire holds until June.

11	Humanitarian aid flows into Tigray	2 Apr 2022	*All*	The first humanitarian aid trucks enter the region, although it is by far not enough to cater to the needs of the Tigrayans.
12	Eritrean troops launch attack on North Western Tigray	24 May 2022	North Western	Despite the ceasefire, the EDF launched attacks in North Western Tigray, which was successfully retaliated by the TDF, upon which the EDF shelled Sheraro.
13	Fighting between the ENDF and TDF restarted along the southern border	24 Aug 2022	Southern	Increased movement of ENDF and allies is observed leading up to 24 August. A new front opens in Eritrea.
13	Multiple offensives are launched in Northern Tigray	24 Aug 2022	Northern	The ENDF and EDF launched multiple offensives in Northern Tigray.
13	Fierce battles take place in the Western Zone	24 Aug 2022	Western	The EDF is fighting the TDF on multiple fronts, and intense fighting over Dedebit town takes place lasting 70 days.

13	Airstrikes hit Mekelle	24 Aug 2022	Mekelle	ENDF carries out numerous aerial strikes on Tigray, focusing on Mekelle. Ayder Hospital in Mekelle gets an overwhelming influx of patients. The attacks slow down the delivery of humanitarian aid.
14	The ENDF & allies launch a largescale offensive on the North Western Zone	10 Oct 2022	North Western	The ENDF and EDF attack Zalambesa, Rama, Tserona and Adigrat. By 18 October, ENDF had captured Shire.
15	The Cessation of Hostilities Agreement is signed	2 Nov 2022	*All*	Negotiations for peace mediated by the African Union start on 25 October, with an agreement on cessation of hostilities signed in Pretoria on 2 November between the federal Ethiopian government and TPLF.

Note: Combat (underlined), administration (black), *aid and ceasefire* (italicised).

These events are important markers affecting the conditions related to the health of the Tigrayan population, as well as the capacity of the healthcare system to deal with changes in the health of the population.

The events were categorised as relating to combat (underlined), administration (black), and aid and ceasefire (*italicised*).

Fisher information results

The Fisher information trendline depicted below gives information on the stability of the system between 2021 and 2022. In general, increases in Fisher information signify that the order in the system is rising. In contrast, a decreasing Fisher information shows a decline in order. Steep declines in Fisher information indicate a critical transition. In the results calculated from the health data in Tigray, we can see that there is general stability in the system, with the steepest decline takes place at the start of 2021.

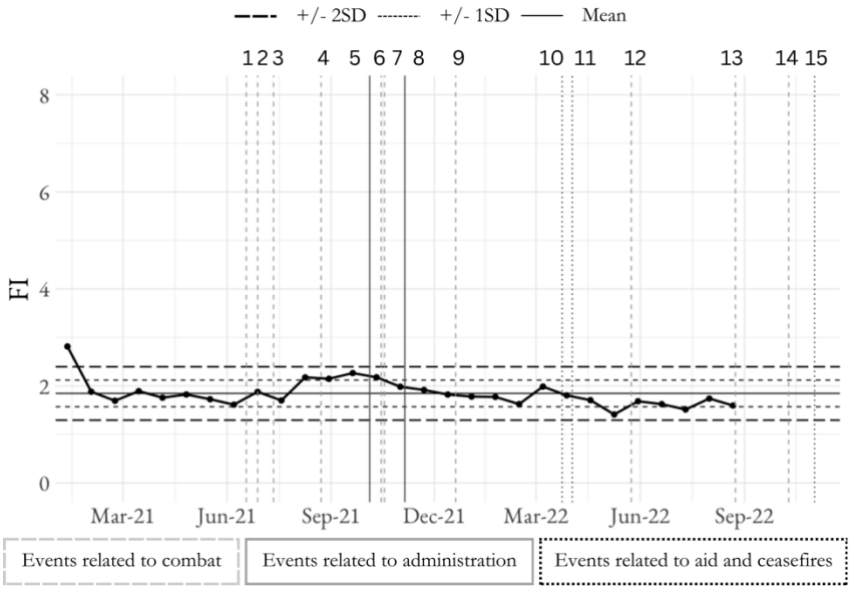

Figure 11.3. Fisher information for all zones

A slow and more gradual decline can be seen at the end of 2021 and start of 2022. The increase in Fisher information, indicating an increase in order, matches the recapturing of Mekelle by the TDF and subsequent operations that largely took place outside of Tigray. By September 2021 large-scale offensives are launched in Tigray by the ENDF and allies, which matches with the decrease in Fisher information, marking increasing instability. Interestingly, a short increase in Fisher information is seen around March 2022, which is

when a ceasefire was announced, and humanitarian aid was able to pour into the region. However, the increase in Fisher information takes place before this, followed by a decrease again reaching an all-time low around May 2022.

The results per zone show widely divergent stories in the different regions.

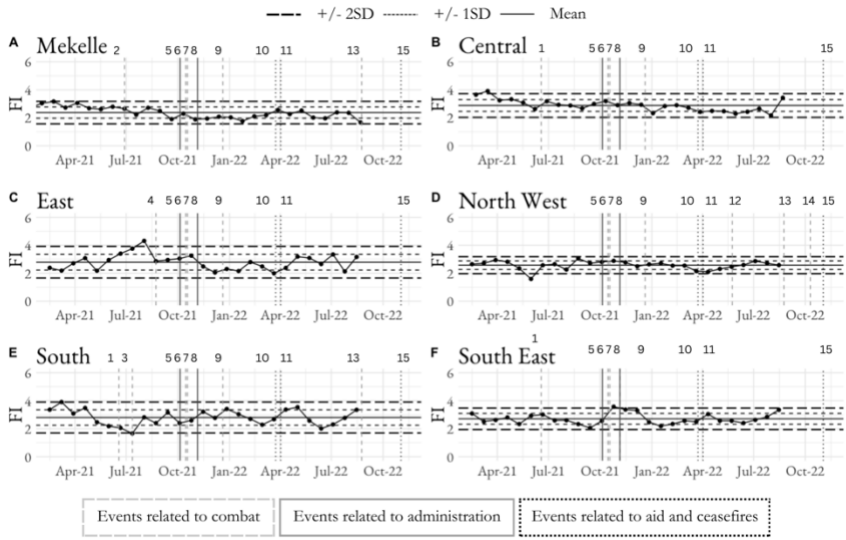

Figure 11.4. Fisher information per zone

Mekelle starts with a high Fisher information, which decreases upon the recapturing of Mekelle in June 2021. After this, it remains relatively stable at a low Fisher information, increasing now and then to reach the mean before going down again. The last point, in August 2022, is the lowest. The ceasefire and humanitarian aid in March and April 2022 match with an increase in Fisher information and a more stable trend.

The Central Zone also starts high, decreasing at the start of 2021 after which it remains relatively stable, around the mean until April 2022 when there is a slight decrease leading to the lowest point in August 2022. This point is followed by a steep increase in system order.

The Eastern Zone is among the least stable zones, with big fluctuations, especially in 2021. It is to be noted that this zone had a number of missing data points which were interpolated. This may

contribute to the large fluctuations. For instance, the significant peak around August 2021 matches with several missing data points. The interpolation thereof would have led to a semblance of stability, Fisher information interprets as an increase in system order. However, there are some notable points from the results. The Fisher information trendline matches well with the events that take place, with an increase in order after the recapturing of Mekelle and the start of the TDF operations outside of Tigray. The rebuttal from the ENDF and allies is also clearly visible in the drop that is observed, which remains until the ceasefire is announced and humanitarian aid is allowed to enter the region. This is followed by an increase in Fisher information.

The North Western Zone is largely stable, outside of a significant drop around May and June 2021, which is followed by a return to the mean. Like other zones, the Fisher information decreases as the ENDF and allies launch new offensives, and the TDF withdraws out of the regions outside of Tigray. The decline continues until the ceasefire, after which there is an increase in Fisher information. Interestingly, the increase in Fisher information continues despite an offensive from Eritrean troops in the zone.

The Southern Zone shows a lot of fluctuations. Here too there were several missing data points, especially between June and August 2021. Contrary to the effect of the missing point on the Eastern Zone, here the Fisher information incurs a significant drop followed by an increase. The big fluctuations continue throughout the period, with the second lowest point in June 2022, followed by an increase.

Like in other zones, the South Eastern Zone starts high with a gradual decrease until August 2021, where it rapidly rises before falling again to below the mean, coinciding with the retreat of TDF troops outside of Tigray. A gradual increase is visible until April 2022, matching the ceasefire, with relative stability around the mean after that.

Comparison of the results per zone

A Kruskal-Wallis test was performed to compare the Fisher information results of the zones with each other and with the results for all the zones together, with a significant difference found (chi-

squared = 59.154, p-value = 6.686e-11). To better see what the differences were, a Dunn test using the Bonferroni method was conducted. The results of this test are shown in Table 11.3.

Table 11.3. Results of Dunn post-hoc test using Bonferroni method

Comparison	Z	P.unadj	P.adj
All – Central	-63,246,835	2.54E-10	**5.33E-09**
All – Eastern	-53,899,763	7.05E-08	**1.48E-06**
Central – Eastern	0.9184501	3.58E-01	1.00
All – Mekelle	-25,575,610	1.05E-02	2.21E-01
Central – Mekelle	38,132,084	1.37E-04	**2.88E-03**
Eastern – Mekelle	28,785,013	4.00E-03	8.39E-02
All – North Western	-43,560,960	1.32E-05	**2.78E-04**
Central – North Western	19,343,485	5.31E-02	1.00
Eastern – North Western	10,158,984	3.10E-01	1.00
Mekelle – North Western	-18,446,210	6.51E-02	1.00
All – Southern	-56,031,986	2.10E-08	**4.42E-07**
Central – Southern	0.7089363	4.78E-01	1.00
Eastern – Southern	-0.2095138	8.34E-01	1.00
Mekelle – Southern	-30,917,236	1.99E-03	**4.18E-02**
North Western - Southern	-12,254,122	2.20E-01	1.00
All – South Eastern	-50,651,842	4.08E-07	**8.57E-06**
Central – South Eastern	12,375,933	2.16E-01	1.00
Eastern – South Eastern	0.3191431	7.50E-01	1.00
Mekelle – South Eastern	-25,537,091	1.07E-02	2.24E-01
North Western – South Eastern	-0.6967553	4.86E-01	1.00
Southern – South Eastern	0.5286570	2.54E-10	**5.33E-09**

Significant differences were found between each zone and all the zones together, except Mekelle Zone. The results from Mekelle also significantly differed from the Central and the Southern Zone. The Southern and South Eastern zones also had significant differing results. Thus, from all the zones, Mekelle was the closest to the results of the entire region, which is probably due to most of the data in the dataset coming from the Mekelle Zone. Mekelle diverged from the Central Zone the most, despite both zones having relatively stable Fisher information trends. The results show that the various zones had more in common with each other than with the entire region together.

Influence of variables on Fisher information results

To identify the influence of each variable on the results, the Fisher information for each zone was calculated, leaving out one variable each time. All the Fisher information results were then compared using a simple Pearson correlation test. The results can be found in Table 11.4.

Table 11.4. Correlation between Fisher information values with all the variables together and Fisher information values, where the named variable was removed from the dataset

	All	Central	Eastern	Mekelle	North Western	Southern	South Eastern
All	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Malaria	0,89	0,76	**0,54**	0,91	0,97	0,95	**0,49**
Microscope/Rapid Diagnostic Test	0,89	0,92	0,92	0,82	0,77	0,98	0,75
Pulmonary fibrosis	0,90	0,82	**0,68**	0,91	0,81	0,97	**0,57**

	All	Central	Eastern	Mekelle	North Western	Southern	South Eastern
polycythaemia vera (PV)	0,89	0,89	**0,52**	0,87	0,99	0,97	**0,59**
Meningitis	0,87	0,91	0,79	0,93	**0,58**	0,75	0,84
Meningitis death	0,91	1,00	0,92	0,95	0,90	0,98	0,98
Dysentery	0,89	0,92	0,99	0,79	**0,58**	0,96	0,87
Typhoid fever	0,89	1,00	0,81	0,89	0,23	1,00	0,70
Rheumatic fever	0,86	0,99	1,00	0,93	0,70	0,86	0,97
Typhus	0,91	0,94	0,93	0,84	0,88	0,85	1,00
SAM	0,89	0,90	0,89	0,83	**0,63**	0,86	0,90
SAM deaths	0,82	0,96	0,72	0,95	0,71	0,85	0,98
Acute flaccid paralysis	0,88	1,00	1,00	0,92	0,95	0,99	1,00
Measles	0,89	0,99	0,93	0,91	0,73	0,83	0,91
Anthrax	0,88	0,75	0,85	0,97	0,99	0,93	**0,62**
Anthrax deaths	0,89	0,98	0,97	0,96	0,98	0,96	1,00

	All	Central	Eastern	Mekelle	North Western	Southern	South Eastern
Number needed to treat deaths	0,86	1,00	0,85	0,96	1,00	1,00	1,00
Acute water diarrhoea	0,89	1,00	0,99	0,96	0,79	1,00	1,00
Rabies	0,89	0,82	1,00	0,91	0,98	0,81	0,80
Rabies deaths	0,86	0,99	1,00	0,96	0,76	1,00	1,00
Maternal deaths	0,88	0,99	0,92	0,94	0,99	0,79	1,00
Pre-natal deaths	0,86	0,84	0,88	0,91	0,95	0,86	0,86
HVOD	0,87	0,93	1,00	0,96	**0,39**	0,94	1,00
HVOD deaths	0,90	1,00	0,98	0,95	0,79	0,99	0,99
Scabies	0,89	**0,53**	0,93	0,89	0,25	1,00	0,95
ARTI	0,90	0,82	0,99	0,80	0,30	0,88	0,80

The results indicate that all Fisher information values were significantly correlated, aside from typhoid fever (p-value = 0,239), scabies (p-value = 0,214) and ARTI (p-value = 0,135) in the North Western Zone. The correlations were especially strong in Mekelle and all the zones together. This would indicate that all variables had similar impacts on the final Fisher information values, indicating robustness in the results.

Discussion

Fisher information reduces a number of variables to a one-dimensional reading of a situation. In this case, it looks specifically at how information changes over time, thereby providing information on stability and resilience. Thus, increases and decreases in Fisher information would be related to the patterns in the data – if there is a lot of change in a lot of variables at once, this will be visible.

The two hypotheses that were formulated for this study were that (1) significant events in the war would be noticeable through an increase or decrease in Fisher information, and (2) the collapse of the health system in Tigray would be visible in a gradual, but significant, decrease in Fisher information. The first hypothesis is accepted in all the zones together, and in most zones separately, although they are not always strongly visible, and the causality is not clear. For instance, whilst in some zones it is very clear that system order increased after the ceasefire, in some it was already happening by the time the ceasefire was implemented. The second hypothesis is only true for all zones together, and the Mekelle and Central zones separately.

There are several reasons why this could be the case. The first is that the data starts a few months into the war, when the conditions were already bad. The steep decrease would have been expected at the end of 2020, although the steep declines that can be seen at the start of 2021 for the Central and Southern zones, could be indicating that this indeed took place and continued up to the first quarter of 2021. Another point of consideration is that it was not always clear where humanitarian aid was being delivered and where (I)NGOs were active. Thus, increases in Fisher information in some areas may be related to this.

An additional aspect to contemplate is whether the variables are good indicators of the health system as a whole. There have been several publications on the collapse of the health system in Tigray (Gesesew *et al.*, 2021; Medhanyie *et al.*, 2024), discussing the closing of health facilities, lack of supplies, and difficult working conditions for health practitioners, etc.; the variables included in this study do not look at these parameters. Instead, several cases and deaths related to dozens

of diseases were used, as it was expected that a less robust care healthcare system would be translated in an increase in cases and mortality. While on one hand it could be said that these are not reliable indicators, it is more likely that the effect on the number of cases and deaths is not straightforward.

An interesting study with which to compare the findings is one conducted by Odhiambo *et al.* (2020), who investigated the health system resilience in conflict, focusing on South Sudan. They found that it is difficult to apply the concept of resilience in fragile settings, where indicators are very low and the situation cannot deteriorate much further. They argue that in these situations, resilience can be demonstrated through the maintenance of coverage at low levels or the improvement thereof.

Because the data used in this study starts a few months after the onset of the war, the situation is similar to the one described above, with a health system that has already been severely weakened: in January only 5 out of the 40 hospitals in the region were physically accessible (EEPA, 2021, SR 52), and in February only 7.59% of health facilities were operational (EEPA, 2021, SR). Thus, at this stage resilience indicates the ability to maintain what is left operational. The relative stability that we can see in the Mekelle and Central zones can, thus, be attributed to this. Repeating this study with data starting before the onset of the war and continuing until after the signing of the Pretoria Agreement would provide a different insight into how and when critical transitions occur related to conflict.

Odhiambo *et al.* (2020) also found that the areas with a higher number of internally displaced people (IDPs) demonstrate higher resilience, possibly due to more relief efforts in those states combined with more local leadership capacity. In Tigray, the highest number of IDPs were received in Shire (North Western Zone) and Mekelle. These regions both have the lowest standard deviations, meaning that there was less variety in Fisher information over time, indicating stability. This could be related to the number of IDPs. The North Western Zone also shows a clear increase in Fisher information after the ceasefire and humanitarian aid entered Tigray, it is feasible to assume that a large

amount of the aid was directed to places where there was a large number of IDPs.

Trustworthiness of Fisher information for the indication of system stability

The results of the analysis seem to align to some extent with what is known about the situation in Tigray at the time. Especially for the entire region together, the trendline matches the timeline of events well.

The analysis indicated that critical transitions occurred at different times in each region, as presented in Table 11.5.

Table 11.5. Overview of critical transitions

Critical transition	Zones	Timeline	Remarks
1	All	February 2021	The trendline starts higher of two standard deviations away from the mean.
2	Eastern	August 2021	Fisher information briefly shoots upwards in August.
3	Central	March 2021	Fisher information starts very high, briefly exceeding two standard deviations from the mean.
4	North Western	June 2021	Fisher information suddenly drops significantly and immediately returns to values close to the mean.
5	South Eastern	October 2021	Fisher information climbs around October, and stays high until the end of the year, before decreasing again.

This can be interpreted in two ways. Either a critical transition took place across all regions in the first months of the war (for which we do not have data) and the critical transitions displayed here are smaller fluctuations in the state – worsening still or improving as the events of the war shifted the conditions. These fluctuations would be on a smaller scale than the original expected transition which brought the Tigray health system to an alternative state, a state similar to that described by Garry and Checchi (2020). This alternative state would continue possibly until years after the cessation of hostilities. If this is the case, the analysis conducted in this study is all-encompassed within the alternative state.

A second interpretation would be that the transition into an alternative state had not yet taken place by 2021. In this case, the transition to the alternative state overall would be at the start of the year, with differences across regions, with the South Eastern Zone only transitioning in October 2021.

From the perspective of the capacity of the healthcare, the former is more likely, as the healthcare system had already been largely destroyed by the start of 2021. However, there is a lag in the emergence of diseases and epidemics. For instance, the number of cases of infectious diseases would have significantly increased months or years into the war. Similarly, the effects on patients of non-communicable diseases would take time. This would create a delay in the occurrence of a critical transition, making the second interpretation more likely.

Quantitative analyses in data black holes

The data that was used in this study contained limitations. Since the data was produced in real time by the health facilities during the war, there were missing data points, and the number of reporting health facilities were not consistent. The extent of missing data was such that one zone had to be excluded from the study. An important limitation that has also been highlighted by Moreno-Serra *et al.* (2022) is the lack of continuous data from before, during, and after the conflict. The data that we found for this study, was similarly limited in its timespan, only covering the middle part of the war. Analysing the system's

stability as it shifted into a war situation and out of it again after the Pretoria Cessation of Hostilities Agreement, would have provided a lot of useful information on system dynamics.

When data is not available from during the war, researchers adapt by collecting data after the conflict, which may lead to recall bias (Moreno-Serra *et al.*, 2022). In this study, parts of the analyses were performed by researchers who had been present on the ground. However, there too, recall bias is a possibility.

These issues are to be expected when using data from conflict areas. The conditions of the health system that we described are also a good indication of how difficult it was to collect data at that time. Travelling was complicated, especially long distances, which means that many places were unreachable. On top of that, there was a communication blackout and no Internet in the entire region. Essentially, Tigray was in a digital black hole: there was very little information coming in or out of the region.

Amare *et al.* (2024) outline the importance of decentralised health data repositing to avoid issues such as these in the future, where relying on data at the central government level resulted in data no longer being available when the region was invaded by the central government. This study shows the relevance of being able to access reliable and complete data to conduct important analyses and assessments to better understand the dynamics of and responses to the conflict.

Conclusion

This study used Fisher information to analyse the stability of the health system in Tigray. Data from EEPA Situation Reports were used to compare the events of the war with the findings. The trends emerging from the analysis matched to some extent with the events of the war, especially when all the zones were analysed together. The lack of (reliable) data was an important issue and continues to be an issue in areas suffering from conflict and war.

Thus, the results indicate that the most stable regions were the Mekelle and North Western zones, with the least stable regions being

the Eastern, Southern, and South Eastern zones. The latter had the most missing data points, which is also a sign that the regions were less stable, inhibiting data collection. The Central Zone showed a gradual decline in Fisher information, this was also noticeable in the Mekelle Zone and all zones together. A gradual decline in system order would be expected as the war takes an increasing toll on the population of Tigray.

Some events were correlated with a clear increase in Fisher information, demonstrating the resilience of the system being able to recover temporarily when conditions were better. This is interesting, as it could indicate a minimal hysteresis effect – improved conditions lead to a rapid bounce back. However, whether this is the case on a large or small scale is important, and unfortunately cannot be deduced from this limited dataset. If the critical transition had already occurred prior to 2021, relatively small increases in Fisher information would not be indicative of a return to the previous state. On the other hand, if the critical transition had not yet occurred, these increases in Fisher information would have been more significant.

This study demonstrated that Fisher information is a useful method for analysing the stability of a system. However, it did not allow a conclusion to be drawn about the bouncing back effect after the war. Understanding the dynamics prior to, during and after the war would help to identify the long-term effects of the war on the health system of Tigray, and how to build it back better.

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Authors' contributions

The first author designed the study and the models used for this study. She also performed the modelling analysis and the statistical analysis. The second author supported the identification and acquisition of the data, and he advised on the implementation of the research and reviewed the chapter.

Ethical considerations

The data was obtained from the Tigray Health Bureau through a formal request (Reference number: CHS/MARCH/ 196/ 24, dated 14/03/2024). There were no personal identifiers or individual patients' names in the dataset obtained from the bureau.

This chapter should be read in conjunction with the 'Note on Content and Editorial Decisions'.

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