DISASTER AT A DISTANCE: MORTALITY CONSEQUENCES OF THE 1815 TAMBORA VOLCANIC ERUPTION ON RURAL ITALIAN TOWNS

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ABSTRACT

In April 1815, one of the largest known volcanic eruptions occurred at Tambora in Indonesia. The initial eruption killed about 10,000 people instantly and the overall local death toll was estimated at 88,000. Volcanic dust impacted areas beyond the South Pacific; blanketing much of Europe and North America during the summer of 1816 and has been blamed for the below-normal daily temperatures experienced at that time. Lower temperatures came at a critical time for agricultural production, causing many crops to fail, and leading to widespread famine and increased mortality in 1817 in Europe. I document significant mortality consequences of the eruption by examining death data for 32 towns in the Abruzzi region of Italy. Deaths in 1817 were significantly greater compared to adjacent years. Further, I find that the mortality crisis peaked between March 1817 and March 1818, and most age groups were impacted.

INTRODUCTION

In April 1815, one of the largest known historic eruptions occurred (Tambora on the island of Sumbawa) (Simkin, 1994).[1] It is estimated that 10,000 people were killed instantly (Sigurdsson and Lovelace, 2006; Evans, 2002), and 88,000 people died overall because of the eruption between the two islands of Sumbawa and neighboring Lombock (Stothers, 1984). The great quantities of magma and ash fallout from this eruption created global climate anomalies, which had farther ranging demographic consequences than immediately surrounding the volcano and the South Pacific. The volcanic dust from the Tambora eruption blanketed much of Europe and North America during the summer of 1816 and has been blamed for the below normal daily

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[1] For more details regarding the Tambora eruption, see Siebert and Simkin (2002-).

temperatures – known as the "Year Without a Summer," which is a telling description of the climate conditions that people in Europe and northeastern North America were experiencing in 1816 (Simkin, 1994). Previous research in this period (1810-1820) has focused on the meteorological causes of these extreme climatological conditions and the natural ecological destruction that occurred. However, less research has focused on the demographic consequences of these conditions, particularly to rural regions further away. Using summary administrative records and individual-level records for 32 towns in the Sulmona District of the Abruzzi region, this paper examines the mortality consequences of the 1815 Tambora eruption.

DATA AND METHODOLOGY

Data Sources

The primary data for this examination come from the civil registration system, which began about 1810 when many parts of Italy came under the control of the Napoleonic Code.[2] Under this Code, the keeping of birth, death, and marriage records was initiated as a secular responsibility rather than an ecclesiastical responsibility. Each town in Italy was made responsible for maintaining a registration of all births, deaths, and marriages occurring within its boundaries. This information along with descriptive information (e.g., marital status, occupation, in-migration, and out-migration) regarding the population of the towns was submitted to the local provincial capital (in this case L'Aquila) for summarization. After Napoleon's defeat in 1815, some regions and provinces of Italy relinquished their civil registration system duties back to the Church. However, the Kingdom of Naples (which

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[2] Before 1809, the Roman Catholic Church kept many of the earliest vital records. The Napoleonic Code is a system of laws instituted by Napoleon originally in France when he came to power and based on Roman laws.

controlled the Abruzzi region) continued to keep a civil registration system after Napoleon's defeat and the Bourbon's regained control (renamed as the Kingdom of Two Sicilies).

The demographic data on deaths examined in this paper came from two sources. Summarized population data for the 32 towns in the Sulmona District are located in the Archivio di Stato in L'Aquila (A. S. Aq.) for 1810 to 1859. I transcribed the data into a database for analysis and evaluated the deaths for the period 1810 to 1830. In addition, the individual death records have been microfilmed and are available in the United States through the Family History Center Library. I transcribed the selected data from these individual records to analyze and evaluate in more detail for the period 1809 to 1830.[3]

To measure the global climate anomalies, the proxy measure of the Dust Veil Index (DVI) will be used. The DVI came from Lamb (1970). Lamb (1970, 1977, and 1983) developed the DVI to

> ...quantify the impact on the Earth's energy balance of changes in atmospheric composition due to explosive volcanic eruptions. The DVI is a numerical index that quantifies the impact of a particular volcanic eruptions [sic] release of dust and aerosols over the years following the event (Lamb, 1985).

Such releases of dust and aerosols have been shown to generate significant climatic changes through the obscuring of "solar radiation from reaching the Earth's surface" (Simkin, 1994: 913). To calculate the DVI for a particular volcanic eruption, data from observational, empirical, and theoretical studies of an individual eruption are reviewed for "possible impact on climate of volcanic dust veils" (Lamb, 1985) and then an estimate is calculated in reference to the Krakatoa eruption of 1883 – measured at 1000.[4]

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[3] See Appendix A for names of 32 towns in this investigation.

[4] The Krakatoa eruption of 1883 was used as the reference point for measuring against as it was one of the most historic explosive volcanic eruptions and had the most modern measurements available. The benefit of referencing to Krakatoa is that one can compare all other volcanic eruptions with a single numerical index. The DVI for Tambora, which erupted in April 1815, has been estimated to be 3000.

The Setting

Figure 1 shows the location of these 32 towns in the Abruzzi region. Ecologically, the Sulmona District is located in the Abruzzi highlands of the Apennine Mountains. The communities in this area have tended to be isolated because of the overall formation of the Apennine Mountains on a Northwest-Southeast axis through geological formation that hinders access to main roads that connect the northern and southern parts of Italy, as well as connecting roads to plain zones (Bethemont & Pelletier, 1983).[5] Finally, the elevation of this region is quite high (Walker, 1967). Together these features "combine to give the Abruzzi highlands the severest winters of the peninsula, snow lies for five months on the summits and the higher roads are frequently impassable" (Walker, 1967: 181). Thus, the communities in the Abruzzi highlands were at greater risk from harvest failures.

Turning to the time period 1810 to 1820, the 1810s was an eventful decade across Europe and particularly in Italy. Napoleon conquered and put into place various family members to rule the conquered territories and put the Napoleonic Code into practice in these territories. However, in addition to these political changes, there was a little known famine crisis (1816-1817), that "…was born of a combination of multiple harvest failures (the most precipitous decline in production since the mid-1700s), coupled with a rapid erosion of purchasing power among the poor who faced a loss of income, coupled with rising food prices" (Webb, 2002: 2092S).

One of the many reasons that have been put forward by researchers for the causes of these multiple harvest failures is the climatic instability during this period. One drawback for

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[5] Bethemont and Pelletier (1983:13) describe the Apennines as "... one of the most complex yet striking fold chains. ... [They] are an excellent example of a chain of double deposition starting from a highly uplifted central section and the working outward of successively folded zones. The system has grown in this way over time. ... [While they are a] normal model of any chain of this type [similar to the Alps] ... [they] also display specific features of their own."

examining climatic instability in this period is that it is before much of the scientific instrumentation and measurement of weather was well known. However, what can be said about the year of 1816 is that it is "the locus of a period of natural ecological destruction not soon to be forgotten" (Soon & Yaskell, 2003). A number of factors played into the extreme climatic conditions that occurred in 1816, some of which are still not well understood as to the exact mechanism of impact.[6]

What we do know about the 1815 eruption of Tambora volcano on Sumbawa Island, Indonesia is that great quantities of magma and ash fallout were expelled.[7] The volcanic eruption blanketed much of Europe and North America with volcanic dust during the summer of 1816 (Webb, 2002, Oppenheimer, 2003). Other research has found that volcanic ash fallout (measured by the DVI) can "… remain trapped for a long time in the stratosphere, affecting the earth's climate" (Camuffo and Enzi, 1995). Thus, the Tambora eruption of 1815 has been blamed (in part) for the below normal daily temperatures.[8] In addition, the below normal daily temperatures came at critical times for agriculture production which in turn caused many crops to fail, leading to famine and increased mortality. Not only did these climatic instabilities lead to

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[6] Before proceeding, it is important to note that Europe and much of North America had been experiencing for the last 400 years what has been known as the Little Ice Age – which lasted from about the 14th century to the mid- to late-19th century. Two other naturally occurring factors that were happening within this decade of 1810-1820 were: (1) an extended period of low magnetic activity which lasted from about 1795 to the 1820s and known as the Dalton Minimum; and (2) the shifting of the place of the sun in the solar system, "…something it does every 178 to 180 years" (Soon & Yaskell, 2003) and is known as "inertial solar motion." In addition to these "cosmic" factors, in April 1815 a major volcanic eruption occurred – Tambora. This by far was the most important event that created the extreme weather conditions in the Northern Hemisphere. To the earlier point, on "inertial solar motion", Soon & Yaskell (2003), state that "Scientists have not yet confirmed whether or not inertial solar motion affects Earth's climate directly, but it remains a possibility." While no plausible physical mechanism has been identified, the hypothesis is intriguing, since "one solar inertial motion model predicts that a prolonged solar magnetic activity minimum will occur somewhere between 1990 and 2013… [and] is expected to end around 2091" (Soon & Yaskell, 2003).

[7] It is estimated that about 12 cubic miles of dust and ash were ejected into the upper atmosphere (Evans, 2002).

[8] "Global temperatures dropped by 3°C and the following year was known as the 'year without a summer'." (Kennedy, 2006). Stothers (1984) estimates that the average global temperatures decreased between 0.4°C and 0.7°C (between 0.7°F and 1.3°F). Even at this smaller temperature change, this is enough to cause significant agricultural problems, particularly if it occurs during a critical period of the growing season. (Stothers, 1984).

famine, they produced widespread outbreaks of epidemic typhus (1816-1818) and thus increased the social instability occurring in the late 1810s and 1820s as surviving people left their rural communities to find more hospitable climates (Evans, 2002).

Methodology

Using summarized data from individual records; this paper will examine the demographic consequences of the 1815 Tambora eruption on these 32 rural Italian towns between 1809 and 1830 – that includes the “Year Without a Summer” of 1816. As a first step in the evaluation process to determine the relationship between the environment and these recorded deaths, correlation coefficients will be calculated between the annual DVI as a proxy for sudden global cooling and registered deaths for the 32 towns for each year between 1810 and 1820. It is expected that there will be a lag between the increase in DVI and the increase in the number of deaths, as it was through crop failure in 1816 that lead to famine and increased mortality in the following year of 1817 (Stothers, 1984).[9]

The next step in the evaluation will account for the underlying trend and overcome the problem of population size differences between the 32 towns.[10] Z-scores will be calculated using the equation below for the town for each year of 1809 to 1830.

$$Z - score = \frac{E - \overline{E}}{\sigma}$$

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[9] Stothers (1984) states that in 1816 for Europe and North America, “daily temperatures (especially the daily minimums) were in many cases abnormally low from late spring through early fall… Many crops failed to ripen and the poor harvest led to famine, disease, and social distress compounded by the aftermath of the Napoleonic wars.” The climatological conditions of 1816 also spawned the last major typhus epidemic in Europe (1816-1818) (Post, 1970; 1976). Evans (2002) states that in addition, “… the settling of the American heartland was apparently shaped by the eruption of [Tambora] 10,000 miles away. Thousands left New England for what they hoped would be a more hospitable climate west of the Ohio River. Partly as a result of such migration, Indiana became a state in 1816 and Illinois in 1818.”

[10] This methodology is consistent with that used by Witham and Oppenheimer (2005) studying mortality in England during 1783-4 Laki Crater eruption. Witham and Oppenheimer (2005) based their research methodology on the research techniques in the demographic studies of Charbonneau and Larose (1979) and Dobson (1997).

In the equation above, E designates the observed number of registered deaths for the particular year; while $\overline{E}$ is the mean annual number of registered deaths; and σ is the standard deviation of the number of registered deaths during the period including the year 1817 for each town. The interpretation of these scores with respect to deaths is that positive Z-scores demonstrate higher registered deaths than the mean and negative scores indicate below average deaths. Consistent with other historical demographic research, we will interpret Z-scores for deaths of greater than 2 to represent a crisis year.[11]

Historically, these rural regions relied upon an agricultural economic base for the subsistence of its population.[12] In addition, many rural communities were quite isolated with limited transportation, thus additional food could not just be brought in to make up the difference if there was a shortfall. The timing of the long cold snap “coincided with the June-to-September growing season” (Evans, 2002) had serious consequences for many rural communities to sustain itself. People either died or left the community and thus the social stability of such rural communities was at risk.[13] Thus an examination of the seasonality of deaths within each year, as well as the age distribution patterns of deaths is important. To account for these patterns, the next step of the analysis will examine patterns of seasonality; this part of the evaluation will examine monthly totals of registered deaths similarly through calculated Z-scores from the individual records. An examination of the monthly totals of registered deaths will give an indication of which months contributed most to the crisis year of 1817. Since the number of

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[11] This is consistent with the “mortality crisis” definition used by Witham and Oppenheimer (2005). They based their definition on the work of Wrigley and Schofield (1989) and Dobson (1997).

[12] Bell (1979: 8) wrote that variations in physical features such as altitude, climate, soil conditions and physical accessibility (to name a few), “affect every aspect of rural Italians’ lives and cause discernible fluctuations in rates of birth, marriage, and death.”

[13] Out-migration will not be examined in this paper, but data is available to show that the number of out-migrants from the 32 towns in the Sulmona district was the highest in 1817 compared to the other years between 1814 and 1820.

deaths occurring within a month in the 19th century varies naturally and significantly with season this is an important feature to know.[14] In addition, these monthly Z-scores will also compare the differences, if any, between Solmona and the surrounding comuni in the District.

Patterns of age distribution of death using broad age categories will also be examined. Age at death was listed on the death certificate. In order to minimize possible age misreporting this analysis will use the following age categories: less than 1 year; 1 to 4 years; 5 to 14 years; 15 to 44 years; 45 to 64 years and 65 or more years.[15] Because of the difficulty that deaths under 1 year old may be impacted by the number of live births during the period, infant mortality will also be calculated and analyzed.

RESULTS

While the political instability during the 1810s had important consequences for all of Italy, because of the geographic isolation of the Aquila province and its historical reliance upon an agricultural economic base for the subsistence of its population, climatic instability, rather than political instability, likely had greater consequences for the demography of the communities in the Sulmona district, and in turn the social stability of the communities. Climatic instability during the agricultural growing season would contribute significantly to an unstable economic environment as described by Stothers (1984) through limited resources and rising prices of foodstuffs. To connect these demographic events to the sudden global cooling event as

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[14] Civil registration records have two dates listed. The first date on the form is the date of registration of the event and the second date on the form is the date of the actual occurrence of the event. Preliminary examination of the records in Pettorano-sul-Gizio appear to indicate that the time between the date of occurrence of the event and the date of registration of the event were usually no more than 1 to 2 days apart and usually occurred within hours of the event (Ongoing research).

[15] A preliminary examination of the records from the town of Pettorano-sul-Gizio indicates that the age reported on death certificate is fairly consistent within 1 year. This was determined by linking death records with birth records and comparing the age reported on the death record and the calculated age at death. For those records where a birth record was found the age reported at death was within 1 year of the calculated difference between the birth date and the death date (Ongoing research).

measured by the DVI, correlation coefficients were calculated between DVI and registered deaths in each of the communities in the Sulmona District. Table 1 shows the correlation coefficients for each town between the registered deaths and the DVI for the period 1810 to 1820. Because of the timing of the impact of volcanic air pollution on mortality, it is expected that there will be a lag in the impact between DVI and deaths of up to 2 years. For most of the towns in the Sulmona district the correlation coefficient is the highest with a 2-year lag between the DVI and registered deaths. This is not surprising since the climate of Italy (as well as Europe and northeastern North America) was not immediately impacted by the eruption of Tambora in April 1815. It was the 1816 agricultural cycle that was most impacted with unusually cold periods at critical points in the agricultural season. The extreme food shortfall through the harvest failure of 1816 would have been felt in 1817. Although it cannot be examined in this paper because the data are not directly available, the morbidity of the community could also have been impacted during this time with respect to chronic respiratory health issues from the volcanic air pollution as represented by DVI (Durand and Grattan, 2001; Grattan, et al., 2003; Pope III and Dockery, 2006). Researchers studying the Laki fissure eruptions (Iceland) in 1783-84 found contemporary descriptions of morbidity such as “headaches, eye irritation, decreased lung function, and asthma” (Grattan, et al., 2003). In addition to respiratory impacts, there were descriptions of cardiovascular health impacts, as well as general comments of fevers and epidemics.[16] In northern Italy the following contemporary description (1783-84) was found,

> A phenomenon of prolonged and very dense fog, which completely hid the sun, and at night made the moon appear reddish and murky. This fog caused,

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[16] The Laki fissure eruptions (Iceland) in 1783-84, while closer to Europe/Italy, were of a much smaller magnitude than Tambora. It is expected that if we were able to find contemporary writings on the morbidity experience during the years following Tambora in the rural communities of the Sulmona district, we would probably find similar descriptions.

> moreover, many illnesses and putrid and acute fevers, so that many people died. (Fajonio, cited in Camuffo & Enzi, 1995)

Turning back to the demographic data available, Table 2 shows the distribution of Z-scores of annual registered deaths by year of occurrence (1809-1830) for each of town in the Sulmona District, as well as a District summary. For most towns, the year 1817 was a “crisis” year with Z-scores above 2. Of the five towns that did not show Z-scores above 2, three are smaller towns (Ateleta, Castrovalva, and Villetabarrea). They are attached to a larger village and thus the deaths of residents in these towns could have been registered in the larger town rather than the smaller town.[17] With regard to the final two towns (Introdacqua and Frattura), the Z-score is higher than the year before and the year after, but does not reach the 2.0 threshold.

Figure 2 shows the Z-score distribution of registered deaths by month and year of occurrence shown for the period 1815 to 1819 summarized, calculated using data from 1809 to 1830. The average Z-score shows an elevated level of death during the months of March 1817 to January 1818. When the Z-scores are calculated separately for Solmona and compared to all other comuni in the District, Sulmona shows elevated level of deaths during the months of July 1817 to December 1817, except for November 1817. While all other comuni show the same overall District pattern in elevated levels of deaths.

Figure 3 shows the Z-scores of deaths by age of occurrence. For the distribution of deaths reported for individuals under age 1 year, there does not seem to be a consistent pattern of change in the mortality levels. However, this may be due in part because there were fewer births during the crisis years 1816/1817, and those births that did occur were possibly more robust. [18] However, for the other broad age groups, there does appear to be a consistent pattern of

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[17] More thorough investigation needs to be done to understand why these five towns do not show a mortality crisis in 1817 compared to the other towns in the Sulmona district.

[18] Birth data will not be examined in this paper, but data is available to show that the number of births declined in 1817 (Ongoing research).

increased mortality in the year 1817. When infant mortality was examined, it was found that it too showed a consistent pattern of increase in the year 1817.

SUMMARY AND DISCUSSION

The volcanic eruption of Tambora in 1815 is documented as one of the largest known historic eruptions, yet the demographic impact of this eruption has only been judged with regards to its local impact on the population in Indonesia. Research on volcanic air population connects huge quantities of magma and ash fallout to global climate anomalies which could have farther ranging population consequences than those already described immediately surrounding the volcano. This paper begins to examine this farther ranging impact by examining the deaths in 32 towns in rural Italy. The data shows that there was an overall mortality crisis in 1817 that can be correlated with the 2-year lagged increase in DVI. In addition, examining individual-level death records for these towns, the mortality crisis occurred specifically between March 1817 and January 1818, and all age groups of these communities were impacted.

While the primary focus of this paper has been on deaths, this is not the only indicator that can be used to document the demographic consequences of the sudden climate change caused by the Tambora volcanic eruption of 1815 on historic rural communities. As mentioned above, there should also be consequences on migration and births within these towns during this period, and it is possible that the number of marriages may have also been impacted. While deaths are the most extreme reaction to climatic instability, migration, births and marriages may also be impacted by climatic instability. Individuals within a rural community in response to limited resources or unstable economic environment through poor harvests can voluntarily adjust to such events by leaving the community (out-migration), delaying marriages if they stay in the community and thus in turn delaying fertility. Climatic instability during the agricultural growing season would contribute significantly to an unstable economic environment as described by Stothers (1984) through limited resources and rising prices of foodstuffs. Preliminary examination of the birth data indicate that there were fewer births occurring in 1816 and 1817 period. In addition, since in this period marriage is strongly tied to fertility, if there is a decline in marriages then this too would decrease the number of births that occurred.

Out-migration is another way that individuals could respond to limited resources or an unstable economic environment, for example huge outflows of Irish from Ireland during the Irish Potato famine in the 1840s. In this study, while the data for aggregate numbers of out-migrants are available in the archival data (A. S. Aq), they were not examined for this paper. One of the difficulties encountered with the migration data was that there was no documentation of where these individuals went to, only the number of individuals leaving the community was reported in the data. However, if other data sources could be found to link migrants between their origin town and their destination towns, this would be another important avenue for future research.

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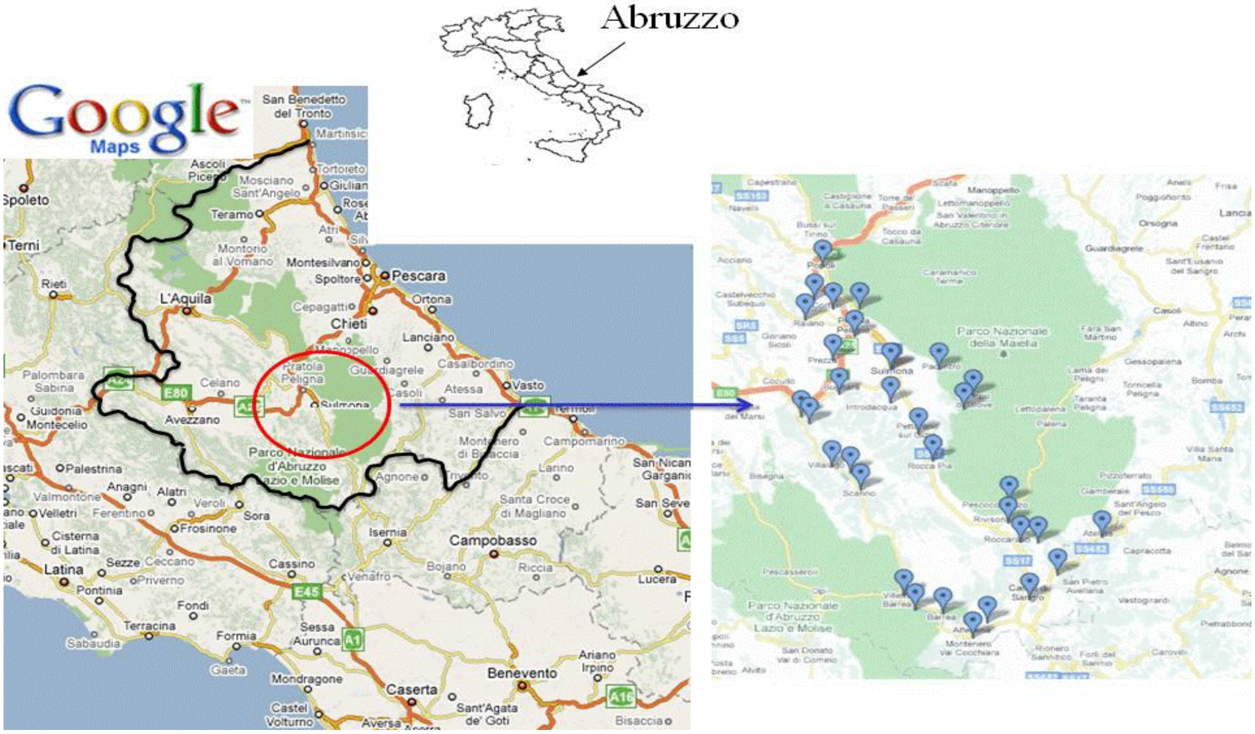
Figure 1: Towns of Solmona District, Abruzzo, Italy



Appendix A lists the names of all towns in this study.

Table 1: **Correlation between DVI and Registered Deaths (1810-1820)**

	No lag	1-year lag	2-year lag
DISTRICT	0.06	0.45	0.84
Alfedena	-0.14	0.08	0.40
Anversa	0.06	0.50	0.67
Ateleta	-0.05	0.37	0.88
Barrea	0.17	0.34	0.61
Bugnara	0.04	0.34	0.75
CampodiGiove	-0.01	0.37	0.83
Cansano	0.18	0.46	0.75
Castel di Sangro	0.27	0.35	0.56
Castrovalva	0.03	-0.13	-0.13
Civitella	0.34	0.42	0.67
Frattura	-0.18	0.34	0.84
Introdacqua	-0.36	0.10	0.56
Pacentro	-0.11	0.39	0.66
Pentina	-0.12	0.34	0.89
Pescocostanzo	0.06	0.35	0.41
Pettorano	0.10	0.45	0.69
Pietansieri	0.23	0.48	0.75
Popoli	0.01	0.23	0.51
Pratola	-0.18	0.35	0.87
Prezzo	0.22	0.47	0.79
Raiano	0.32	0.53	0.75
Rivinsondoli	0.04	0.42	0.58
Roccacasale	0.25	0.55	0.77
Rocca Cinque Miglia	0.23	0.40	0.68
Roccarosa	0.26	0.61	0.58
Roccaveleoscura	-0.04	0.24	0.48
Scanno	0.20	0.45	0.89
Scontrone	0.18	0.43	0.59
Solmona	0.11	0.45	0.83
Villalago	0.04	0.38	0.69
Villetabarrea	-0.23	0.34	0.34
Vittorito	-0.05	0.31	0.78

Source:

Table 2: **Z-score distribution of registered deaths for towns in the Sulmona District (1809-1830)**

	1809	1810	1811	1812	1813	1814	1815	1816	1817	1818	1819	1820	1821	1822	1823	1824	1825	1826	1827	1828	1829	1830
Alfedena	-0.94	-0.62	1.46	1.60	-0.48	-0.29	-0.94	-0.57	**2.01**	0.49	-0.43	-0.76	-0.52	-0.11	**2.57**	-0.52	-0.57	-0.20	-0.43	-0.80	-0.20	0.26
Anversa	-1.90	-1.28	-0.57	-0.04	0.49	-0.66	-0.75	0.40	**2.43**	0.05	1.64	-0.48	0.84	1.02	-0.57	-0.31	0.05	0.84	-0.48	-0.13	-1.28	0.67
Ateleta	-1.16	-0.77	-0.21	-0.49	-0.49	-0.49	-0.60	-0.55	0.51	0.18	-0.05	-0.49	-0.49	-0.43	0.45	-0.71	0.07	-0.38	-0.43	**2.29**	1.29	**2.96**
Barrea	-0.23	-0.04	1.37	0.67	-0.50	-0.62	-0.31	-0.04	**3.93**	0.12	-0.85	-0.66	-0.04	-0.31	-0.15	-0.39	-0.46	-0.42	-0.11	-0.74	-0.07	-0.15
Bugnara	-1.41	0.42	-0.44	-0.49	-0.28	-0.81	-0.98	-0.49	**3.54**	-0.44	-0.33	0.10	0.69	-0.55	-0.01	-0.01	0.64	0.69	1.23	-0.22	-0.44	-0.44
Campo di Giove	-0.72	0.99	-0.07	0.10	-0.47	-0.07	-0.72	-0.47	**3.91**	0.50	0.42	-0.80	-0.31	0.01	0.10	0.42	-0.55	-0.31	-0.07	-0.88	-0.80	-0.23
Cansano	-0.35	0.75	0.10	-0.28	-0.39	0.10	-0.39	0.10	**4.21**	-0.01	-0.50	-0.54	-0.39	0.29	-0.39	-0.43	-0.47	-0.43	-0.05	-0.73	-0.35	0.14
Castel di Sangro	-0.66	-0.72	0.78	0.52	0.09	0.09	-0.15	-0.24	**3.84**	-0.07	-1.20	-1.01	0.09	-0.53	-0.05	-0.61	0.01	0.22	-0.72	-0.45	0.22	0.57
Castrovalva	-1.48	1.71	-1.27	1.92	0.86	-0.20	0.43	0.43	0.86	0.01	-0.42	1.92	-0.63	0.22	-0.63	0.22	-1.27	-0.63	-1.05	0.22	-0.63	-0.63
Civitella	-0.98	-0.58	-0.38	0.22	-0.98	0.22	-0.18	-0.18	**3.41**	0.02	-1.38	-0.38	0.22	0.42	1.61	-0.18	-0.18	-0.18	-0.98	-0.58	0.62	0.42
Frattura	-0.50	0.60	-0.72	-0.06	-0.50	-0.06	-0.72	-0.50	1.69	**2.79**	0.82	-0.28	0.60	1.47	-0.94	0.16	-0.72	-0.06	-0.28	-0.28	-1.59	-0.94
Introdacqua	-1.63	**2.68**	-0.01	-0.56	0.48	-0.47	-1.11	-1.02	1.87	1.18	0.16	-0.73	0.28	0.02	-0.01	-0.36	0.54	-0.76	-0.10	-0.85	-0.39	0.80
Pacentro	-1.12	**2.51**	-0.61	-0.64	-0.58	0.04	-0.95	0.12	**2.48**	0.46	0.12	-0.61	-0.58	0.54	-0.89	-0.69	0.18	0.04	-0.33	-0.89	0.06	1.36
Pentina	0.58	-0.17	-0.52	-0.67	-1.57	-0.72	-1.52	-0.72	**2.78**	0.18	0.23	0.18	-0.57	-0.47	-0.37	-0.32	1.58	1.33	-0.02	0.18	0.98	-0.42
Pescocostanzo	-1.41	1.62	-0.13	-0.13	0.34	0.75	-0.80	0.21	**2.57**	-0.06	-1.54	-0.60	-0.40	1.69	0.34	-0.33	0.14	-0.20	-1.14	-0.13	0.21	-1.00
Pettorano	-0.72	1.30	-0.37	-0.40	0.42	-0.43	-0.72	-0.11	**3.62**	0.19	-0.61	-1.02	0.89	0.69	-0.69	0.01	-0.31	-0.46	-0.69	-0.52	-0.34	0.28
Pietansieri	-0.41	0.15	-0.34	-0.20	0.22	-0.27	-0.34	0.08	**4.40**	-0.13	-0.27	-0.48	-0.27	-0.13	-0.27	-0.48	-0.27	-0.13	-0.06	-0.34	-0.06	-0.34
Popoli	-1.39	**2.57**	0.31	-0.37	-0.82	0.61	-0.37	-0.18	**2.61**	0.46	-1.28	-0.41	0.42	-0.63	-0.11	-0.07	-0.14	0.54	-0.60	-0.94	-0.14	-0.07
Pratola	0.24	0.34	-0.49	-0.09	-1.58	-0.42	-1.06	-0.70	**2.19**	**2.19**	1.86	-1.25	-0.06	-0.42	-0.42	0.61	0.31	0.09	0.12	-0.42	-0.76	-0.27
Prezzo	-0.76	-1.35	-1.09	-1.26	0.26	0.93	-0.25	-0.42	**3.47**	0.43	0.43	-0.67	0.26	-0.17	-0.59	0.76	-0.33	0.43	-0.42	0.51	0.09	-0.25
Raiano	-0.94	-0.61	-0.80	-0.28	0.12	-0.47	-0.28	-0.28	**3.15**	0.05	-0.47	-1.33	-0.61	-0.47	0.45	0.65	0.25	1.31	-1.07	0.45	-0.34	1.50
Rivinsondoli	-1.69	-1.14	-0.33	-0.12	1.30	-0.67	-1.14	-0.19	**2.32**	0.90	-0.67	-0.26	-0.73	1.10	-1.01	-0.06	0.56	0.42	0.62	0.08	-0.80	1.51
Roccacasale	-0.87	1.40	-0.40	-0.82	-0.08	-0.66	-0.03	0.40	**3.25**	1.14	-0.77	-0.29	-0.34	0.18	-0.66	-0.98	0.92	0.34	0.40	-1.03	-0.50	-0.61
Rocca Cinque Miglia	-0.56	-0.72	0.80	-0.56	0.08	0.00	-0.24	-0.16	**3.94**	-0.24	-0.56	-0.56	-0.32	1.04	-0.08	-0.56	-0.48	0.32	-0.08	-0.72	0.32	-0.64
Roccarosa	0.15	1.49	-1.20	0.34	-0.52	0.44	-0.43	1.01	**2.94**	0.24	-0.72	-0.91	0.73	-0.24	-0.81	-0.14	-0.43	-0.91	-0.72	-1.20	-0.24	1.11
Roccaveleoscura	-0.48	1.75	-0.74	-0.83	**2.01**	-0.23	-0.66	-0.57	**2.95**	0.03	-0.48	-0.40	0.55	0.03	-0.23	0.03	-0.66	-0.48	0.03	-0.83	-0.91	0.12
Scanno	-1.13	-0.41	-0.91	0.09	-0.41	-0.48	0.16	-0.41	**2.39**	**2.17**	0.45	-0.41	0.88	1.53	0.38	-0.99	-1.06	-0.48	0.38	-0.77	-0.99	0.02
Scontrone	-0.47	-0.27	-0.60	0.18	-0.66	**2.49**	-0.15	0.18	**2.36**	**2.17**	-0.79	-0.79	-0.47	-0.21	-0.21	0.24	-0.34	-0.34	-0.85	-0.72	-0.40	-0.34
Solmona	-1.96	0.91	-1.10	-0.53	-0.14	-0.05	-0.54	-0.37	**3.11**	0.81	-0.40	-0.38	-0.38	0.53	-0.47	0.69	1.47	-0.34	-0.19	-0.57	-0.06	-0.05

	1809	**1810**	**1811**	**1812**	**1813**	**1814**	**1815**	**1816**	**1817**	**1818**	**1819**	**1820**	**1821**	**1822**	**1823**	**1824**	**1825**	**1826**	**1827**	**1828**	**1829**	**1830**
Villalago	-0.92	1.92	-0.80	-0.27	-0.74	-0.51	-0.74	-0.03	**3.46**	-0.51	0.09	-0.51	-0.33	-0.09	-0.39	0.09	-0.27	-0.57	0.32	0.98	-0.33	0.15
Villetabarrea	-0.77	-0.18	-0.03	1.31	0.12	-0.03	-1.06	0.42	0.27	**2.49**	0.71	-1.21	-0.62	-0.77	1.60	1.16	-0.62	-0.18	-0.92	-1.21	0.57	-1.06
Vittorito	0.06	0.41	-0.37	-0.72	-0.63	-1.32	-1.15	-0.98	**2.83**	-0.54	0.06	-0.89	-0.11	-0.80	1.88	-0.11	0.41	-0.02	0.24	-0.20	0.58	1.36
DISTRICT	**-1.37**	**0.90**	**-0.47**	**-0.30**	**-0.28**	**-0.18**	**-0.81**	**-0.34**	**3.88**	**0.75**	**-0.35**	**-0.76**	**-0.15**	**0.21**	**-0.22**	**-0.01**	**0.42**	**-0.12**	**-0.29**	**-0.58**	**-0.21**	**0.28**

Figure 2: **Monthly Z-Score for Recorded Deaths (shown for Jan 1815 – Dec 1820, calculated using data 1809 to 1830) for District Summary, Sulmona, and All Other Comuni**

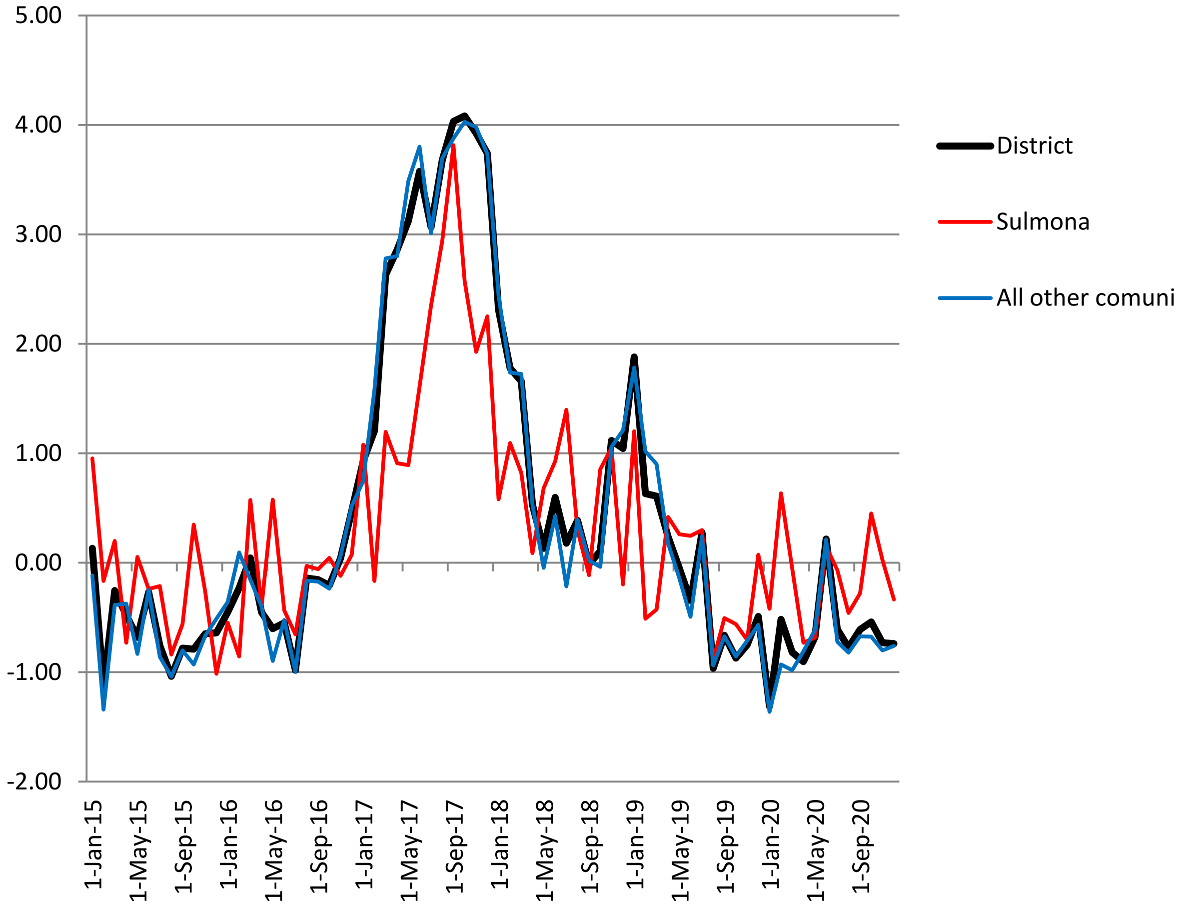
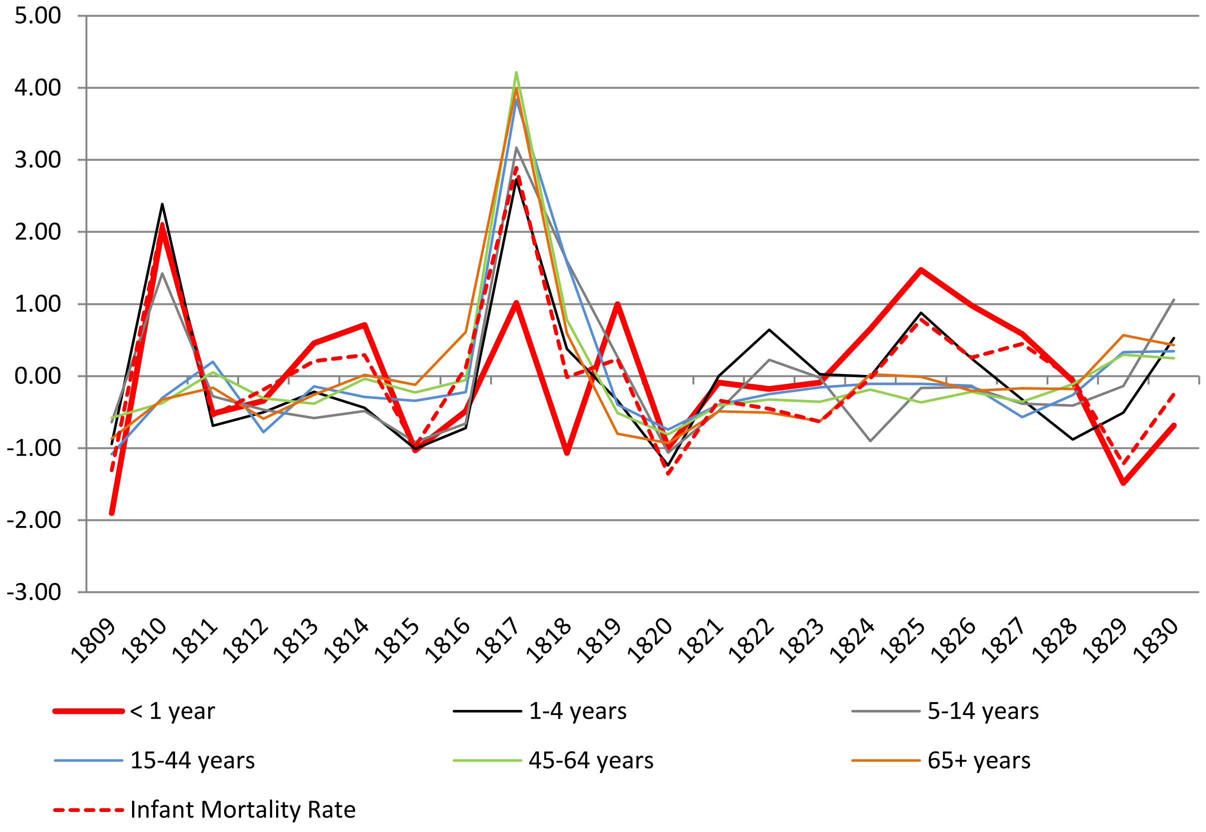


Figure 3: **Z-score distribution of registered deaths by selected age group and infant mortality by year of occurrence (1809-1830) for District**



Appendix A: List of Comuni within Solmona District

- Alfedena
- Anversa
- Ateleta
- Barrea
- Bugnara
- Campo di Giove
- Cansano
- Castel di Sangro
- Castrovalva
- Civitella
- Frattura
- Introdacqua
- Pacentro
- Pentina
- Pescocostanzo
- Pettorano
- Pietansieri
- Popoli
- Pratola
- Prezzo
- Raiano
- Rivinsondoli
- Roccacasale
- Rocca Cinque Miglia
- Roccarosa
- Roccaveleoscura
- Scanno
- Scontrone
- Solmona
- Villalago
- Villetabarrea