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Cost estimation of listeriosis (*Listeria monocytogenes*) occurrence in South Africa in 2017 and its food safety implications

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ABSTRACT

Periodic outbreaks of foodborne pathogens have resulted in food safety concerns, due to health implications and cost consequences. Occurrence of *Listeria monocytogenes* in foods and listeriosis have been reported in developed countries; however, documentation of listeriosis in South Africa is limited. In 2017-2018, *Listeria* was reported on polony (processed deli meat) and listeriosis was observed in South Africa (*L. monocytogenes* sequence type 6 (ST-6) was identified as the causal agent for listeriosis). Due to its potential effects, we conducted cost estimates to assess the implications of listeriosis outbreak with respect to illnesses, hospitalizations and deaths, and productivity losses. Cost estimates were computed on publicly available data by using USDA-ERS cost computation model for *Listeria*. Listeriosis had significant impacts, as mortality of 204 individuals with confirmed listeriosis cases was reported, with infants having the highest percent of fatalities (42%). The cost valuation of fatality cases was over US$ 260 million. Hospitalization costs associated with one-month recovery from listeriosis were estimated at US$ 10.4 million. Productivity losses attributed to listeriosis for humans and export value losses for food processors were in excess of US$ 15 million. Increase of food safety measures in South Africa could reduce foodborne disease outbreaks. Pre-emptive pathogen detection, sanitary procedures and bacterial inactivation can enhance control of *L. monocytogenes* in food processing environments.

Keywords: Foodborne pathogen, *Listeria monocytogenes*, listeriosis, polony (deli meat), cost analysis, South Africa

1. Introduction

On a worldwide basis, over 91 million people are sickened as a consequence of foodborne pathogens and associated illnesses (World Health Organization, 2013). Foodborne pathogens and outbreaks of associated diseases occur frequently and pose significant constraints to consumer health in many parts of the world, resulting in morbidity, mortality and economic losses (Havelaar et al., 2015, World Health Organization, 2013). It has been reported that vast differences in the distribution and impacts of foodborne illnesses exist among countries and geographical regions (Havelaar et al., 2015). This is based on diverse food systems and production to consumption patterns that may subject food products to contamination by pathogenic microbes (van Berkum et al., 2017).

In the United States, more than 48 million cases of illnesses per year are associated with foodborne pathogens (Scallan et al., 2011a, 2011b). Furthermore, over 128,000 hospital admissions and mortality of over 3,000 individuals are attributed to foodborne illnesses on a yearly basis in the U.S. (Scharff, 2012). Total monetary expenditures associated with food safety, control of pathogenic microbes in the U.S. and consequences of outbreaks can exceed US$ 51 billion a year (Scharff, 2015). Although significant gains in food safety have been made in the developed nations, improvements in food safety are needed in developing countries. Therefore, intervention measures to enhance food safety and mitigate foodborne pathogens and disease outbreaks are paramount.

In Sub-Saharan Africa (South Africa inclusive), costs associated with foodborne pathogens and illnesses are not precisely known, as many cases go unreported or have incomplete diagnosis (De Noordhout et al., 2014). However, periodic outbreaks of foodborne diseases are common and based on World Health Organization estimates, foodborne diseases may be responsible for well over 142,000 mortalities a year in Sub-Saharan Africa (Havelaar et al., 2015). The majority of fatalities from foodborne illnesses in Sub-Saharan Africa may be attributed to non-typhoidal *Salmonella* (diarrheal), especially among children (De Noordhout et al., 2014). Due to poor sanitary conditions and lack of rigorous food safety regulations, outbreaks of other enteric diseases including Shiga toxin-producing *Escherichia coli* O157:H7, along with parasitic and protozoa-incited diseases may occur (Havelaar et al., 2015). Additionally, foodborne pathogens and disease outbreaks can lead to economic losses especially if phytosanitary and sanitary compliance is lacking (USDA-FAS GAIN, 2018). Similarly, contamination of agricultural commodities or food

items with foodborne pathogens can lead to costly recalls and other losses.

Despite research progress on foodborne pathogen control (Mukhopadhyay et al., 2018; Olanya et al., 2018, Oladunjoye et al., 2016; Ukuku et al., 2012; 2016), listeriosis outbreaks have been recorded on many food products (Buchanan et al., 2017). *Listeria monocytogenes* has been ranked seventh, as a global burden of foodborne pathogens (De Noordhout et al., 2014). The worldwide outbreaks of listeriosis have often been associated with ready-to-eat (RTE) foods, minimally processed and with long shelf-life. Outbreaks of listeriosis have been reported in developed countries. In the European Union (32 countries), 1,763 confirmed listeriosis cases were reported in 2013 with a total of 191 fatalities (EFSA, 2013). Here, listeriosis outbreaks were associated with meat products, pork and pork products, seafood, cheese, vegetables and juices (EFSA, 2013). Similarly, in New Zealand, *L. monocytogenes* outbreak was documented on seafood (Cruz et al., 2014). Listeriosis outbreak was also documented on deli meat in Canada in 2008, resulting in 24 fatalities (Currie et al., 2015). In the U.S., several outbreaks of listeriosis have been reported recently including cantaloupes in Colorado and several states, resulting in 33 fatalities (CDC, 2011), pre-cut contaminated diced celery in Texas hospitals, resulting in 5 fatalities (Gaul et al., 2013), pre-packaged caramel apples in several states resulting in 7 fatalities (CDC, 2015a), ice cream in several states resulting in 3 fatalities (CDC, 2015b), and mung bean sprouts in Illinois and Michigan resulting in 2 fatalities (CDC, 2015c). In South Africa and Sub-Saharan African region, there have been no previous documentation on listeriosis outbreaks due to lack of reporting systems, but listeriosis in ruminants were noted in South Africa (de Toit, 1977).

The costs that have been previously quantified in foodborne outbreaks (Ahmed 2014; Batz et al, 2014) include: a) assembling of a team and collection of information (initial report). Interviews/surveys of healthy and sick individuals, samplings of foods and specimens from affected individuals for microbial determinations, visual inspections of sites or locations of contaminated products and where sick individuals are present; laboratory determinations of samples and medical lab diagnosis of affected individuals; b) Data compilation and organization e.g. the microbiological tests and laboratory results, inspection reports / interviews, cases of foodborne illnesses and medical reports used to evaluate the cause of illnesses; c) Surveillance and containment of foodborne outbreak. The extent of outbreaks is examined, problems identified, and determination of how future illnesses could be curtailed are outlined. Recommendations to improve health and safety, as well as extensive trainings are provided to specific groups and the

general population on how to remove the threat of foodborne illnesses; d) documentation of the findings (detail reports) based on the investigation.

In 2017, an outbreak of listeriosis was reported on deli meat commonly referred to as "polony" in South Africa (Department of Health South Africa, 2018). Polony, produced mainly from pork and processed by food manufacturers in South Africa is regularly consumed by many people (Ijabadeniyi, 2018, Unpublished; Ronquest-Ross et al., 2015). Processed meat from South Africa was also regularly exported to Southern African Development Coordination (SADC) countries and to other Sub-Saharan African countries, (USDA-FAS GAIN, 2018).

During the outbreak, it took 60 weeks to identify polony as the culprit in the outbreak. The outbreak was declared on December 5, 2017 (Department of Health, S. Africa, 2018). The data collection by the Department of Health, South Africa and food safety group and other response team began January 1, 2017, during which interviews were conducted on individuals diagnosed with listeriosis prior to the recall (Department of Health, S. Africa, 2018a, 2018b). Actual investigation for the potential role deli meat had in the listeriosis outbreak begun in August 2017. Prior to the recall from January 1, 2017 to March 4, 2018, individuals interviewed indicated that they had consumed polony (processed deli meats). People began to realize that the culprit was probably polony (and might have reduced their purchases) when a recall was issued on March 5, 2018 (Department of Health, South Africa, 2018). The recall process was continued until the outbreak was contained and declared over in late May 2018. The export ban for processed meat (deli meats) from South Africa began in March 2018 (USDA-FAS GAIN 2018**).** The duration that the recall process lasted has not been precisely determined since import data and duration of the ban from the importing countries has not been published. Similarly, the deli producing plants were temporarily closed for sanitization in May 2018, but it was not clear how long the various plants were not operational since plant data are not readily available. Therefore, the costs involving plant sanitization and implementation of better food safety standards were not included in this research.

In this paper, only the direct costs of listeriosis associated with human impacts (mortality and hospitalizations) and processed meat export trade (deli meats) were utilized in computing short-term costs associated with foodborne outbreak (Figure 1A). The costs associated with assembling a *Listeria* management team, collection of information (interviews, inspections, lab samples, processing and diagnosis); data analysis: surveillance costs; medical costs; documentation and administrative costs; changes in consumer demand or product substitutions costs; plant sanitization

costs and the long-term social and societal costs were not computed (Figure 1B). Costs with available, non-confidential data that could be quantified were illnesses, hospitalizations, and mortalities.

Due to potential economic consequences associated with outbreaks and limited published data on foodborne outbreaks from South Africa and Sub-Saharan Africa, we conducted cost estimates using publicly available data, to have a better understanding of outbreak effects and potential implications. There are various methods that have been previously used to quantify the costs of foodborne illnesses such as willingness to pay method (Andersson et al., 2015), or cost of illness method (Ahmed 2014). Other methods combined the two approaches which quantifies direct and indirect costs. We used incidence-based methods to assess listeriosis effects based on USDA-ERS cost estimation method (ERS-USDA 2014). Therefore, the objective of this research was to determine the cost implications of the 2017 listeriosis outbreaks in South Africa on morbidity and hospitalization costs, mortality, and productivity losses to affected individuals, food processors, and processed meat export.

2. Materials and Methods

2.1. Data sources

The National Listeria Incident Management Team of South Africa was formed after the outbreak investigation began in August 2017 and produced situations reports (Department of Health South Africa, 2018). This served as public data source for this paper. Laboratory confirmed listeriosis cases, morbidity, number of hospitalized individuals, age-group distribution of patients with listeriosis cases, numbers discharged from treatment facilities and mortality from South African provinces was utilized in computing cost estimates. The South African processed meat export data was retrieved from USDA Foreign Agriculture Service, Global Agricultural Information Network Report (USDA-FAS GAIN, 2018). This was used to estimate costs on temporary import ban of processed meat product from South Africa by SADC countries (due to listeriosis outbreak).

2.2. Cost calculations

The cost calculator of *Listeria* foodborne illness produced by the Economic Research Service (ERS-USDA, 2014; Hoffman et al., 2012; Havelaar et al., 2015; Bartz et al., 2014) was used to

compute costs associated with listeriosis outbreaks in South Africa. The computation had low, average, and high cost listeriosis-case outbreak scenarios. The components of listeriosis losses were estimated as direct and indirect costs (Figure 1). The direct costs were computed from valuation of human life (value of statistical life ($/person) × deaths from outbreak), hospitalization costs (mean cost of regular or internal care unit ($/person) × number of hospital cases), work losses from *Listeria* affected individuals was computed as mean productivity loss ($/person × number of cases missing work), and costs ($) of contaminated polony (quantity (kg) × price ($/kg) of polony) (Figure 1). The direct costs that were not estimated consisted of: current and future value of outpatient care and medication costs to treat chronic and acute cases, future cost of human suffering and lost productivity, value of lost polony consumption in South Africa's domestic market, as well as lost human life and productivity in polony importing countries during the outbreak. The indirect costs not included in this paper include: administrative costs (*Listeria* Management Team), surveillance, sample collection and processing, plant sanitization costs, and this outbreak's long-term societal costs. Our computations were also based on previous reports and considerations of costs of similar foodborne pathogens (Scharff, 2012, 2015; Olanya et al., 2016).

2.3. Health outcomes

The human impacts and health outcomes associated with listeriosis outbreak were derived from the listeriosis situation report (Department of Health South Africa, 2018). These included sick individuals but those who did not go to the doctor (costs can't be quantified), sick and went to the doctor, and hospitalized with final outcomes within time periods (costs measured), sick and hospitalized without a final outcome (costs could not be measured). Data for hospitalization consisted of adolescent, mothers, children, infants (newborn to <28 days). The hospitalized outcomes for infants, children, and adolescents were based on age groups with morbidity and mortality records for cost analyses.

In order to calibrate the ERS model for South African conditions, we evaluated mortality compensation values from Miller (2000) which were estimated for all countries in the world through meta-analysis of available global data to derive ranges of multipliers (global average ~120) required to convert per capita GDP to the estimated value of a human life. These multipliers estimated for South Africa were used to derive the minimum to maximum range of life valuation for the analysis. Therefore, mortality cases were assigned compensation values of US$ 1,244,747

and US$ 2,524,312 per fatality for minimum and maximum human life valuation adjusted for South Africa (Miller, 2000) which was 15% to 80% of U.S. values (ERS-USDA, 2014). Compensation values for mortality were derived by adjusting current South African per capita GDP (IMF, 2018) by estimated multipliers (Miller, 2000). These values were then multiplied by the average percent (64.94%) of South African life expectancy (SSA, 2018b) remaining for all age-classes specific to the 204 outbreak fatalities (Department of Health South Africa, 2018).

2.4. Hospitalization costs

Although cost accounting for hospitals and medical costs for listeriosis may differ among countries and medical establishments, due to variation in healthcare systems (Goudge et al., 2009; Ivanek et al., 2004; Hoffman et al., 2012; Minor et al., 2015), the basic components for hospitalization costs are similar (ERS-USDA, 2014). In this computation, the South African hospital costs per patient were assumed to be 12.1% of U.S. hospital costs (Goudge et al., 2009). The medical cost estimates included the average costs per care of regular hospitalization due to listeriosis for intensive care units (ICU) based on South African conditions (Goudge et al., 2009). We excluded the cost computations for chronic cases of listeriosis, as data on disability attributed to listeriosis were not readily available and chronic conditions have yet to manifest themselves. In some instances, the outcomes of hospitalization were still pending (have not yet been determined).

2.5. Productivity losses

Productivity losses (the average number of work days) due to listeriosis outbreak was assessed, on the assumption that able-bodied working age (15 to 64 years old) individuals were gainfully employed (SSA, 2018a). The productivity losses per case were computed for a duration of one month (ERS-USDA, 2014), as this was the estimated duration of hospitalization and medical recovery from listeriosis for acute or non-fatal cases and pending in which case outcomes have not yet been determined (185 cases of 15-49 years old and 34 cases of 50-64 years old) as well as 89 (15-49 years old) and 26 (50-64 years old) cases discharged from hospitalization (Table 1). Lost income during hospitalization was computed using the average monthly income in South Africa (SSA, 2018a).

The losses in revenue associated with temporary suspension of processed meat import from South Africa by SADC countries were computed using trade data from USDA-FAS (USDA-FAS

GAIN, 2018). The 2016 and 2017 processed meat export statistics were averaged to project potential 2018 export values. The average weights were multiplied by the domestic price for polony per kg, based on market surveys and consumer price index data for South Africa (NAMC, 2018). It is not known if the prices for 2017 reflected any adverse effect on consumer demand for polony, given that from January 1, 2017 to March 4, 2018, individuals were interviewed regarding consumption of polony and its association with sickness. Therefore, the prices that would have been in effect after polony was identified as the culprit might have been different from that in the previous two years.

2.6. Statistical analysis

The mean and variance components of health outcomes associated with listeriosis were computed by Proc Means of the Statistical Analysis System (SAS Institute Inc., Cary, N. Carolina, USA). Parameters of the listeriosis computation (ERS-USDA, 2014) were updated for minimum and maximum human life valuation for listeriosis case-scenarios. Results for cost computations were presented as lower and upper bounds of cumulative costs due to high variability of human life valuation.

3. Results

3.1. Health outcomes

The outbreak of listeriosis contamination of polony and associated deli meat products led to serious health consequences for consumers in South Africa (Table 1). Listeriosis occurrences were recorded in all nine provinces in South Africa. Among the provinces, confirmed listeriosis ranged from 6 to 606 cases with mortality of 3 to 106 cases (Table 1). Overall, there were 1,034 total confirmed listeriosis cases with 204 fatalities. Listeriosis was recorded on babies (≤ 28 days old) to adults over 65 years old (Table 1). The total cases varied among age groups as 441 cases were babies and 83 cases were > 65 years old. The number of fatalities was lowest for those > 65 years old, and highest for infants (Table 1). No data were available on the exact ages of listeriosis-affected individuals due to confidentiality regulations. Reports indicated that all individuals diagnosed with listeriosis had consumed polony or deli meat contaminated with *L. monocytogenes*.

Over 95% of the costs of listeriosis was human mortality and cost estimates varied depending on life valuation (Figure 2). Based on previous estimates (Miller, 2000) and listeria cost model

using (ERS-USDA, 2014), low (US$ 1.2 million) and high (US$ 2.5 million) life valuation costs were computed. The total valuation of mortalities over the 16 months of the outbreak ranged from US$ 265 million using the low valuation for a fatality to US$ 525 million using the high valuation (Supplemental Materials, Table S1). At both one year (52 weeks) and at the recall for contaminated product at 62 weeks of listeriosis, the cumulative costs of listeriosis were already approaching values similar to the total estimated cost for listeriosis for both minimum and maximum estimates (Figure 2, Table 2). The South African Rand (ZAR) equivalent cost estimates are also presented (Supplemental Materials, Table S2 and Figure S1).

3.2.Hospitalization costs

The number of cases with no hospitalization after consumption of contaminated product, were assumed to be zero as no data or records were indicated. There were no estimates from other countries as to how many people might have been affected by listeriosis. The hospitalization of adults with severe cases of listeriosis (Internal Care Unit), who subsequently recovered was also assumed to be zero as there were no reports. Similarly, no stillbirths were reported for infants, and post-hospitalization outcomes for mild, moderate or severe disability were assumed to be zero as no data were reported under this category. There was a total of 544 adults, where hospitalized cases consisted of 338 adults and 92 mothers, while mortality totaled 114 cases. Hospitalized newborn recovery from listeriosis totaled 400 cases with 90 mortalities (Supplemental Materials, Table S3). For adolescents and adults greater than 15 years of age or those in unknown age groups, there were 285 cases. The hospitalized adolescents and adults over 15 years old or those with unknown ages and with pending outcome of hospitalization from foodborne listeriosis had 145 cases. There were 255 hospitalized newborns that recovered, while newborns with pending outcome comprised 145 listeriosis cases (Supplemental Materials, Table S4).

The total mortality costs for 204 individuals was at least US$ 265 million. The hospitalization costs for babies born with listeriosis were estimated at US$ 15,840 per case with a total estimated cost of over US$ 6 million (Table 2). The mortality cases of babies born with listeriosis computed based on Miller (2000) standards amounted to US$ 1.28 million/case for a total cost of US$ 115 million (Table 2). For the adults, the medical costs for maternal hospitalization cases amounted to over US$ 364,000, while for other adults and deceased adults, hospitalization costs were over US$ 1.3 million and US$ 902,000, respectively (Table 2). The costs associated with the mortality of

311 114 adults attributed to listeriosis amounted to over US$ 145 million. The total costs associated
312 with the projected hospitalization were US$ 10,367,280 (Table 2). Hospitalization costs per case
313 varied at US$ 15,840/case for babies, US$ 7,920/case for hospitalized older individuals that died,
314 and US$ 3,960/case for being hospitalized (Table 2).
315
316 *3.3. Productivity losses*
317 The total losses in one month of lost productivity for maternal, adult cases was computed as
318 US$ 184,276 at US$ 2,003 per case. For other adults with moderate cases (no mortality recorded)
319 of listeriosis, loss productivity was computed at US$ 1,230 per case totaling US$ 415,740 (Table
320 2). Productivity losses were only 0.22% of listeria outbreak costs.
321
322 *3.4. Potential outbreak effects on South African food processors*
323 Listeriosis contamination in South Africa's food processing industry resulted in recalls of
324 about 4,000 metric tons of polony-related food products (Ijabadeniyi, 2018, Unpublished). The
325 aggregate monetary loss to processing industry due to recall was US$ 52.9 million (164 million
326 ZAR), not including incineration or other disposal costs. The transportation costs and other costs
327 associated with pig farmers, and polony retail sales or changes in consumer demand / product
328 substitution were not computed. This was based on consumer price index and commodity price
329 statistics (NAMC, 2018), in which polony retail price was US$ 3.20 /kg (43 ZAR /kg, exchange
330 rate, 1 US$=13.4 South African Rand - ZAR). During the outbreak period, there was a 50% drop
331 in consumer demand for pork (primary ingredient in polony) and subsequent losses to affected pig
332 farmers was reflected by 20-40% reduction in producer prices of pork which was not computed in
333 this paper (NAMC, 2018).

334 *3.5. Potential losses to South African processed meat export*

335 The export of processed meat (polony, sausages, preserved chicken, bovine meat, and related
336 processed meat products) from South Africa to SADC countries were temporarily suspended as a
337 consequence of the listeriosis outbreak (GAIN, 2018). Estimated aggregate potential losses in
338 export revenue (assuming export levels of 2016-2017 were maintained) from listeriosis outbreak
339 amounted to US$ 11.3 million (Table 3) or 151.77 million ZAR (Supplemental Materials, Table
340 S5). This is ~40% of the US $28.1 million estimated cost of the recall of South African polony

and other deli products bound for both domestic and international sales (Ijabadeniyi, 2018, unpublished).

4. Discussion

The health impacts of the 2017-2018 listeriosis outbreak in South Africa were diverse, ranging from hospitalization to mortality. Listeriosis was reported in various parts of the country, implying that contaminated polony could have been distributed and consumed in various regions of South Africa. This suggests possible *Listeria* contamination of polony from various sources. However, more listeriosis cases were recorded in Gauteng province, implying that greater population exposure, consumption of contaminated polony, and pathogen infections could have occurred in that province. Infants were more susceptible or predisposed to mortality from South African listeriosis, consistent with previous findings (Mateus et al., 2013). This indicated greater susceptibility of pregnant women and infants to listeriosis, due to reduced immune responses.

In this paper, no attempt was made to characterize *L. monocytogenes* serotypes, the dynamics of listeriosis outbreak, nor severity of listeriosis in age-group populations in 2017. However, this is the first widespread documentation of listeriosis outbreak in the Republic of South Africa and in Sub-Saharan Africa, as no previous human outbreaks were reported. The only exception of listeriosis occurrence in South Africa was in ruminant animals in Western Cape (du Toit, 1977) and in sheep (Meredith and Schneider, 1984). The lack of previous reports of listeriosis in South Africa may be that listeriosis was not included among the list of notifiable diseases in South Africa (Department of Health South Africa, 2018). Elsewhere in Sub-Saharan African countries, the lack of listeriosis reports indicated that either there were no occurrences, or the pathogen was below detection limits. In contrast, frequent and occasional outbreaks of listeriosis have been reported elsewhere (EFSA, 2013; Cruz et al., 2014; Currie et al. 2015; Gaul et al., 2013; CDC, 2015a, 2015b, 2015c).

In comparison to previous *Listeria* outbreaks, the number of hospitalization and mortality cases recorded in the South African listeriosis in 2017-2018 is greater than any previously reported in the U.S., European Union, Australia and New Zealand or elsewhere (CDC, 2015c; Cruz et al., 2014; EFSA, 2015). This implies wider distribution of pathogen-contaminated products within South Africa, leading to greater consumption and subsequent infections, or longer duration of listeriosis contamination, since product recalls occurred 60 weeks after first listeriosis case.

Variation in food safety regulations, detection methods, trace-back methodologies and recall procedures associated with South Africa (middle-income economy), as opposed U.S. or the European Union (developed economies) could have resulted in delayed responses and impacted *Listeria* control measures. The high number of cases could also be explained by greater consumption of contaminated processed polony, prior to outbreak containment. Increases in the consumption of processed foods in urban areas of South Africa have been reported recently (Ronquest-Ross et al., 2015; van Berkum et al., 2017).

Although *L. monocytogenes* can be inactivated by various food safety interventions (Olanya et al., 2018; Ukuku et al., 2016), rigorous sanitary precautions in food processing environments and retail outlets should be maintained to mitigate potential pathogen contamination. Published reports indicate that *Listeria* can survive on food products and processing environments for long durations. *L. monocytogenes* persisted and survived for 4 months in frankfurters in the U.S. (Wenger et al., 1990), 1 year in cooked poultry in Ireland (Lawrence and Gilmour, 1995), 14 months on smoked fish in Switzerland (Boerlin et al., 1997), 4 years in sliced lunch meat in Norway (Loncarevic et al., 1996), and 7 years in cheese in Sweden (Unnerstad et al., 1996). Therefore, precautions should be exercised in the detection and control of *L. monocytogenes* on polony and other food products in retail outlets, storages and food processing environments.

The costs associated with fatalities due to listeriosis were the most significant valuation in affected populations. Mortality case compensations attributed to foodborne illnesses based on current literature indicate that monetary valuation of human fatality as a consequent of foodborne illness should be computed at ~120 times per capita GDP of a country (Miller, 2000). In our analyses, the quality adjusted life years (QALY) were not used for computation of life valuation since this requires discounting annualized values of life over time horizon of the impact of illnesses (Bartz et al., 2014). For the South African listeriosis, the time horizons of the impact and other variables are not clearly known at this time. Similarly, human capital measures based on expected lifetime earnings was not used since this is not current methodology (Viscusi, 2008). Similarly, no attempt was made to quantify disability-adjusted life years (DALY, where one DALY equals one year of healthy life lost, that was attributed to listeriosis), due to lack of specific data (exact ages, case severity, and duration) of affected individuals (De Noordhout et al., 2014). Therefore, hospitalization costs were assumed to be the same for all cases. In this paper, valuation used per mortality case ranged from US$ 1.24 million/case to US$ 2.52 million/case. This is not totally

403 unexpected, as average monetary loss due to *L. monocytogenes* per case was estimated at US$ 1.5
404 million for the United States (Minor et al., 2015). The aggregate annual cost of foodborne illnesses
405 in the U.S. was estimated at US$ 77.7 billion (Scharff, 2012).
406 In South Africa, compensation value of US$ 88,588.18 (1.2 million ZAR) per mortality case
407 was awarded in 2018 as punitive liability resulting from negligence for mortality of mentally-ill
408 patients (Ijabadeniyi, 2018, Unpublished). Regardless of the cost attribution, valuation of human
409 life is a daunting task as uncertainties associated with productivity in a lifetime can be subject to
410 very many unpredictable variables. It is possible that lower costs would have occurred if accurate
411 determinations of contamination sources and recall procedures were initiated during earlier weeks
412 of the listeriosis outbreak. Therefore, projected estimation for compensation can be very costly.
413 The hospitalization costs indicated an amount in excess of US$ 15,000 per case would easily
414 have been spent as this is consistent with hospitalization costs for South Africa for similar cases
415 (Goudge et al., 2009). Hospitalization costs were computed for one month as the recovery period
416 from listeriosis. However, this duration could be greater depending on the severity of cases.
417 The estimated productivity losses varied as values ranged from US$ 1,230 for adults with moderate
418 recovery (where listeriosis cases did not result in death) to US$ 2,003 per maternal case. The lost
419 productivity (paid work hours) due to hospitalization for a month assumed that losses were 50%
420 for adults with moderate listeriosis and 81.4% for mothers. The lost productivity is consistent with
421 potential monthly lost earnings for South African workers, based on average household-wage
422 income in South Africa (SSA, 2012). In contrast, the annual benefit of listeria food safety measures
423 was approximated at US$ 0.01 billion to $2.4 billion (De Noordhout et al., 2014).
424 The loss in polony products in South Africa's domestic market is difficult to quantify in the
425 absence of consumption and sales data. However, aggregate lost value of products due to recall
426 (US$ 52.9 million) is substantial (Ijabadeniyi 2018, Unpublished). It is possible that losses in value
427 chains and retail sales for deli products could be higher and may never be accurately quantified.
428 Similar losses in exported processed meat (US$ 7.8 million) indicate that losses attributed to
429 foodborne *Listeria* could be huge, as our estimates do not account for the entire spectrum of meat
430 products affected.
431 In conclusion, the 2017 outbreak of listeriosis, caused by *L. monocytogenes* and conveyed by
432 a single food product, had enormous consequences in South Africa. The most significant costs
433 were mortality and hospitalization from listeriosis. The drawbacks for this study is that there were

some direct and indirect costs that could not be quantified due to medical confidentiality issues that were excluded from the analyses. These include medication costs, sampling, laboratory /diagnosis costs, administrative costs, surveillance costs, the long-term effects of listeriosis on affected individuals in South Africa and possibly other countries. Similarly, the costs of value chains (pork producers / pig farmers, retail sales for polony and other processed meat, butcheries / loss productivity in value chains), and changes in consumer demand / product substitution costs. These limitations indicate that costs detailed in this paper may under-estimate the impact of listeriosis as some long-term data have not yet been obtained. Improvements in food safety control measures in South Africa could minimize reoccurrence of outbreaks, Future studies should quantify long-term effects of listeriosis as well as changes in consumer behavior, food manufacturing practices and regulatory compliances. Pre-emptive pathogen detection, sanitary procedures and pathogen inactivation would enhance control of *L. monocytogenes* in food and processing environments.

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Table 1. Health outcomes of listeriosis outbreak following consumption of polony (processed deli meat) that was subsequently determined to be contaminated by *Listeria monocytogenes* in South Africa[a].

Provinces with listeriosis outbreak[b]	Total listeriosis cases[c]	Listeriosis cases with outcomes[d]	Mortality cases[f]	Percentage of mortality[g]
Gauteng	606	383	106	17.5
Western Cape	130	114	30	23.1
Kwazulu-Natal	75	66	21	28.0
Mpumalanga	48	47	11	22.9
Limpopo	52	34	7	13.4
Eastern Cape	53	30	11	20.7
Free State	35	30	8	22.8
North West	29	25	7	24.1
Northern Cape	6	6	3	50.0
Total	1,034	735	204	-
Means	115	82	23	25
Std Errors	62.4	39.1	10.7	3.4

Age groups[b]	Total listeriosis cases[c]	Listeriosis with cases undetermined outcomes[e]	Mortality cases[f]	Discharged[h]
≤ 28 days	441	139	87	215
1 month-14 years	68	20	8	40
15-49 years	323	89	49	185
50-64 years	89	26	29	34
>65 years	83	10	26	47
Age not known	30	15	5	10
Total	1,034	299	204	531
Means	172	50	34	87
Std Errors	68.5	21.4	12.4	36.2

[a] Data from public records of Department of Health, The Republic of South Africa, Listeriosis Situation Report, May 21, 2018. Data was used in the computation of cost analyses of listeriosis.
[b] Geographical regions with outbreak and age groups of listeriosis-affected individuals.
[c] Total number of laboratory confirmed listeriosis cases.
[d] Outcomes of listeriosis in affected individuals determined.
[e] Cases with unknown health outcomes.
[f] Refers to mortality cases of individuals from various South African provinces and different age groups with positive, confirmed, laboratory diagnosis of listeriosis.
[g] Percentages of mortality attributed to listeriosis relative to total number of cases in each region.
[h] Number of individuals discharged from hospitalization after medical treatment and recovery from listeriosis.

655 **Table 2.** Estimated total costs for 2017 listeriosis in South Africa.
656

Listeria outbreak cost center category	Description of various cost category	Number of *Listeria* cases	Estimated costs per case (US$)	Total category cost (US$)
Human lives	Deaths (low estimate)	204	1,244,747	253,928,388
	Deaths (high estimate)	204	2,524,312	514,959,648
	Death in export countries	n/a[a]	-	-
Medical	Hospitalized patients	1,034	10,026,383	10,367,280
	Medical in export countries	n/a[a]	-	-
Productivity	Patients out of work	430	1,395,386	600,016
Society costs	Long-term social costs	unknown[b]	-	-
TOTAL HUMAN	Total human costs (low value human life)	1,034	256,185,381	**264,895,684**
	Total human costs (high value human life)	1,034	508,633,408	**525,926,944**
Listeria outbreak cost center category	Description	Number of units	Cost/unit (US$)	Total category cost (US$)
Outbreak containment	Listeria management team, surveillance, containment, sampling, sanitize plant	n/a[c]	-	-
Polony revenue losses	Export ban value (3-month estimates)	3,539.5 Mt	3,200/Mt	11,326,400
	Drop in consumer demand, product substitutions	n/a[c]	-	-
TOTAL ECONOMIC		-	-	**11,326,400**
TOTAL HUMAN & ECONOMIC	Total human costs (low value human life)	-	-	**276,222,084**
	Total human costs (high value human life)	-	-	**537,253,344**

657 [a] Data to estimate costs not available (n/a). Similarly, *Listeria* specific medicines, sample
658 collection, lab analysis and future chronic outpatient costs were not computed due to
659 unknown variables.
660 [b] Future costs of outbreak on-going so unknown at this time. Similarly, long-term society costs
661 are also unknown.
662 [c] The costs of outbreak containment (e.g. administrative, *Listeria* Management Team,
663 information collection, data analysis, plant sanitization) as well as drop in consumer demand
664 or product substitutions which were not computed due to lack of data.
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Table 3. Estimation of potential revenue losses (US$) associated with temporary suspension of processed meat import by SADC (Southern African Development Coordination) countries due to listeriosis outbreak in South Africa following consumption of contaminated polony (deli meat)[a].

Product types[b]	Trading countries[c]	Processed Meat Export value in 2016 (Mt)[d]	Processed Meat Export value in 2017 (Mt)[d]	Annual mean Processed Meat Export Value (Mt)[d]	Quarterly (3 months) Value (Mt)[e]	Potential revenue losses (US $)[e]
Sausages/ meat	Lesotho	6,053	5,944	5,998	1,499.5	4,798,400
	Mozambique	2,797	3,375	3,086	771.5	2,468,800
	Namibia	1,233	1,212	1,222	305.5	977,600
	Swaziland	212	172	192	48	153,600
	Botswana	202	145	174	43.5	139,200
	Zambia	298	122	210	52.5	168,000
	Zimbabwe	23	64	43	10.75	34,400
	Other countries	326	338	332	….[f]	….[f]
Preserved chicken & other meat	Angola	429	270	350	87.5	280,000
	Namibia	521	184	352	88	281,600
	Mozambique	211	113	162	40.5	129,600
	Botswana	105	67	86	21.5	68,800
	UAE	452	278	365	….[f]	….[f]
	Other countries	775	348	562	….[f]	….[f]
Bovine meat of animals, prepared & preserved	Namibia	852	1,366	1,109	277.25	887,200
	Lesotho	543	510	527	131.75	421,600
	Botswana	190	381	285	71.25	228,000
	Swaziland	255	188	221	55.25	176,800
	Mozambique	134	147	141	35.25	112,800
	UAE	1,138	1,306	1,222	….[f]	….[f]
	Other countries	1,048	720	884	….[f]	….[f]
Total (US$)					**3,539.5**	**11,326,400**

[a] Export value data from public records of USDA Foreign Agricultural Services, Global Agricultural Information Network was used to compute potential revenue losses. The computation of potential revenue loss due to listeriosis outbreak on deli meat (polony) was based on temporary import ban on processed meat from South Africa by SADC countries.

[b] Types of processed meat exported from South Africa. Mean annual processed meat export values for 2016 and 2017 was used to project 2018 export values for the computation.

[c] Countries with temporary import ban of processed meat from S. Africa during 2018.

[d] Mean annual processed meat export values for 2016 and 2017. Value rounded to nearest ton and data was used to estimate revenue losses for 2017.

[e] Revenue losses were computed for quarterly (period), assuming that temporary import suspension would resume when food processing plants re-opened. Valuation was computed as the selling price of polony / kg on the domestic market (43 Rand/kg or US$ 3.2/kg) multiplied by tons (x907 kg) of processed meat normally exported, but suspended as a consequent of *Listeria* outbreak in South Africa (Exchange rate – 1US$ = 13.4 ZA Rand).

[f] Processed meat export to UAE & other countries were omitted from loss computation due to unknown status of processed meat import from South Africa during listeriosis outbreak.

685 **Figure legends**

686

687 **Figure 1 A.** Direct costs of 2017 listeria outbreak in South Africa that were estimated (—) and
688 those not estimated (---), and Figure 1 B. Indirect costs of 2017 listeria outbreak in South Africa
689 that were not estimated (---).

690
691 **Figure 2.** Maximum and minimum bounds of estimated cumulative cost of 2017 listeria outbreak
692 in South Africa. The costs were calculated from data extracted from public records of the
693 Department of Health, The Republic of South Africa, Listeriosis situation report of May 21, 2018,
694 using U.S. Department of Agriculture, Economic Research Service, Cost Estimate of Listeria
695 Excel calculator. Costs include value of human lives lost, hospitalization, and lost work
696 productivity.
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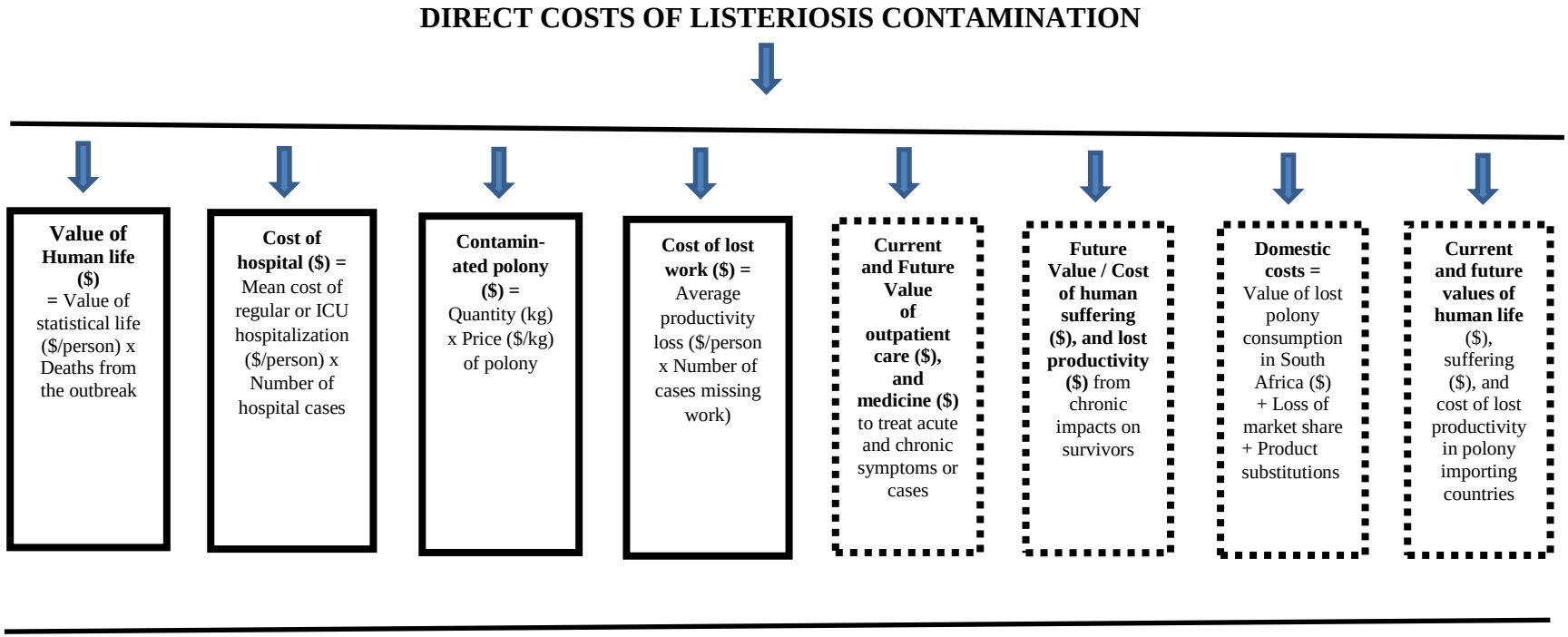

DIRECT COSTS OF LISTERIOSIS CONTAMINATION
Value of Human life ($) = Value of statistical life ($/person) x Deaths from the outbreak
Cost of hospital ($) = Mean cost of regular or ICU hospitalization ($/person) x Number of hospital cases
Contamin-ated polony ($) = Quantity (kg) x Price ($/kg) of polony
Cost of lost work ($) = Average productivity loss ($/person x Number of cases missing work)
Current and Future Value of outpatient care ($), and medicine ($) to treat acute and chronic symptoms or cases
Future Value / Cost of human suffering ($), and lost productivity ($) from chronic impacts on survivors
Domestic costs = Value of lost polony consumption in South Africa ($) + Loss of market share + Product substitutions
Current and future values of human life ($), suffering ($), and cost of lost productivity in polony importing countries

Fig. 1A.

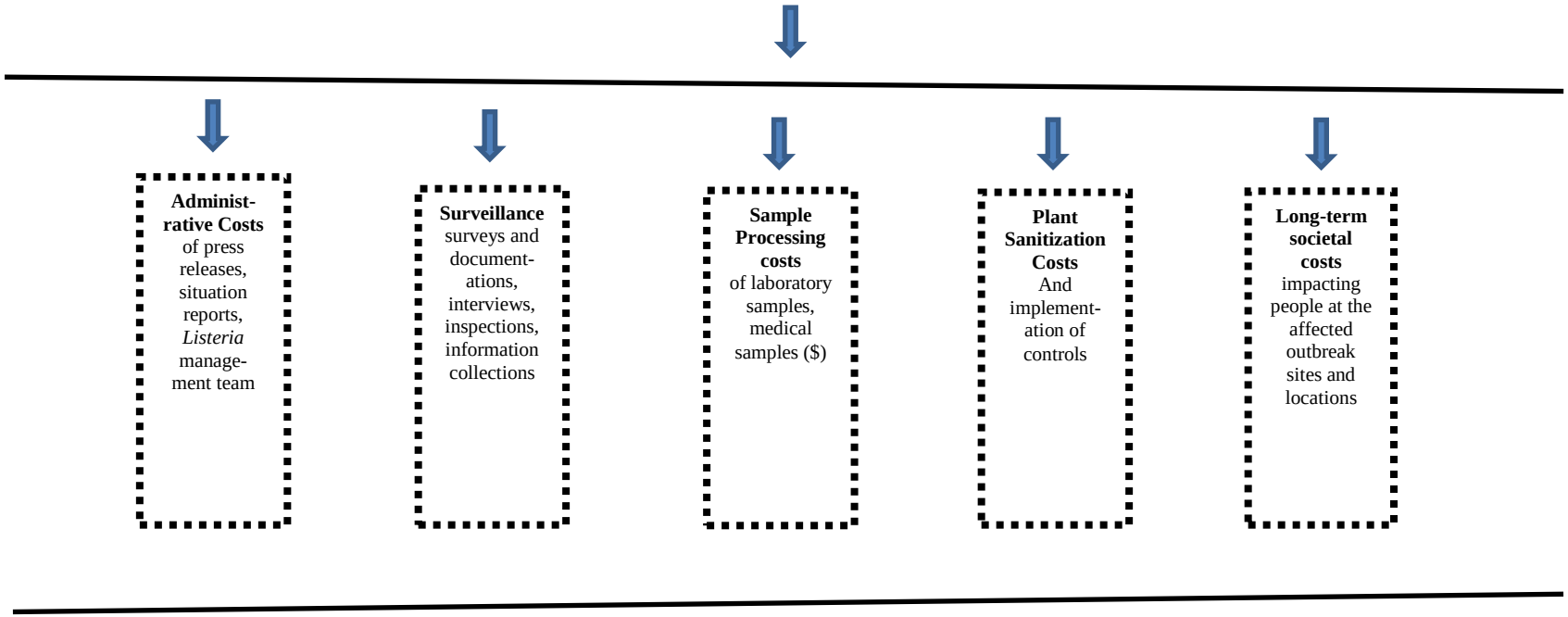
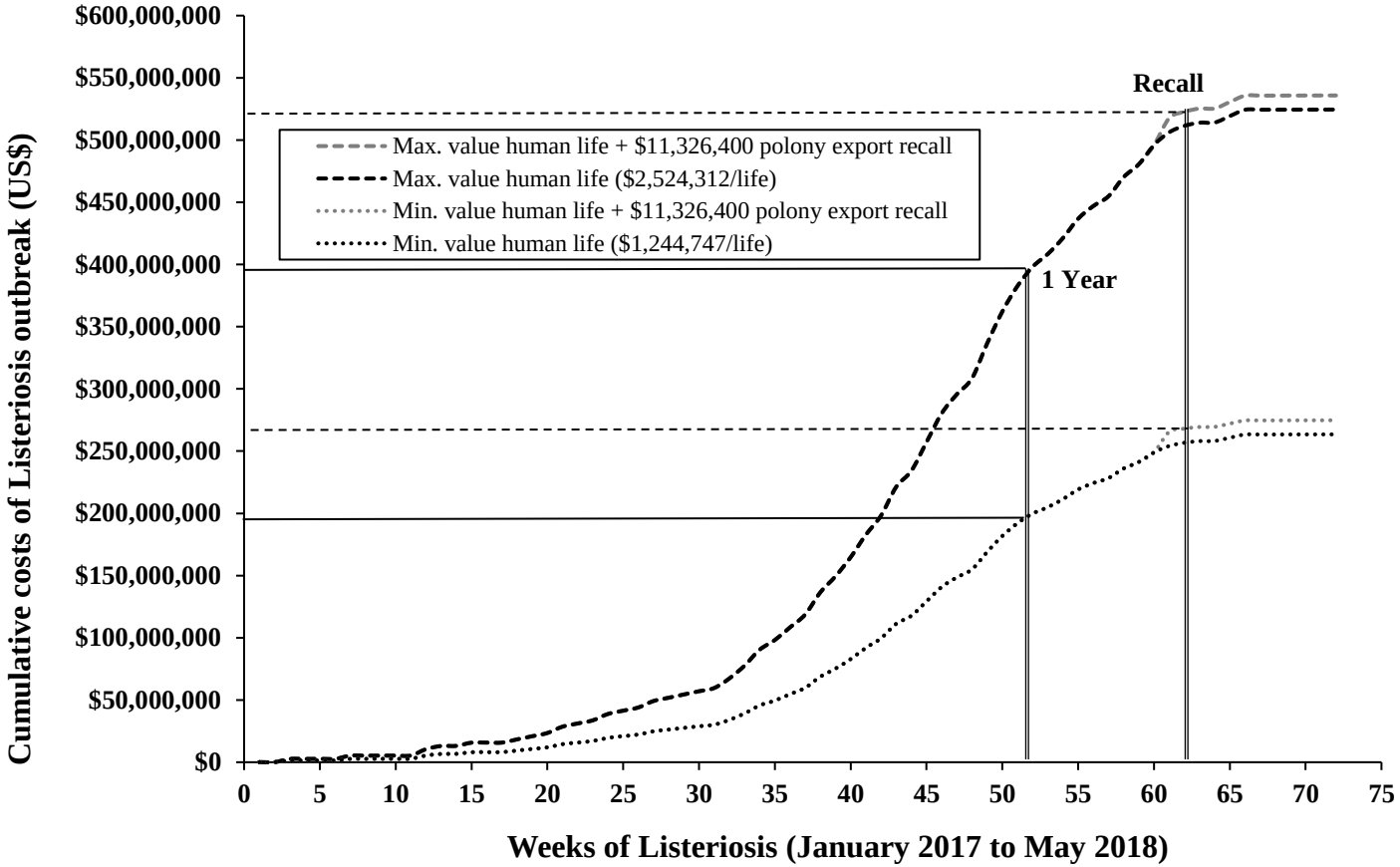

IN-DIRECT COSTS OF LISTERIOSIS CONTAMINATION (NOT QUANTIFIED)
Administ-rative Costs of press releases, situation reports, Listeria manage-ment team
Surveillance surveys and document-ations, interviews, inspections, information collections
Sample Processing costs of laboratory samples, medical samples ($)
Plant Sanitization Costs And implement-ation of controls
Long-term societal costs impacting people at the affected outbreak sites and locations

Fig. 1B.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Cumulative costs of Listeriosis outbreak (US$)
Max. value human life + $11,326,400 polony export recall
Max. value human life ($2,524,312/life)
Min. value human life + $11,326,400 polony export recall
Min. value human life ($1,244,747/life)
Recall
1 Year
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Weeks of Listeriosis (January 2017 to May 2018)

Fig. 2.

Table S1. Minimum and maximum estimates of costs (US$) of hospitalization, lost productivity, and mortality for 2017-2018 listeriosis outbreak in South Africa[a]. **(Supplemental Materials)**

Estimates	Case types	Recovered	Mortality #	Patients	Costs / loss center	Costs / case ($)	Line item total costs ($)
Minimum	Babies	400		Babies	Hospital	15,840[b]	6,336,000
			90	Deceased babies	Hospital	15,840[b]	1,425,600
				Deceased babies	Lives	1,244,747	112,027,230
	Adults	92		Mothers	Hospital	3,960[b]	364,320
				Mothers	Productivity	2,003[c]	184,276
		338		Other adults moderate	Hospital	3,960[b]	1,338,480
				Other adults moderate	Productivity	1,230[c]	415,740
			114	Deceased adults	Hospital	7,920[b]	902,880
				Deceased adults	Lives	1,244,747	141,901,158
	Total	**830**	**204**			**Total cost**	**264,895,684**
	All		204	All	Lives	1,244,747	253,928,388
		830	204	All	Hospital	10,026.383	10,367,280
		430		All	Productivity	1,395.386	600,016
	Total	**830**	**204**			**Total cost**	**264,895,684**
Maximum	Babies	400		Babies	Hospital	15,840[b]	6,336,000
			90	Deceased babies	Hospital	15,840[b]	1,425,600
				Deceased babies	Lives	2,524,312	227,188,080
	Adults	92		Mothers	Hospital	3,960[b]	364,320
				Mothers	Productivity	2,003[c]	184,276
		338		Other adults moderate	Hospital	3,960[b]	1,338,480
				Other adults moderate	Productivity	1,230[c]	415,740
			114	Deceased adults	Hospital	7,920[b]	902,880
				Deceased adults	Lives	2,524,312	287,771,568
	Total	**830**	**204**			**Total cost**	**525,926,944**
	All		204	All	Lives	2,524,312	514,959,648
		830	204	All	Hospital	10,026.383	10,367,280
		430		All	Productivity	1,395.386	600,016
	Total	**830**	**204**			**Total cost**	**525,926,944**

[a] Calculated from public records of Department of Health, The Republic of South Africa, Listeriosis situation report of May 21, 2018, using ERS-USDA, Cost Estimate of Listeria Excel model.
[b] South African hospital costs per patient was assumed to be 12.1% of U.S. hospital costs.
[c] Value of lost productivity measured in paid work hours lost due to hospitalization based on USDA-ERS Cost estimate of *Listeria* assumption of 1 month loss for adults, severe with less assumed loss for mothers (81.43%) and other adults, moderate (50%).

Table S2. Minimum and maximum estimates of human costs (South African Rand - ZAR) of hospitalization, lost productivity, and mortality for 2017-2018 listeriosis in South Africa[a].

		---- Number ----			Cost / loss	Cost /	Line item
Estimate	**Case type**	**Recovered[d]**	**Deaths**	**Patients**	**center**	**cases (R)**	**total costs**
Minimum	Babies	400		Babies	Hospital	203,861[b]	81,544,400
			90	Deceased babies	Hospital	203,861[b]	18,347,490
				Deceased babies	Lives	16,019,632	1,441,766,880
	Adults	92		Mothers	Hospital	50,965[b]	4,688,780
					Productivity	25,773[c]	2,371,116
		338		Other adults, moderate	Hospital	50,965[b]	17,226,170
				Other adults, moderate	Productivity	15,826[c]	5,349,188
			114	Deceased adults	Hospital	101,931[b]	11,620,134
				Deceased adults	Lives	16,019,632	1,826,238,048
	Total	**830**	**204**			**Total cost**	**3,409,152,206**
	All		204	All	Lives	16,019,632	3,268,004,928
		830	204	All	Hospital	129,039.62	133,426,974
		430			Productivity	17,954.195	7,720,304
	Total	**830**	**204**			**Total cost**	**3,409,152,206**
Maximum	Babies	400		Babies	Hospital	203,861[b]	81,544,400
			90	Deceased babies	Hospital	203,861[b]	18,347,490
				Deceased babies	Lives	32,487,365	2,923,862,850
	Adults	92		Mothers	Hospital	50,965[b]	4,688,780
				Mothers	Productivity	25,773[c]	2,371,116
		338		Other adults, moderate	Hospital	50,965[b]	17,226,170
				Other adults moderate	Productivity	15,826[c]	5,349,188
			114	Deceased adults	Hospital	101,931[b]	11,620,134
				Deceased adults	Lives	32,487,365	3,703,559,610
	Total	**830**	**204**			**Total cost**	**6,768,569,738**
	All		204	All	Lives	32,487,365	6,627,422,460
		830	204	All	Hospital	129,039.62	133,426,974
		430			Productivity	17,954.195	7,720,304
	Total	**830**	**204**			**Total cost**	**6,768,569,738**

[a] Calculated from public records of Department of Health, The Republic of South Africa, Listeriosis situation report of May 21, 2018, using ERS-USDA, Cost Estimate of *Listeria*.

[b] South African hospital costs per patient assumed to be 12.1% of U.S. hospital costs.

[c] Value of lost productivity measured in paid work hours lost due to hospitalization based on ERS-USDA, Cost Estimate of *Listeria* assumption of 1month loss for adults, severe with less assumed loss for mothers (81.43%) and other adults, moderate (50%).

838 **Table S3.** Projected estimates of non-hospitalized, hospitalized, and post-hospitalization outcomes of listeriosis following
839 consumption of polony (deli meat) contaminated with *Listeria monocytogenes* in South Africa. Data was estimated based on ERS-
840 USDA foodborne illness model for different scenario of listeriosis occurrences.
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Cases		**Patients**	**Non-Hospitalized**	**Hospitalized**			**Post-hospitalized outcomes**	
Case types	Total cases[a]	Adults	Non-Hospitalization (No physician visit) Recovered	Hospital cases	Hospitalized maternal	Hospitalized recovered adults	Hospitalized adults, severe (mortality)	Hospitalized adults, severe (ICU) Recovered
All	1,034	544	0[b]	544	92	338	114	0[c]
Cases	**Patients**	**Hospitalized**			**Post-hospitalization outcomes**			
Case types	Babies	Babies, Recovered[a]	Babies and children mortality[d]	Stillbirth Cases[e]	Babies and children, mild disability[f]		Babies and children, moderate disability[f]	Babies and children, severe disability[f]
All	490	400	90	0	0		0	0

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843 [a] Hospitalized cases (recovered + outcomes pending currently), no chronic listeriosis assumed.
844 [b] No data is available at this time (not known).
845 [c] No data on severe hospitalization (Internal Care Unit) and recovery.
846 [d] Estimated as 85 newborns and 5 children mortality (90).
847 [e] Assumed there were no stillbirths.
848 [f] No chronic mild, moderate or severe disability cases were documented.
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Table S4. Projected estimates of hospitalization for different age groups and congenital cases (≤ 28 days old and 1month-14 years old) as a consequent of listeriosis outbreak in South Africa following consumption of polony (deli meat) in which contamination by *Listeria monocytogenes* was determined. Data was estimated based on ERS-USDA foodborne illness model for different scenario of listeriosis occurrences.

Case Category	Hospitalized ≥ 15 yrs old (exact age unknown) Recovered cases[a]	Hospitalized ≥ 15 yrs old (exact age unknown) Outcomes unknown[b]	% Mothers in adult populations[c]	Hospitalized babies Recovered cases[d]	Hospitalized babies Outcome unknown[e]
All	285	145	21	255	145

[a] Hospitalized and released as: 180 of ages 15-49, 48 of ages 50-64, 47 of ages ≥ 65, and 10 of unknown ages (mean category).
[b] Hospitalized and outcome pending as: 90 of ages 15-49, 25 of ages 50-64, 20 of ages ≥ 65, and 10 of unknown ages (mean category).
[c] Assumed mothers have averages of 2 kids since population growth rate is low (https://www.statssa.gov/za/publications/P0302/P03022014.pdf). Half of the population (< 15 years old) is divided by the rest of population ≥ 15 years old.
[d] Hospitalized and released as: 215 newborns and 40 children (average category).
[e] Hospitalized and outcome pending as: 130 newborns and 15 children (average category).

Table S5. Estimation of revenue losses (South African Rand - ZAR) associated with temporary suspension of processed meat import by SADC (Southern African Development Coordination) countries due to listeriosis outbreak from contaminated polony (deli meat) in South Africa[a].

Product types[b]	Trading countries[c]	Processed Meat Export value in 2016 (Mt)[d]	Processed Meat Export value in 2017 (Mt)[d]	Annual mean Processed Meat Export Value (Mt)[d]	Quarterly (3 months) Value (Mt)[e]	Potential revenue losses (ZAR)[e]
Sausages/ meat	Lesotho	6,053	5,944	5,998	1,499.5	64,298,560
	Mozambique	2,797	3,375	3,086	771.5	33,081,920
	Namibia	1,233	1,212	1,222	305.5	13,099,840
	Swaziland	212	172	192	48	2,058,240
	Botswana	202	145	174	43.5	1,865,280
	Zambia	298	122	210	52.5	2,251,200
	Zimbabwe	23	64	43	10.75	460,960
	Other countries	326	338	332	….[f]	….
Preserved chicken & other meat	Angola	429	270	350	87.5	3,752,000
	Namibia	521	184	352	88	3,773,440
	Mozambique	211	113	162	40.5	1,736,640
	Botswana	105	67	86	21.5	921,920
	UAE	452	278	365	….[f]	….
	Other countries	775	348	562	….	….
Bovine meat of animals, prepared & preserved	Namibia	852	1,366	1,109	277.25	11,888,480
	Lesotho	543	510	527	131.75	5,649,440
	Botswana	190	381	285	71.25	3,055,200
	Swaziland	255	188	221	55.25	2,369,120
	Mozambique	134	147	141	35.25	1,511,520
	UAE	1,138	1,306	1,222	….[f]	….
	Other countries	1,048	720	884	….	….
Total (ZAR)					**3,539.5**	**151,773,760**

[a] Export value data from public records of USDA Foreign Agricultural Services, Global Agricultural Information Network was used to compute potential revenue losses. The computation of potential revenue loss due to listeriosis outbreak on deli meat (polony) was based on temporary import ban on processed meat from South Africa by SADC countries.

[b] Types of processed meat exported from South Africa. Mean annual processed meat export values for 2016 and 2017 was used to project 2018 export and in the computation.

[c] Countries with temporary import ban of processed meat from South Africa during 2018.
[d] Mean annual processed meat export values for 2016 and 2017. Value rounded to nearest metric ton. Data was used to estimate revenue losses for 2017.
[e] Revenue losses were computed for quarterly (three-month period), assuming that temporary import suspension would resume when food processing plants are re-opened. Valuation was computed as the selling price of polony /kg on the domestic market (43 Rand/kg or US$ 3.20/kg) multiplied by tons (x907 kg) of processed meat exported, but suspended as a consequent of Listeriosis outbreak in South Africa (Exchange rate during the outbreak, 1US$ = 13.4 South African Rand - ZAR).
[f] Processed meat export to UAE & other countries were omitted from loss computation as the status of their processed meat import from South Africa during listeriosis was unknown.

Supplementary Figure legend

Fig. S1. Maximum and minimum bounds of estimated cumulative cost (South African Rand - ZAR) of 2017 listeria outbreak in South Africa. The cumulative costs were computed from data extracted from public records of the Department of Health, The Republic of South Africa, Listeriosis Situation Report of May 21, 2018, using ERS-USDA, Cost Estimate of Listeria computation. Costs include valuation of human lives lost, hospitalization, and lost work productivity.

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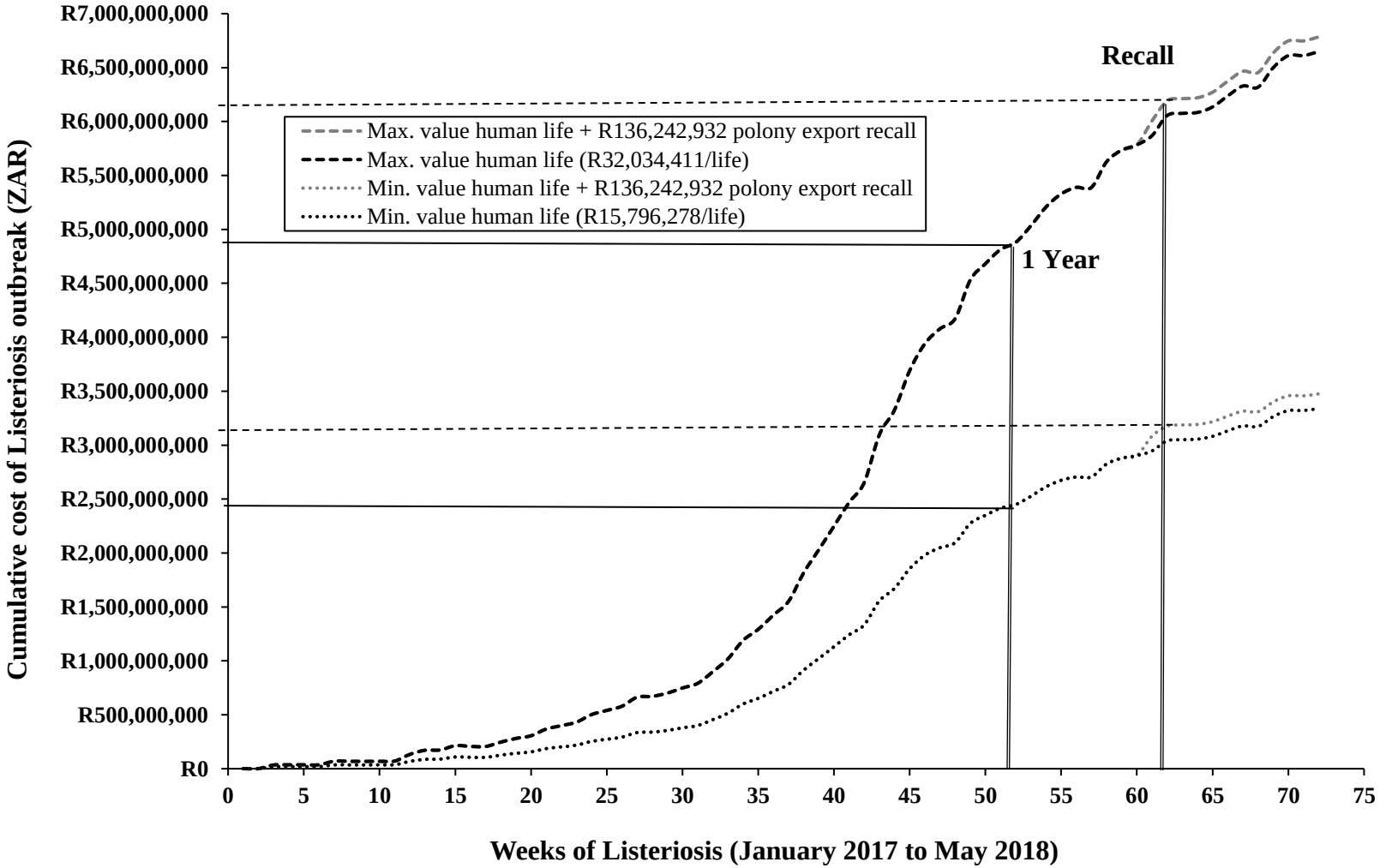

933 **Fig. S1.**
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