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Cystic echinococcosis in marketed offal of sheep in Basrah, Iraq: Abattoir-based survey and a probabilistic model estimation of the direct economic losses due to hydatid cyst

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A R T I C L E I N F O

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A B S T R A C T

Cystic echinococcosis (CE) is a highly endemic parasitic zoonosis in Iraq with substantial impacts on livestock productivity and human health. The objectives of this study were to study the abattoir-based occurrence of CE in marketed offal of sheep in Basrah province, Iraq, and to estimate, using a probabilistic modelling approach, the direct economic losses due to hydatid cysts. Based on detailed visual meat inspection, results from an active abattoir survey in this study revealed detection of hydatid cysts in 7.3% (95% CI: 5.4; 9.6) of 631 examined sheep carcasses. Post-mortem lesions of hydatid cyst were concurrently present in livers and lungs of more than half (54.3% (25/46)) of the positive sheep. Direct economic losses due to hydatid cysts in marketed offal were estimated using data from government reports, the one abattoir survey completed in this study, and expert opinions of local veterinarians and butchers. A Monte-Carlo simulation model was developed in a spreadsheet utilizing Latin Hypercube sampling to account for uncertainty in the input parameters. The model estimated that the average annual economic losses associated with hydatid cysts in the liver and lungs of sheep marketed for human consumption in Basrah to be US$72,470 (90% Confidence Interval (CI); ± 11,302). The mean proportion of annual losses in meat products value (carcasses and offal) due to hydatid cysts in the liver and lungs of sheep marketed in Basrah province was estimated as 0.42% (90% CI; ± 0.21). These estimates suggest that CE is responsible for considerable livestock-associated monetary losses in the south of Iraq. These findings can be used to inform different regional CE control program options in Iraq.

1. Introduction

Livestock diseases can impact animal production and adversely affect the security of the human food supply chain. Added to that, many livestock diseases are zoonotic in nature and can infect humans via several routes. Parasitic zoonoses continue to pose serious concerns at the human-animal interface in many developing countries (McManus et al., 2003). Cystic echinococcosis (CE) is an important parasitic infection impacting both animal and public health, notably throughout the Middle East and North Africa. CE is caused by *Echinococcus granulosus*. Livestock (e.g. sheep, cattle, goats, and pigs) can acquire the infection indirectly from grass and

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water contaminated by the eggs of *E. granulosus*, which are excreted with faeces of dogs (Craig et al., 2007; Deplazes et al., 2017). Human can become infected with CE accidently by ingesting the eggs of *Echinococcus* through contaminated food and water, or from handling faeces of infected dogs, and other carnivores. Once ingested, the eggs hatch inside human's intestine, realising oncosphere larvae, which has a capability to penetrate the gut wall and then is conveyed by blood stream to different organs, mainly the liver and lungs where they settle and develop into cysts (McManus et al., 2003; Kebede et al., 2009). Worldwide, there may be in excess of 1 million people living with CE at any one time. Many of these people will be experiencing severe clinical syndromes which are life-threatening if left untreated (Craig et al., 2007).

CE in humans is most commonly found in rural communities and among people involved in raising sheep, as a result of the sheep's role as an intermediate host of the parasite and the presence of working dogs that are allowed to eat the offal of infected sheep. Ingested eggs can develop into the parasite's larval stage (metacestoda) in the livestock's internal organs (Brunetti et al., 2010). The hydatid cysts grow slowly, with minimal clinical signs observed in livestock animals, and typically are only discovered during routine meat inspection. In the majority of animals harbouring hydatidosis, the cysts are most commonly located in the liver and/or lungs (Craig et al., 2007).

The economic cost of CE in livestock can be divided into direct costs (mainly the loss of revenue through the condemnation of offal) and indirect costs (reduction in growth, fecundity and milk production of infected animals). At the abattoir, detecting hydatid cysts during routine meat inspection will lead to condemnation of the infested offal (mainly livers and lungs). Fertile cysts (with viable protoscoleces) in livestock offal are very important for continuation of the sheep-dog transmission cycle (Torgerson et al., 2003). A study in Jordan, estimated the annual loss of edible livers due to hydatidosis at around US$850,000 annually (Torgerson and Dowling, 2001).

In Iraq, the small ruminant sector is very important for sustaining the country's food security. There are presently an estimated 7–8 million sheep in Iraq contributing a valuable source of meat, and providing income and job security to people working across the agricultural sector (Jarjees and Al-Bakeri, 2012; Thweni and Yassen, 2015). The fragile veterinary services in Iraq, after years of international economic sanctions and on-going political and ethnic conflicts, is very challenging for setting organized efforts to combat endemic livestock diseases. Various studies have reported the prevalence of hydatidosis in the livestock in different regions of Iraq (Jarjees and Al-Bakeri, 2012; Maktoof and Abu Tabeekh, 2015; Saida and Nouraddin, 2011; Thweni and Yassen, 2015). However, none of these studies considered a detailed estimation of the direct or indirect economic losses incurred by such endemic livestock disease. Estimation of such financial losses is largely handicapped by poor record keeping and reporting systems at abattoirs in Iraq, thus limiting the value of any economic evaluation using retrospective abattoir data. Added to that, in Iraq there are widespread informal butcheries with their on-site slaughter slabs, where freshly slaughtered meat and offal are sold directly to the public without any kind of meat inspection. Given the fact that informal meat markets are widespread in Iraq, they should be considered alongside with the formal meat market (where animals are slaughtered and inspected at an official abattoir) in order to enumerate the realistic economic impact of CE in sheep.

The sheep industry is an important segment of the agriculture sector in Basrah, the third largest province in Iraq (Maktoof and Abu Tabeekh, 2015). In this study, we conducted an active abattoir survey at the central abattoir of Basrah, located in the south of Iraq, to determine the abattoir based occurrence of hydatid cysts in sheep slaughtered for human consumption. In parallel to this active abattoir survey, we developed a probabilistic model to estimate the direct financial loss from offal condemnation due to hydatid cysts in slaughtered sheep. We interviewed local veterinarians and butchers to gather expert-opinions for populating some of the model variables. This model-based approach could be extended to other regions in Iraq, and might be applicable to similar developing country settings where the infrastructure of abattoir data collection system is lacking.

2. Materials and methods

2.1. Study setting

This study was conducted in Basrah province located in the south of Iraq. The total human population of Basrah province was estimated at 2,403,301 million according to the last census achieved in 2014. Basrah is situated in a desert-type environmental zone with a monsoon climate; the province is in a fertile agricultural region and contributes to the Iraqi agriculture sector through its large agricultural and livestock industries (Maktoof and Abu Tabeekh, 2015).The study was carried out over a period of six months (between May and October 2016), at the central governmental abattoir in Basrah province.

2.2. Post-mortem abattoir inspection and cyst viability examination

A cross-sectional survey was conducted at the abattoir in order to determine the prevalence, organ distribution, viability and economic implications of hydatid cysts in the slaughtered sheep. Both the meat inspection and laboratory work were carried out personally by the first author of this study. Regular visits (3 days per week) were made to the central governmental abattoir in Basrah. The visits were assured to be varying over different days of the week. On a given day, sheep were selected using a systematic selection sampling; the sheep were held in the loading pen and then were allowed to pass through a race to the slaughter floor. Every 5th animal was then selected as it passes through. In total 631 sheep were examined by detailed post-mortem inspection for the presence of hydatid cysts; this is included visual inspection and palpation for hydatid cysts in visceral organs including the liver, lungs, spleen, heart and kidneys. All animals were from native flocks, and none were imported. The post-mortem examination procedure employed visual examination, palpation and systematic incision of each carcass and visceral organs, particularly the lung, liver, spleen, kidney and heart (Herenda et al., 1994). The numbers of hydatid cysts per animal and per organ were recorded, in addition to information on the age and sex of each examined animal. The age of each animal was estimated based on the dentition formula as used by (Kumsa, 1994).

On detection cysts were carefully incised and examined for the presence of protoscoleces, and cysts with protoscoleces were characterized as fertile cysts. Fertile cysts were subjected to a viability test where fluid of the cysts was poured into a petri dish and 3–4 drops of 0.1% aqueous eosin solution were added to the sediment and left for one minute. A drop of the stained sediment was then placed onto a microscopic slide, covered with a cover slip and examined for amoeboid like peristaltic movements under a microscope at ×40 magnification (Smyth and Barrett, 1980).

2.3. Analysis of abattoir survey

Abattoir survey data were recorded into a MS Excel sheet, and all descriptive analyses were made using the software STATA (version 11, SE for Windows). The abattoir-based occurrence (frequency) of hydatid cysts was calculated as the number of affected animals (with post-mortem lesion) divided by the total number of inspected animals. Multivariable logistic regression analysis was used to determine the association of the occurrence of hydatid cysts in the offal with the sex and age of the slaughtered sheep. The effect of confounding interaction between animals' age and sex was investigated by observing the change in the estimated odds ratios of the variables that remain in the model once a non-significant variable is removed. When the removal of a non-significant variable led to a change of > 25% of any parameter estimate, that variable was considered a confounder and was not removed from the model.

2.4. Model-based estimation of direct economic losses due to offal condemnation

During the abattoir visits we noticed that hydatidosis were recorded in the abattoir daily inspection reports only if there was a severe case of profuse (multiple cysts) organ infestation that lead to "total organ condemnation". Localized cysts were typically trimmed off the affected offal and then the organs and carcasses were collected by the attending butcher. After removal of these localized cysts the remaining organ entered the domestic market; however no record of these events were included in the daily abattoir inspection reports. Given such limitation in the recording system, we built a probabilistic model based on the results from the active abattoir survey (as described above), combined with expert-opinions of local veterinarians and butchers working in Basrah.

2.4.1. Model objective and scope

The objective of the model was to estimate the direct economic loss form the condemnation of livers and lungs of the slaughtered sheep. The model scope was to cover both formal and informal meat markets as a sizable proportion of animals are slaughtered without official abattoir inspection (e.g. by informal butcheries). The model was run with Iraqi Dinars and focused on losses arising from partial or total condemnation of livers and lungs as these organs are economically more valuable than other visceral organs, and also because of their high involvement in hydatid infestation as was revealed from the active abattoir survey. The model notation, variable description and parameterization are described in Table 1.

2.4.2. Model implementation and software

Uncertainty and variability of the economic variables were incorporated in the model using probability distributions of parameters as described in Table 1. The model was run for 50,000 iterations using a Monte Carlo simulation approach (Latin Hypercube sampling) in the commercial software @Risk version 7.5, Palisade Corporation, running as add-in to Microsoft Excel©. Sensitivity analysis was undertaken, using a stepwise linear regression of the estimated costs against the input parameter values, to assess the impact of each input parameter on the overall cost estimate.

2.4.3. Model inputs and data sourcing

a) *Retrospective abattoir data-number of sheep slaughtered at Basrah abattoir*:
Official records were only available for eight years between 2008 and 2015. The mean and standard deviation of these data were used to set parameters for a Normal Distribution describing variability in the annual number of sheep slaughtered at Basrah abattoir (Vose, 2008);
b) *Active abattoir survey data - completed during this study*:
Results from inspection of slaughtered sheep (n = 631) were used to provide input parameters for a Beta Distribution describing uncertainty in the prevalence of hydatid cyst in the lung and livers of slaughtered sheep (Vose, 2008);
c) *Expert opinions of the local meat hygiene veterinarians*: We interviewed all (n = 6) meat hygiene veterinarians working in meat control at the abattoir and markets of Basrah. The veterinarians provided their expert opinion on the percentage of sheep slaughtered for human consumption at Basrah abattoirs, as compared to the proportion of sheep slaughtered at informal markets (out of the control of the official meat inspection system). Then the opinions of all the interviewed veterinarians were combined using a Discrete distribution which is a general type of function used to describe a variable that can take one of several explicit discrete values {x_i, % of all sheep slaughtered at the abattoir} and where a probability weight {p_i} is assigned to each value of the expert opinion and was based on the number of years of experience that each veterinarian spent working in local meat hygiene. It was not necessary to normalize the probability weights {pi}, as @RISK automatically rescaled them to ensure they summed to one

Table 1
A probabilistic model used to estimate the direct economic losses due to hydatid cysts in livers and lungs of sheep marketed for human consumption at Basrah, south of Iraq.

Notation	Variable description	Distribution parameterization and model formula	Source of information
P_{ss_in}	Probability of having sheep slaughtered at abattoir (with official meat inspection)	RiskDiscrete ({x_i},{p_i}) =RiskDiscrete ({10%, 24%, 3%, 25%, 2%, 10%}, {10, 5, 30, 10, 5, 25})	Expert-opinion (veterinarians (n = 6) interviews) on % of sheep slaughtered in abattoir, out of the total sheep slaughtered for human consumption in Basrah
N_{ss_in}	Number of sheep slaughtered per annum at abattoir	Normal (Mean N_{ss_in}, St. Dev N_{ss_in}) =RiskNorm (9011, 2831)	Retrospective data from abattoir records for numbers of sheep slaughtered from 2008 to 2015
P_{ss_out}	Probability of having sheep slaughtered elsewhere than the abattoir (without official meat inspection)	Probability rule of subtraction; $= 1 - (P_{ss\_in})$	Model equations
N_{ss_out}	Number of sheep slaughtered per annum elsewhere from abattoir	$= (N_{ss\_in} \times P_{ss\_out}) / P_{ss\_in}$	Model equations
P_{H_Lung}	Probability of having hydatid cyst in lung of a slaughtered sheep	Beta (α1, α1); where α1 = N of sheep with post-mortem hydatid cyst in lung +1 α2 = N of sheep with post-mortem hydatid cyst in lung − total inspected sheep + 1 =RiskBeta (30, 603)	Active abattoir survey data (generated in this study)
CH_{FV}	Estimate of the full value of a healthy sheep (carcass and offal) marketed in Basrah	Uniform (minimum, maximum) =RiskUniform (143.000, 238.000)	Expert-opinion (in Iraqi Dinars): Butchers (n = 23) interview
C_{Lung}	Retail price of a sheep lung sold at local market	Pert (minimum, most likely, maximum) =RiskPert (10.000, 15.000, 17.000)	Expert-opinion (in Iraqi Dinars): Butchers (n = 23) interview
D_{H_lung}	Probable percentage of decline in the retail price of a trimmed lung due to hydatid cyst	Pert (minimum, most likely, maximum) =RiskPert (5.000, 8.000, 10.000)	Expert-opinion (in Iraqi Dinars): Butchers (n = 23) interview
CD_{H_lung}	Estimated retail price of a trimmed (downgraded) whole sheep lung due to hydatid cyst	$C_{Lung} - D_{H\_lung}$	Probability distribution of the difference between two distributions
P_{H_Liver}	Probability of having hydatid cysts in the liver of a slaughtered sheep	Beta (α1, α1); where α1 = N of sheep with post-mortem hydatid cyst in liver +1 α2 = N of sheep with post-mortem hydatid cyst in liver − total inspected sheep + 1 =RiskBeta (42, 591)	Active abattoir survey data (generated in this study)
C_{Liver}	Retail price of a sheep liver sold at local market	Pert (minimum, most likely, maximum) =RiskPert (10.000, 15.000, 17.000)	Expert-opinion (in Iraqi Dinars): Butchers (n = 23) interview
D_{H_liver}	Probable percentage of decline in the retail price of a trimmed liver due to hydatid cysts	Pert (minimum, most likely, maximum) =RiskPert (5.000, 8.000, 10.000)	Expert-opinion (in Iraqi Dinars): Butchers (n = 23) interview
CD_{H_liver}	Estimated retail price of a trimmed (downgraded) whole sheep liver due to hydatid cysts	$C_{Liver} - D_{H\_liver}$	Probability distribution of the difference between two distributions
$Total_{LLL}$	Total estimated annual cost due to hydatid cysts in the lungs and liver of a slaughtered sheep	$= (N_{ss\_in} \times P_{H\_Lung} \times CD_{H\_lung}) + (N_{ss\_out} \times P_{H\_Lung} \times CD_{H\_lung}) + (N_{ss\_in} \times P_{H\_Liver} \times CD_{H\_liver}) + (N_{ss\_out} \times P_{H\_Liver} \times CD_{H\_liver})$	Product of model distributions: output estimated after 50,000 iterations using a Monte Carlo simulation
$Total_{PV}$	Estimated annual meat products value of sheep marketed in Basrah province	$= (N_{ss\_in} + N_{ss\_out}) \times CH_{FV}$	
$Perc_{PVL}$	Proportion of annual losses in meat products value of sheep marketed in Basrah province	$= (Total_{LLL} / Total_{PV}) \times 100$	

(Vose, 2008).

d) *Expert opinions of local butchers*: Butchers (n = 23) attending the Basrah abattoir were interviewed for their input of the market price (namely minimum, most likely, and maximum) of liver and lungs (price per organ, as it is sold as a whole organ rather than sold per kilogram). The butchers were also requested to provide their opinion regarding their valuation of the reduction percentage (minimum, most likely, and maximum) in market revenue due to partial trimming of hydatid cysts from affected livers and lungs. A PERT distribution was used to describe the model parameters summarizing the price variables based on the combined butchers' expert opinion (Vose, 2008). Butchers were also asked to provide their estimate of the full value of a healthy sheep carcass marketed in Basrah. A UNIFORM distribution was used to describe model parameters (minimum and maximum) summarizing variability in the meat products market value (Vose, 2008).

2.4.4. Model assumptions

The following underlying assumptions were considered while conceptualizing this model-based estimation.

Table 2
Occurrence of hydatid cysts in relation to sex and age of sheep slaughtered at Basrah abattoir (n = 631, between May and October 2016).

Slaughtered sheep characteristics	Number examined	Number positive	Occurrence (%)	Odd ratio	P value
Sex					
Male	418	13	3.1	1	
Female	213	33	15.5	0.70	0.670
Age					
Young (< 1 year)	294	9	3.1	1	
Adult (> 1 year)	337	37	11.0	0.86	0.792
Interaction between age and sex					
Male and young (< 1 year)	210	7	3.3	1	
Female and adult (> 1 year)	129	31	24.0	15.05	0.004

a) The prevalence of hydatid cysts in the lungs and liver of sheep slaughtered at informal markets was same to that observed in the sheep slaughtered at Basrah abattoir;
b) Local butchers at the informal markets will trim off any visible hydatid cyst from the liver or lungs before selling it to the consumer.

3. Results

Results of meat inspection in the abattoir survey indicated that 7.3% (95% CI: 5.4; 9.6) of the examined 631 sheep carcasses had one or more hydatid cysts. The occurrence of hydatid cysts was higher in the carcasses of female animals (Table 2). However, the two-way interaction between animals' age and sex was statistically significant (P = 0.004), indicating a confounding correlation; as females are sent to slaughter older than male sheep.

As indicated in Table 3, the majority of the cysts were located in the livers and lungs, with only one cyst detected outside these organs in the spleen. Hydatid cysts were concurrently present in the livers and lungs of more than half (54.3% (25/46)) of the positive sheep. In total, 37.1% (98/264) of the liver and lung cysts examined were viable.

The probability distribution (P_{ss_in}) describing the aggregated expert opinions of veterinarians (n = 6) working in meat hygiene and inspection indicated that on average only 11% (Median: 10%, Standard Deviation: 7.3%) of the total sheep in Basrah are slaughtered at the certified abattoir (with official meat inspection). Hence, the majority of sheep meat and offal in Basrah come from carcasses of animals slaughtered informally out of the abattoir. The average simulated number of sheep slaughtered elsewhere from abattoir (N_{ss_out}) in Basrah was estimated at 103,026 per annum (Median: 90,036; Std Dev: 65,241.45).

The monetary value of the results was calculated at an exchange rate of 100,000 Iraqi Dinars = US$85.30 (September – 2017). Based on the aggregated opinions of the local butchers (n = 23), the simulated retail market price of the liver and lungs was estimated at an average of US$12.70 (Std Dev: 0.32) (=14,881 Iraqi Dinars; Std Dev: 371) per sheep. The model estimated that the average retail price of a trimmed whole sheep liver or lung due to the presence of hydatid cysts US$4.50 (Std Dev: 0.36) (=5,286 Iraqi Dinars; Std Dev: 424). The model estimated that the annual economic losses (considering both formal and informal markets) associated with hydatid cysts in the livers and lungs of sheep ($Total_{LLL}$) lost/condemned in Basrah to be an average of US$72,470 (90% Confidence Interval (CI); ± 11,302) (=84,948,104 Iraqi Dinars; 90% CI; ± 132,499) (Fig. 1.A). The mean proportion of this monetary value of losses due to hydatid cysts in the livers and lungs was estimated as 0.42% (90% CI; ± 0.002) of the annual sheep product value (PV_{AL}) in Basrah province (Fig. 1.B). The normalized regression coefficient values in Fig. 2 illustrate the impact of uncertain parameters on the overall costs; under the present model conditions, the input variable on the probability of having sheep slaughtered at the official abattoir became most important in determining the overall costs. The regression estimate for this variable (having sheep slaughtered at the official abattoir) resulted in a negative coefficient value (−0.61), indicating that this input variable has a negative impact; thus, increasing this input will decrease the output uncertainty.

4. Discussion

Studies at the abattoir level provide valuable data on prevalence and pathology profiles of diseases encountered during meat

Table 3
Organ level distribution and viability of hydatid cysts in sheep slaughtered at Basrah abattoir (n = 631, between May and October 2016).

Organs	Number (%) of positive organs	Total cysts recovered	Number (%) of viable cysts
Liver	16 (34.8)	37	7 (18.9)
Lung	4 (8.7)	8	0
Liver & lung	25 (54.3%)	218	91 (41.7)
Spleen	1 (2.2)	1	0
Kidney	0	0	0
Heart	0	0	0
Total	46 (7.3)	264	98 (37.1)

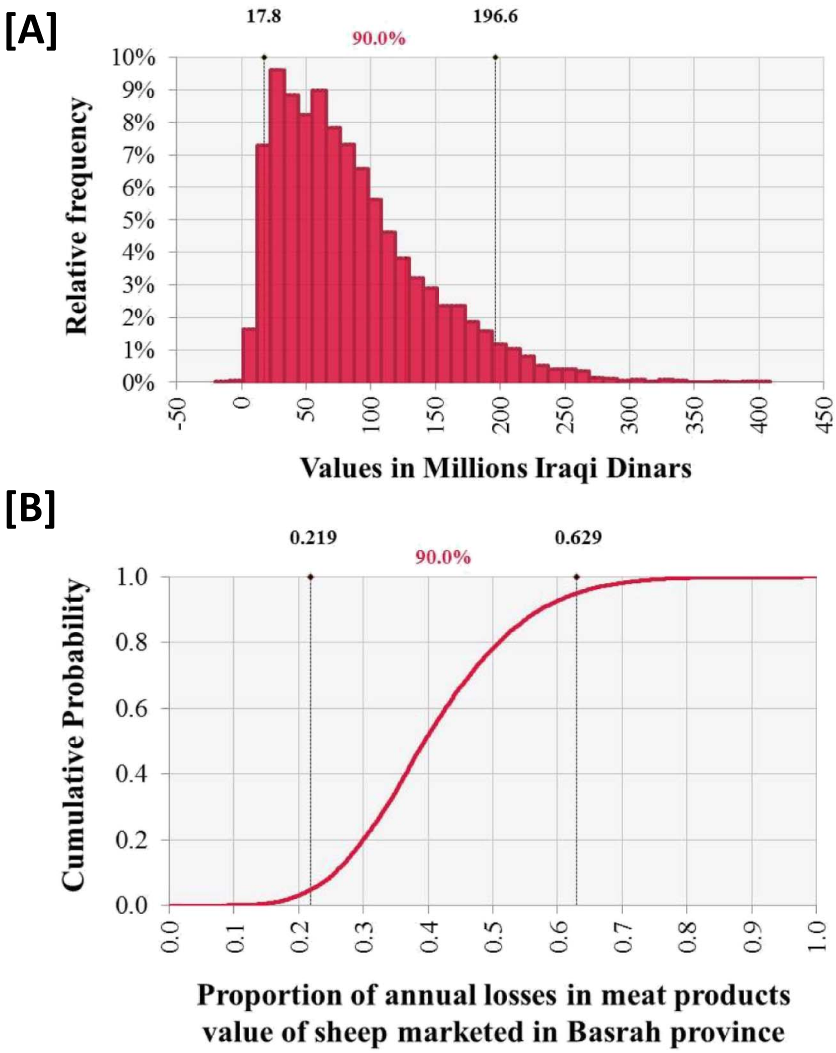

Fig. 1. Monte Carlo simulation output representing; [A] the distribution of the estimated annual direct losses, and [B] the proportion of annual losses in meat products value due to hydatid cysts in livers and lungs of sheep marketed at Basrah province.

inspection which could be utilized in the assessment disease burden or for future planning of livestock disease control strategies (Ahmadi and Meshkehkar, 2011). Cystic echinococcosis is an endemic disease in Iraq and still poses significant health consequences in humans (Sawady and Al-Faddagh, 2012). A total of 748 cases of human with CE were diagnosed and operated in Basrah hospitals from January 2005 to December 2015, equivalent to an annual clinical incidence of approximately 4.5 cases per 100 000 people (Abdulhameed et al., 2018). In this study, our active abattoir survey focused on inspection of sheep carcasses slaughtered in Basrah, the second biggest province in Iraq. The study focused on sheep, given the fact that consumption of sheep meat is traditionally important in Iraq, where it is widely preferred to beef. The results of the present study indicate that hydatid disease is relatively prevalent (7.3%) in sheep in Basrah. This result is comparable to a recent finding from an active abattoir survey (12 months) done in Erbil, in the north of Iraq, where a CE occurrence of 9.1% was reported in 2556 slaughtered sheep (Hassan et al., 2016). Regionally our abattoir frequency result was also comparable to that (8.7%) reported by Al-Khalidi (1998) in Libya, however it was lower than that reported by Yosoufi (2007) in Iran (14.7%), while variable rates have been reported in different regions of Morocco (7.4% in Rif and 11.1% in Middle Atlas) (Azlaf and Dakkak, 2006). Our results signify the importance of sheep as an intermediate host of *E. granulosus* and the potential important role they play in the transmission of the parasite in the southern region of Iraq.

The present abattoir-based survey in Basrah revealed a significantly higher occurrence of hydatid cysts in carcasses of females older than one year. The most consistent risk factor for intermediate host infection and hydatid cyst burden is animal age, with older animals being more likely to be infected and generally harbouring more protoscolices than younger animals (Kebede et al., 2009; Marshet et al., 2011). This is expected as cyst persistence is generally life-long and as such cyst burden represents an on-going infection pressure over time.

Based on our survey data, it was obvious that the most frequently condemned organs in sheep slaughtered in Basrah were the

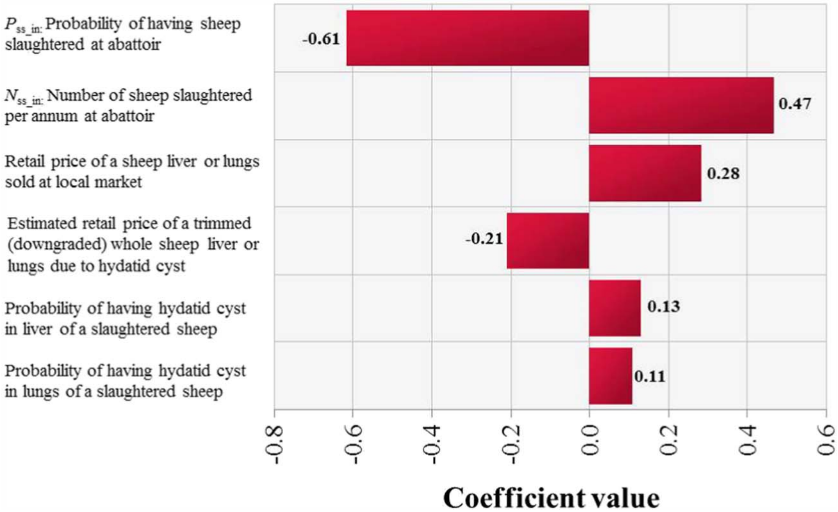

Fig. 2. Tornado chart shows univariate sensitivity analysis of contributions to output uncertainty by various model inputs. Estimated normalized regression coefficients showing the association between uncertain parameters and total estimated annual direct economic losses due to hydatid cysts in livers and lungs of sheep marketed at Basrah, south of Iraq.

livers and lungs. In line with our findings, previous research confirmed that in the Middle East the most common location of hydatid cysts in sheep was the liver, followed by the lungs (Abo-Shehada, 1993; Al-Yaman et al., 1985; Kamhawi et al., 1995; Saeed et al., 2000), but for cattle and camels it was the reverse (Al-Yaman et al., 1985; Kamhawi et al., 1995; Ahmadi, 2005). Interestingly, 37.1% of the cysts in the livers and lungs were fertile, viable cysts. The proportion of animals with fertile, viable cysts is an important indicator of the significance of a species as an intermediate host (Gebremeskel and Kalayou, 2009). In our study, the majority of infected sheep (54.3%) had hydatid cysts in both the liver and the lungs, similar to that which has also been reported elsewhere (Kebede et al., 2009; Yildiz and Gurcan, 2003). This is explained by the fact that lungs and liver possess the first great capillary sites encountered by the migrating *Echinococcus* oncosphere which adopts the portal vein route and primarily negotiates the hepatic and pulmonary filtering systems sequentially before any other peripheral organ is involved (Kebede et al., 2009).

Another goal of our study was to estimate the direct economic losses due to hydatid cysts in livers and lungs of sheep marketed for human consumption in Basrah, Iraq. This is the first study to produce a comprehensive estimate of the annual direct economic burden of CE in a livestock sector in the Iraqi setting. In this study, the Monte-Carlo simulation technique has been applied in the model using a Latin Hypercube sampler method to represent the uncertainty surrounding the input parameters and is particularly suitable for estimating economic costs when accurate epidemiological data are scare (Majorowski et al., 2001; Torgerson et al., 2003). We attempted to develop a simple model that is tailored to the local situation in Basrah, which we believe is very similar to the situation in several regional and developing countries where informal (outside formal abattoirs) markets are common, and where also records keeping is not yet well established in a systematic way in the official abattoirs. Added to that, and in order to make the estimates more robust, we used local expert opinions based on interviews with veterinarians and butchers. Expert opinion can be and has been used to address the critical lack of data existing for prevalence and incidence of many global animal diseases and is a cost effective method of obtaining an estimate in resource poor countries (Garabed et al., 2009; Brookes et al., 2017).

The probabilistic model used in this study estimated an average annual direct economic loss of US$72,470.93 (Std Dev: US $48,593.85) (considering both formal and informal markets) due to the visible hydatid cysts in livers and lungs of sheep marketed for human consumption in Basrah. This estimated figure for only direct losses in sheep represents the potential impact that this disease has on the agricultural industry in Iraq. Given the scarcity of data availability in the study setting, this model estimation was limited to only estimating direct economic loss. Hence, our estimation should be regarded as a partial overview of the estimate of the economic burden. The importance of the contribution of direct versus indirect losses to the total economic burden varies according to livestock species, animal population sizes, and disease prevalence (Torgerson et al., 2003). Bingham et al. (2016) estimated that the annual direct costs associated with CE in sheep in Rio Negro Province, Argentina in 2010, using officially reported slaughter values, was an average of US$15,000. That study also indicated that indirect costs (production losses) represented 96.4% of the total annual livestock-associated losses, when government-reported slaughter statistics were used. Added to that, a study analysing the economic impact of CE in livestock in Spain concluded that indirect losses account for almost 99% of the total cost association with CE, whereas the direct losses were negligible (Benner et al., 2010). However, this could vary in lower to middle income developing country in the Middle East. For instance, an economic evaluation in Ahwaz, south-western Iran combining both direct (liver and lung abattoir condemnation) and indirect losses (meat, milk, fleece, and infertility) estimated an economic loss of US$123,490.0 based on the market prices in 2008 (Ahmadi and Meshkehkar, 2011). In Jordan, where echinococcosis is highly endemic, Torgerson et al. (1998) estimated that the loss due to liver condemnation was over US$850,000 whilst total losses to the livestock industry in the whole country were over $3.5 million annually. Direct comparison between different studies on economic losses is difficult due to a lack of standardized methods for estimating costs, differences in chain logistics from farm-to fork across different settings, and also due to inherent socioeconomic patterns and periods of valuation (Benner et al., 2010).

Although the current model developed in this study was limited only to sheep slaughtered in Basrah; we believe that the proposed model-based approach could be easily extended to a wider national assessment of the annual economic burden of CE in livestock in Iraq. However, to achieve such a goal, it is important to re-enforce adequate meat inspection procedures in abattoirs, and to enable improved capacities for proper record keeping of abattoir data, with the ultimate development of a centralized regional and national digital recording of such data (Yibar et al., 2015). Otherwise the actual prevalence and epidemiologic characterization of the diseases encountered during meat inspection of slaughtered animals may be underestimated.

The economic model could be improved by combining both direct and indirect losses. Although a number of studies have suggested that CE is responsible for livestock production losses, these losses are difficult to accurately estimate due to the lack of available experimental data (Bingham et al., 2016). The sensitivity analysis (Fig. 2) of the input-output relationships between model variables highlights the total model uncertainty could be reduced by gathering more data on the baseline estimate of the percentage of sheep slaughtered at abattoir (with official meat inspection) out of the total sheep slaughtered for human consumption in Basrah.

The results of this study demonstrate that CE is frequently prevalent and represents an important economic problem in Basrah province, Iraq. In addition, because this is the first study to examine the direct monetary burden of CE in Basrah; it adds valuable information to the existing body of knowledge about CE in this region. It should be emphasised also that an abattoir frequency comparable to ours were also concluded in a study in the North of Iraq (Hassan et al., 2016). CE is responsible for considerable losses of edible offal resulting in monetary losses to the livestock sectors in Iraq. Therefore, it is important to continue efforts to combat CE in different regions of Iraq. While the present work focused on collecting evidences to inform the economic model, we were not able to collect data on measures taken at abattoirs or informal market levels for controlling the transmission cycle of *E. granulosus* (e.g. for example to keep offal waste away from dogs) and about other possible control measures. In future work, it is recommended to evaluate the frequencies of CE in the informal market level and to gather data specific on control measures at both abattoir and informal market levels. Stakeholders and policymakers can use these data to better allocate resources for combatting CE in this endemic region.

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References

Abdulhameed, M.F., Habib, I., Al-Azizz, S.A., Robertson, I., 2018. A retrospective study of human cystic echinococcosis in Basrah province, Iraq. Acta Trop. 178, 130–133.

Abo-Shehada, M.N., 1993. Some observation on hydatidosis in Jordan. J. Helminthol. 67, 248–252.

Ahmadi, N.A., 2005. Hydatidosis in camels (Camelus dromedarius) and their potential role in the epidemiology of *Echinococcus granulosus* in Iran. J. Helminthol. 79, 119–125.

Ahmadi, N.A., Meshkehkar, M., 2011. An abattoir-based study on the prevalence and economic losses due to cystic echinococcosis in slaughtered herbivores in Ahwaz, south-western Iran. J. Helminthol. 85, 33–39.

Al-Khalidi, N.W., 1998. Cystic echinococcosis in sheep, goats, cattle and camels in Shahat Abattoir, Al-Jabal, Libya. In: Proceedings of the 3rd Annual Meeting for Animal Production Under Arid Conditions. 1.

Al-Yaman, F.M., Assaf, L., Hailat, N., Abdel-Hafez, S.J., 1985. Prevalence of hydatidosis in slaughtered animals from north Jordan. Ann. Trop. Med. Parasitol. 79, 501–506.

Azlaf, R., Dakkak, A., 2006. Epidemiological study of the cystic echinococcosis in Morocco. Vet. Parasitol. 137, 83–93.

Benner, C., Carabin, H., Sánchez-Serrano, L.P., Budke, C.M., Carmenad, D., 2010. Analysis of the economic impact of cystic echinococcosis in Spain. Bull. World Health Organ. 88, 49–57.

Bingham, G.M., Larrieu, E., Uchiumi, L., Mercapide, C., Mujica, G., Del Carpio, M., Hererro, E., Salvitti, J.C., Norby, B., Budke, C.M., 2016. The economic impact of cystic echinococcosis in Rio Negro Province, Argentina. Am. J. Trop. Med. Hyg. 94, 615–625.

Brookes, V.J., Kennedy, E., Dhagapan, P., Ward, M.P., 2017. Qualitative research to design sustainable community-based surveillance for rabies in northern Australia and Papua New Guinea. Front. Vet. Sci. 4.

Brunetti, E., Kern, P., Vuitton, D.A., 2010. Expert consensus for the diagnosis and treatment of cystic and alveolar echinococcosis in humans. Acta Trop. 114, 1–16.

Craig, P.S., McManus, D.P., Lightowlers, M.W., Chabalgoity, J.A., Garcia, H.H., Gavidia, C.M., Gilman, R.H., Gonzalez, A.E., Lorca, M., Naquira, C., Nieto, A., Schantz, P.M., 2007. Prevention and control of cystic echinococcosis. Lancet Infect. Dis. 7, 385–394.

Deplazes, P., Rinaldi, L., Alvarez Rojas, C.A., Torgerson, P.R., Harandi, M.F., Romig, T., Antolova, D., Schurer, J.M., Lahmar, S., Cringoli, G., et al., 2017. Global Distribution of Alveolar and Cystic Echinococcosis. Adv. Parasitol. 95, 315–493.

Garabed, R.B., Perez, A.M., Johnson, W.O., Thurmond, M.C., 2009. Use of expert opinion for animal disease decisions: an example of foot-and-mouth disease status designation. Prev. Vet. Med. 92, 20–30.

Gebremeskel, B., Kalayou, K., 2009. Prevalence, viability and fertility study of bovine cystic echinococcosis in Mekelle City, Northern Ethiopia. Rev. Med. Vet. 160, 92–97.

Hassan, Z.I., Mero, W.M.S., Casulli, A., Interisano, M., Boufana, B., 2016. Epidemiological study of cystic echinococcosis in sheep, cattle and goats in Erbil Province. J. Univ. Zakho 4, 43–55.

Herenda, D., Chambers, P.G., Ettriqui, A., Seneviratna, P., da Silva, J.J.P., 1994. Manual on Meat Inspection for Developing Countries. Rome, FAO.

Jarjees, M.T., Al-Bakeri, H.S., 2012. Incidence of hydatidosis in slaughter livestock at Mosul, Iraq. Iraqi J. Vet. Sci. 26, 21–25.

Kamhawi, S., Hijjawi, N., Abu-Ghazaleh, A., Abbas, M., 1995. Prevalence of hydatid cysts in livestock from five regions in Jordan. Ann. Trop. Med. Parasitol. 89, 621–629.

Kebede, W., Hagos, A., Girma, Z., Lobago, F., 2009. Echinococcosis/hydatidosis: its prevalence, economic and public health significance in Tigray region, North Ethiopia. Trop. Anim. Health Prod. J. 41, 865–871.

Kumsa, B., 1994. Hydatidosis in Nekemet: Prevalence in Slaughtered Cattle and Sheep Estimated Economic Loss and Incidence in Stray Dog. Faculty of Veterinary Medicine, Debre Zeit, Ethiopia vol. DVM Thesis. (Addis Ababa University).

Majorowski, M., Carabin, H., Kilani, M. & Bensalah, A. (2001) Echinococcosis in Tunisia: an economic analysis. In Proceedings of the Society for Veterinary Epidemiology and Preventative Medicine Annual Conference Menzies, F. & Reid, S. (Eds.). (Noordwijkerhout, The Netherlands, 28–30 March 2001).
Maktoof, A.R., Abu Tabeekh, M.A.S., 2015. Classification of endemicity of cystic echinococcosis in Basra Governorate-Iraq. Savant J. Agric. Res. 1, 006–009.
Marshet, E., Asamre, K., Bekele, J., Anteneh, T., Abera, M., Aragaw, K., Abebe, R., 2011. The status of cystic echinococcosis (hydatidosis) in small ruminants slaughtered at Addis Ababa municipal abattoir. J. Anim. Vet. Adv. 10, 1445–1449.
McManus, D.P., Zhang, W., Li, J., Bartley, P.B., 2003. Echinococcosis. Lancet 362, 1295–1304.
Saeed, I., Kapel, C., Saida, L.A., Willingham, L., Nansen, P., 2000. Epidemiology of *Echinococcus granulosus* in Arbil province, northern Iraq, 1990–1998. J. Helminthol. 74, 83–88.
Saida, L.A., Nouraddin, A.S., 2011. Epidemiological study of cystic echinococcosis in man and slaughtered animals in Erbil province, Kurdistan Regional-Iraq. Tikrit J. Pure Sci. 4, 45–50.
Sawady, N.J., Al-Faddagh, Z., 2012. Study of bile leak after hepatic hydatid cysts surgery in Basrah. Basrah J. Surg. 18, 40–50.
Smyth, J.D., Barrett, N.J., 1980. Procedure for testing the viability of human hydatid cysts following surgical removal, especially after chemotherapy. Trans. R. Soc. Trop. Med. Hyg. 74, 649–652.
Thweni, M.M., Yassen, L.Y., 2015. Hepatic Hydatidosis in man and livestock in Nassiriyah, Iraq. Int. J. PharmTech Res. 7, 310–314.
Torgerson, P.R., Dowling, P.M., 2001. Estimating the economic effects of cystic echinococcosis. Part 2: an endemic region in the United Kingdom, a wealthy industrialized economy. Ann. Trop. Med. Parasitol. 95, 177–185.
Torgerson, P.R., Williams, D.H., Abo-Shehada, M.N., 1998. Modelling the prevalence of *Echinococcus* and *Taenia* species in small ruminants of different ages in northern Jordan. Vet. Parasitol. 79, 35–51.
Torgerson, P.R., Shaikenov, B.S., Rysmukhambetova, A.T., Ussenbayev, A.E., Abdybekova, A.M., Burtisurnov, K.K., 2003. Modelling the transmission dynamics of *Echinococcus granulosus* in dogs in rural Kazakhstan. Parasitology 126, 417–424.
Vose, D., 2008. Risk Analysis: A Quantitative Guide, 3rd edn. Wiley, Chichester, England.
Yibar, A., Selcuk, O., Senlik, B., 2015. Major causes of organ/carcass condemnation and financial loss estimation in animals slaughtered at two abattoirs in Bursa Province, Turkey. Prev. Vet. Med. 18, 28–35.
Yildiz, K., Gurcan, S., 2003. Prevalence of hydatidosis and fertility of hydatid cysts in sheep in Kirikkale, Turkey. Acta Vet. Hung. 51, 181–187.
Yosoufi, H., 2007. Molecular cartelization of the strains cause sheep hydatid cyst, in Chaharmahal va bakhtiyary province using restriction fragment length polymorphism. J. Shahrekord Univ. Med. Sci. 9, 23–29 (In Persian).