Supporting Information:

Global Cryptosporidium loads from livestock manure

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**S1. Distribution of livestock over the world**

The number of animals in a grid cell (Ni) are from the Gridded Livestock of the World v2.0\(^1\) for six animal species: cattle, sheep, goats, pigs, chickens and ducks. We made assumptions on the spatial distribution for five other livestock species (buffaloes, horses, mules, donkeys, camels) for which only country totals were available (from the FAO\(^2\)). We assumed that buffaloes are distributed over grid cells within countries proportionally to the distribution of cattle, and that horses, camels, mules and donkeys are distributed proportionally to the distribution of sheep plus goats. We chose cattle because we assume that these are most likely to be kept in similar circumstances as buffaloes, as they are both used for dairy and meat production. And the same holds for sheep plus goats and horses, mules, donkeys and camels, which are all animal species that are often kept free range. The way the country totals for these animals are distributed over the grid cells does not influence our calculation of the total oocyst load, it only influences where on the map this load is assigned too. However, as buffaloes, horses, mules, donkeys and camels are relatively little in number compared to the other livestock species (Figures S1 and S2) the appearance of the final oocyst load map is hardly influenced either.

Figures S1 and S2 shows the distribution of livestock over the world, aggregated over seven world regions: Europe, Asia, Africa, North America, Latin America, Middle East - North Africa (MENA) and Oceania. We distinguish these seven regions as our input data for prevalence make the same distinction. The MENA region was taken separately from Africa and Asia because its characteristics differ from the surrounding areas, for example in relative occurrence of different livestock species (Figure S1 and S2). On the Livestock Geowiki website, detailed maps displaying the Gridded Livestock of the World v2.0 data can be found (http://livestock.geo-wiki.org/home-2/).
Figure S1: Distribution of livestock over the world. This figure shows the numbers of livestock summed per world region. Horses, camels, mules, donkeys and ducks were taken together in the category ‘other’. Chicken and duck totals were divided by 10 for visual comparison purposes.

Figure S2: Distribution of livestock over the world. This figure shows the numbers of livestock summed per world region for horses, camels, mules, donkeys and ducks. Duck totals were divided by 10 for visual comparison purposes.
S2. Manure production

Manure production rates are calculated from average adult animal body mass (Table S1) and manure production per day per 1000 kg live animal mass (Table S2), similar to what is done in manure production estimates for greenhouse gas emission inventories. For animals under three months old, we take the following birth weights for our calculations: cattle and buffaloes 40 kg, pigs 1.5 kg, sheep and goats 4.5 kg. Oocyst production per animal likely varies much more strongly with other factors than body mass, such as immune status. This is, for example, reflected by the fact that for many animal species it has been observed that younger (and thus smaller) animals excrete more oocysts than adults (Table S4). However, as there is no extensive research relating livestock factors to oocyst production, this is the best possible estimate with the available data. Using birth weight to calculate manure production of animals under three months might give an underestimation, as the animals grow and their manure production increases during this period. However, as oocyst shedding peaks shortly after birth in most livestock species, we believe we made reasonable estimates for our purpose of calculating annual oocyst loads. No body weight estimates for chickens and ducks are needed, as the oocyst excretion rate values for these animals are in oocysts / infected animal / day, instead of excretion in oocysts / gram manure.

Table S1. Average adult body mass (kg) for the different animal species. Based on data from the IPCC guidelines for National Greenhouse Gas inventories.

|             | Cattle | Buffaloes | Pigs | Sheep | Goats | Camels | Horses | Mules | Donkeys |
|-------------|--------|-----------|------|-------|-------|--------|--------|-------|---------|
| Africa      | 250    | 400       | 28   | 28    | 30    | 217    | 238    | 130   | 130     |
| Asia        | 350    | 400       | 28   | 28    | 30    | 217    | 238    | 130   | 130     |
| Europe      | 550    | 400       | 190  | 48.5  | 38.5  | 217    | 377    | 130   | 130     |
| Latin America | 400   | 400       | 28   | 28    | 30    | 217    | 238    | 130   | 130     |
| Middle East /North Africa | 250 | 400       | 28   | 28    | 30    | 217    | 238    | 130   | 130     |
| North America | 550  | 400       | 190  | 48.5  | 38.5  | 217    | 377    | 130   | 130     |
| Oceania     | 450    | 400       | 190  | 48.5  | 38.5  | 217    | 377    | 130   | 130     |
Table S2. Manure production per day per 1000 kg live animal mass. These data are based on the USEPA report. For cattle, we take the average of the reported values for beef cattle and dairy cattle, as the Gridded Livestock of the World dataset does not distinguish between beef and dairy cattle. For mules, we take the same values as for horses, donkeys and camels.

Table S2

| Animal          | Kg manure/day/1000 kg body mass |
|-----------------|---------------------------------|
| Beef cattle & buffaloes | 58                              |
| Dairy cattle     | 86                              |
| Pigs             | 85                              |
| Sheep            | 40                              |
| Goats            | 41                              |
| Horses           | 51                              |
| Donkeys          | 51                              |
| Camels           | 51                              |

S3. Fraction young animals

To estimate the fraction of animals that is young (defined as under three months old) (Table S3), we made assumptions based on the fertility rates and average age at first parturition as described in the Global Livestock Environmental Assessment Model (GLEAM).

Table S3 Estimating the fraction of animals that is young (defined as under three months old)

| Animal       | Average fertility rate (fraction of females having young per year)* | Average age at first parturition* (years) | Typical number of offspring per parturition | Fraction of animals that is under 1 year old (our estimate) | Fraction of animals that is under three months (our estimate) |
|--------------|---------------------------------------------------------------------|----------------------------------------|-------------------------------------------|----------------------------------------------------------|-------------------------------------------------------------|
| Cattle       | 0.8                                                                | 2.7                                    | 1                                         | 0.33                                                     | 0.08                                                        |
| Buffaloes    | 0.7                                                                | 3.2                                    | 1                                         | 0.33                                                     | 0.08                                                        |
| Pigs         | 2                                                                  | 1.3                                    | >10                                       | 0.90                                                     | 0.22                                                        |
| Sheep        | 0.85                                                               | 1.7                                    | 2                                         | 0.60                                                     | 0.15                                                        |
| Goats        | 0.85                                                               | 1.5                                    | 2                                         | 0.60                                                     | 0.15                                                        |

*Numbers are based on the Global Livestock Environmental Assessment Model (GLEAM)
S4. Prevalence and excretion rates

S4.1 Systematic literature review

Average prevalence of cryptosporidiosis ($P_y$ and $P_a$) and average oocyst excretion rate of infected animals ($R_y$ and $R_a$) are based on an extensive systematic literature review\textsuperscript{7}. Table S4 shows the model input derived from this review. For all livestock except cattle we combined the prevalence data from studies from different parts of the world, as there is not enough data to reliably deduce regional prevalences. For cattle, buffaloes, pigs, sheep and goats we make a distinction in prevalence and excretion rates between young and adult animals. We do not distinguish between age groups for the other species due to a lack of data.

Table S4. Model input for cryptosporidiosis prevalences ($P_y$ and $P_a$) and oocyst excretion rates ($R_y$ and $R_a$) for the different livestock species. These numbers are based on a systematic literature review\textsuperscript{7}\textsuperscript{a}.

| Livestock species | Average prevalence (%) | Average excretion (log oocysts / gram feces) |
|-------------------|------------------------|---------------------------------------------|
|                   | All ages combined (P)   | Aged over 3 months (Pa) | Aged under 3 months (Py) | Number of studies | All ages combined (R) | Aged over 3 months (Ra) | Aged under 3 months (Ry) | Number of studies |
| Cattle            |                        |                               |                          |                 |                          |                          |                          |                 |
| All regions combined |                        |                               |                          | 153             |                          |                          |                          |                 |
| Africa            | 16.7                   | 28.9                          |                          | 20              | 2                          | 4.9                         |                          | 48              |
| Asia              | 15.9                   | 24.7                          |                          | 44              |                           |                             |                          |                 |
| Europe            | 13.4                   | 30.3                          |                          | 38              |                           |                             |                          |                 |
| Latin America     | 12.8                   | 13.2                          |                          | 5               |                           |                             |                          |                 |
| Middle East / North Africa | 16.4        | 26.1                          |                          | 18              |                           |                             |                          |                 |
| North America     | 9.2                    | 25.1                          |                          | 23              |                           |                             |                          |                 |
| Oceania           | 0.6                    | 17.9                          |                          | 5               |                           |                             |                          |                 |
| Buffaloes         | 14.4                   | 27.0                          |                          | 14              | 2\textsuperscript{b}       | 4.9\textsuperscript{b}        |                          |                 |
| Pigs              | 19.8                   | 25.4                          |                          | 34              | 3.9                        | 4.7                         |                          | 12              |
| Sheep             | 13.2                   | 25.1                          |                          | 43              | 2.3                        | 4.4                         |                          | 14              |
| Goats             | 10.6                   | 15.8                          |                          | 28              | 2.2                        | 5.3                         |                          | 10              |
| Horses            | 7.5                    |                                |                          | 19              | 3.1                        |                             |                          | 4               |
| Camels            | 12.2                   |                                |                          | 7               | 3.1\textsuperscript{c}     |                             |                          |                 |
| Chickens          | 11.6                   |                                |                          | 9               | 6.8\textsuperscript{d}     |                             |                          |                 |
| Ducks             | 14.7                   |                                |                          | 3               | 4.7\textsuperscript{d}     |                             |                          |                 |
The literature review also distinguished ‘unknown age’. Where the mean of the ‘unknown age’ group was not in between the means for adults and young, these data were included with the group it was closest to (this was the case for prevalence for goats, pigs, and for cattle in Africa, Latin America and the MENA region).

For buffaloes we take the same values as for cattle.
For camels, donkeys and mules we take the same value as for horses.
For chickens and ducks, the number represents $10^\log$ oocysts per infected animal per day (see section S4.2).
For mules we take the same value as for donkeys.

S4.2 Excretion rates for chickens and ducks

The literature review on which the cryptosporidiosis prevalence and excretion rates are based did not yield any results for oocyst excretion rates for chickens and ducks. This literature review looks specifically at studies published in the period 2001-2015, that concern natural Cryptosporidium infections (no inoculation), and give an estimate of oocysts excretion per gram faeces. We broadened this search with older studies, inoculation experiments and studies that estimate oocyst excretion per animal per day, in order to determine suitable model input for chicken and duck excretion rates.

Table S5 shows the eight studies for chickens we found, one of which also concerns ducks. Some of these studies were experiments with a clinical treatment, in these cases we only looked at the control groups, to stay as close as possible to the situation in regular poultry. In most cases, we used a plot digitizer to obtain the data of interest from graphs as accurately as possible (http://arohatgi.info/WebPlotDigitizer/, accessed in July 2016).

On the basis of the data presented in Table S5, we used 6.8 log oocysts per day as model input for chickens, this is the $10^\log$ of the average excretion rate observed in the eight studies. For ducks we used the single observation as model input. None of these studies concern natural Cryptosporidium infections; all are inoculation.
experiments, where the poultry were fed oocysts and their response was then measured. This might lead to an overestimation of the excretion rates, as it has been found that inoculation with higher oocyst numbers leads to higher oocyst shedding\textsuperscript{13,16}, although another study on calves does not find this\textsuperscript{17}. All eight studies concern very young poultry, mostly in their first week of life. Often, the inoculation studies are done with very young chickens (<1 week old), but lower excretion rates are observed in among somewhat older chickens (9 weeks)\textsuperscript{12}. Furthermore, chickens inoculated at a younger age were found to shed for a much longer period\textsuperscript{12}. Also in many other animal species it is found that young animals shed more oocysts than adults\textsuperscript{7}, so this might also lead to an overestimation in our model. Despite these concerns, we believe that basing our model input on these available data is the best possible assumption.

Table S5. Excretion rates for chickens and ducks. In all studies the reported unit is oocysts per animal per day, and the Cryptosporidium species studied is in all cases *C. baileyi*. This table shows the general characteristics of the studies, the log\(_{10}\) of the mean of the observed oocyst count in feces, the amount of oocysts with which the animals were inoculated prior to fecal measurements, and the age of the animals during the experiment.

| Author  | Publication year | Animal species | \( \log_{10} \) of mean oocyst count | Inoculation amount of oocysts | Animal age during experiment |
|---------|------------------|----------------|-------------------------------------|-----------------------------|------------------------------|
| Hornok  | 1998             | chickens       | 6.98                                | 8.E+05                      | 1 day                        |
| Hornok  | 1998             | chickens       | 6.52                                | 8.E+05                      | 7 days, 28 days              |
| Hornok  | 1999             | chickens       | 6.93                                | 8.E+05                      | 7 days                       |
| Hornok  | 2000             | chickens       | 6.78                                | 8.E+05                      | 10 days                      |
| Rhee    | 1998             | chickens       | 5.54                                | 5.E+05                      | 2 days                       |
| Sreter  | 1995             | chickens       | 6.16                                | 6.E+05                      | 7 days, 63 days              |
| Varga   | 1995             | chickens       | 7.23                                | 6.E+05                      | 7 days                       |
| Rhee    | 1995             | chickens       | 5.43                                | 2.E+02 to 2.E+06            | 2 days                       |
| Rhee    | 1995             | ducks           | 4.72                                | 2.E+02 to 2.E+06            | 2 days                       |
S5. Data on intensive and extensive farming and manure storage systems

Data on whether animals are kept in intensive or extensive farming systems (Fintl, Fextl, Fints, Fexts) were taken from the Integrated Model to Assess the Global Environment (IMAGE) according to Bouwman et al.\(^\text{18}\). The classification is based on an FAO report that distinguishes pastoral systems (extensive) and mixed and landless systems (taken together as intensive)\(^\text{19}\). In both intensive and extensive systems, data are provided for the fraction of manure dropped directly on land during grazing, the fraction going to storage, and the fraction used for other purposes (such as burning for fuel) that leaves the system\(^\text{18}\). The IMAGE model categories ‘dairy cattle’ and ‘beef cattle’ were averaged to represent cattle, as the Gridded Livestock of the World v2.0 does not distinguish between beef and dairy cattle. The IMAGE model category ‘sheep & goats’ was considered representative for both our categories sheep and goats, and ‘poultry’ for ducks and chickens.

Data on the use of different storage systems (FS\(_j\)) for the different animal species are from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories\(^\text{3}\) and underlying data from a USEPA report on Global methane emissions from livestock and poultry manure\(^\text{4}\) (Table S6). The 2006 IPCC guidelines provide data on the manure management systems used for cattle, buffaloes and pigs\(^\text{3}\). For the other animal species the USEPA data were used\(^\text{4}\). The IPCC data are continent-specific, while the USEPA data are country-specific. Data are provided for an extensive list of countries. For countries not on the list, regional averages were used. For the manure management system category ‘burned for fuel’ we assumed manure leaves the system and does not get stored and spread on land. We assumed the category ‘pasture/ range/ paddock’ covers the manure dropped on land directly, as we account for in equation 2 in the main article.

Table S6. Model input for manure storage (FS\(_j\))

\(\text{Table S6. Model input for manure storage (FS}_j\)
According to the description, this category includes both manure going to anaerobic digesters and manure that is burned for fuel. We therefore assume that half of the manure in this category leaves the system, and the other half ends up on land after a 2 log reduction in infectivity.

### S6. Temperature-dependent survival during manure storage

We derived the value of $K$ based on seven studies that reported a relation between temperature ($°C$) and oocyst survival (measured as viability or infectivity) in livestock manure\textsuperscript{20–26} (Table S7). Since the data points of the studies using infectivity show similar inactivation as the data points from studies using viability assays, the data points from all of these studies were pooled (Figure S3). We excluded two studies that measured only presence of oocysts and not viability or infectivity, as these were found not to fit well with the other data\textsuperscript{27,28}. The studies reported their findings in different metrics (e.g. percentage viability decline, $t_{99}$, times reduction, decrease in infectivity). We calculated each metric back to a daily survival rate and from there to a $t_{90}$ value (time in days until a 1 log reduction).

| Manure management system categories (IPCC 2006) | Manure management system categories (Safley et al. 1992) | Assumption on survival ($\overline{V_j}$) | Assumption on storage time ($t_j$) |
|-----------------------------------------------|---------------------------------------------------------|---------------------------------------|----------------------------------|
| Daily spread                                  | Daily spread                                            | All survive ($\overline{V_j} = 1$)    | 0 days                           |
| Lagoon                                        | Anaerobic lagoon                                        | $\overline{V_j}$ according to eq. 5  | 9 months                         |
| Liquid/slurry                                  | Liquid systems (includes liquid/slurry storage and pit storage) | $\overline{V_j}$ according to eq. 5  | 9 months                         |
| Pit < 1 month                                  | $\overline{V_j}$ according to eq. 5                     | 1 month                              |                                  |
| Pit > 1 month                                  | $\overline{V_j}$ according to eq. 5                     | 9 months                              |                                  |
| Solid storage                                  | Solid storage & dry lot                                 | $\overline{V_j}$ according to eq. 5  | 9 months                         |
| Dry lot                                        | $\overline{V_j}$ according to eq. 5                     | 9 months                              |                                  |
| Other                                          | Other (includes deep pit stacks, litter, and other)     | $\overline{V_j}$ according to eq. 5  | 9 months                         |
| Anaerobic digester                            |                                                          | 2 log reduction in infectivity ($\overline{V_j} = 0.01$) | NA                              |
| Burned for fuel                                | Used for fuel $^a$                                       | Leaves the system (not storage, not to land) | NA                              |
| Pasture/range/paddock                         | Pasture/range/paddock                                   | To land (not storage)                 | NA                              |

$^a$According to the description, this category includes both manure going to anaerobic digesters and manure that is burned for fuel. We therefore assume that half of the manure in this category leaves the system, and the other half ends up on land after a 2 log reduction in infectivity.
Figure S3: Oocyst survival in manure (t\textsubscript{90}) under different ambient temperatures. We extracted the temperature and t\textsubscript{90} from seven studies on survival of oocysts in manure under different temperature conditions. These were plotted and a linear trend line was fitted using Microsoft Excel. Since the data points of the studies using infectivity show similar inactivation as the data points from studies using viability assays, the data points from all of these studies were taken together for fitting the linear trend line. Reported temperature is ambient temperature, except for systems in which the storage system itself reached a certain temperature (for example during composting).

Figure S3 shows the data points from the seven studies and the linear relation between temperature and t\textsubscript{90}. Based on this linear trend we use the following equation in GloWPa-Crypto L1 for the relation between ambient temperature and \textit{Cryptosporidium} survival in manure (expressed as t\textsubscript{90} value):

\[
t_{90} = -2.5586 \times T + 119.63
\]  

(S1)
In our model, $T$ is the average annual air temperature in a grid cell, it is the average over 1970-2000 derived from the WATCH forcing data. Average air temperature was used, as we are not interested in the conditions in a specific year, that might be unusually warm or cold in certain locations. We determined a $t_{90}$ value for each grid cell using equation S1. We then substituted $t$ in equation 4 in the main article with $t_{90}$, and $V$ with 0.1 (1 log reduction), to determine a value for constant $K$ for each grid cell.

In this analysis, we pooled data from different types of manure storage systems. Nevertheless, conditions under which manure is stored (e.g. moisture content, mixing with other materials) may differ per system, and these conditions might influence *Cryptosporidium* survival. For example, the two highest points in Figure S3 correspond to the study by Hutchison et al. We can only speculate as to why the observed survival in this study is so much higher than in the other studies. It could have to do with the storage type (liquid tank storage) or the *Cryptosporidium* strain, the researchers might have accomplished better oocyst recovery, or it may simply be natural variation. More research into this topic would be worthwhile, to get more insight into the effect of different manure management practices on oocyst survival. Furthermore, all seven studies concern cattle or pig manure. Information on the relation between temperature and oocyst survival in manure from other livestock species is not available, to our knowledge. Nevertheless, the data in Figure S3 show a reasonable fit that shows a clear decrease in oocyst survival in manure with increasing temperatures. Therefore, we decided to take ambient temperature into account in our model.

Temperatures below zero are modelled as an extrapolation of the trend line from Figure S3. Freezing has been found to reduce oocyst viability more strongly than temperatures just above zero, but the conditions under which oocysts are frozen matter. Snap-freezing oocysts was found to lead to 100% death, while slow freezing lead to higher survival rates, with a small proportion of oocysts still viable even after 750 hours at $-22^\circ$C. Sattar et al. found that oocysts in calf manure that were frozen at $-20^\circ$C for at least 24 hours still had excystation rates between 39-72%. We did not consider freezing temperatures a special case in computing oocyst survival during manure storage, for three main reasons. Firstly, the relation between below-zero temperatures and oocyst survival is not straightforward, as Robertson et al. and Satter et al. show. Secondly, we use ambient temperature...
(average annual air temperature), and when ambient temperatures are below zero, this does not mean that the temperature within a manure storage system will also be below zero. And thirdly, if the average annual air temperature is below zero, it could very well be that part of the year the temperature is above zero and Cryptosporidium survives for a long time. Thus assuming that only few oocysts survive when the temperature is below zero could lead to underestimation of the actual situation. Therefore, we chose to model temperatures below zero as an extrapolation of the relation found in Figure S3.
Table S7. Studies that report a relation between temperature and survival of Cryptosporidium oocysts in manure. This table shows the general information about the seven studies that were found, with the metric they reported (changes in viability or infectivity). From these we calculated a daily survival rate and from that a $t_{90}$ value.

| First author | Publication year | Animal species | Measured viability or infectivity | System description | Storage time | Season | Temperature (°C) | Viability (%) | Infectivity Reduction (times) | Daily survival rate (calculated) | $t_{90}$ (calculated) |
|--------------|------------------|----------------|----------------------------------|--------------------|--------------|--------|-----------------|---------------|-----------------------------|--------------------------|---------------------|
| Collick      | 2006             | cattle         | viability                        | Bedding            | 8 weeks      | winter | 2.6             | 30            | 3.33                        | 0.98                     | 107.1               |
|              |                  |                |                                  |                    |              | spring | 2.2             | 20            | 5                           | 0.97                     | 80.1                |
|              |                  |                |                                  |                    |              | summer | 11.7            | 20            | 5                           | 0.97                     | 80.1                |
|              |                  |                |                                  |                    |              | late summer | 19.7          | 10            | 10                          | 0.96                     | 56.0                |
| Hutchison    | 2005             | pig and cattle | viability                        | Liquid tank storage | 3 months    | summer | 12.4            | From 90 to 60% | 0.99                        | 248.0                    |
|              |                  |                |                                  |                    |              | winter | 4.3             |               | 0.99                        | 232.0                    |
| Jenkins      | 1999             | cattle         | viability                        | Composting         | 82 days     | 35     | 5 days          |               | 5log reduction              | 0.87                     | 16.4                |
|              |                  |                |                                  |                    |              |        | 50              |               | 0.02                        | 0.6                      |
| Jenkins      | 2013             | pigs           | viability                        | Lagoon             | $t_{99}$ of 91.7 days | summer | 25.9            |               | 0.95                        | 45.9                     |
|              |                  |                |                                  |                    | $t_{99}$ of 140.7 days | winter | 5.2             |               | 0.97                        | 70.4                     |
| Kinyua       | 2016             | pigs           | viability                        | Anaerobic digestion | 21          |               | die-off 0.054/day |               | 0.95                        | 42.6                     |
| Olson        | 1999             | cattle         | viability                        | Wet feces in the dark in lab | 12 weeks | 4 | 10 | 10 | 0.96 | 56.0 | 0.96 | 56.0 |
|              |                  |                |                                  |                    | 12 weeks | 25 | 5 | 20 | 0.95 | 43.0 | 0.95 | 43.0 |
| Garcés       | 2006             | cattle         | infectivity                      | Anaerobic digestion | 1 hrs | 38 | Reduced by 2 log units | 1E-48 | 0.0 |
|              |                  |                |                                  |                    | 4 hrs   | 55 | Reduced by 5 log units | 1E-30 | 0.0 |
S7. Sensitivity analysis

We performed a nominal range sensitivity analysis changing one parameter at a time based on a reasonable range the parameter can take, usually both a decrease and an increase were taken. Table S8 shows the changed parameters and the outcomes of the sensitivity model runs for all parameters except prevalence and excretion rates, Table S9 shows it for prevalence, and Table S10 for excretion rates. Here we discuss the changes to the parameters and the results for each of these tables.

S7.1 Sensitivity analysis for all parameters except prevalence and excretion rates

Animal numbers per grid cell, animal mass and manure production were increased and decreased by 20% in the sensitivity analysis. Animal numbers per grid cell are aggregated from the Gridded Livestock of the World data, which have a much finer spatial resolution (3 arc minutes grid) and have been extensively validated. At our 30 min grid we expect these not to vary more than 20%. Average animal mass and manure production are expected not to vary more than 20% due to physiological constraints. The fraction of animals that is under three months old and the mass of young animals were halved and doubled, as we think these are more uncertain. The fractions of manure going to storage and to land were increased and decreased by 50%, and the storage time (average 9 months) was changed to 6 months and 1 year. This is based on an assumed 1 or 2 crop yields per year and spreading of manure at the start of the growing season. The average storage time for the category ‘Pit storage < 1 month’ was varied from two weeks to two months. The constants in equation S1, that describes the relation between temperature and t90, were halved and doubled, as this approximately covers the spread of the points in Figure S3. Instead of average annual air temperature, in the sensitivity analysis we took the average air temperature in January and July to reflect the natural variation between the seasons.

The last column of Table S8 shows that changing these parameters leads to a factor 0.66-1.97 change in the total oocyst load. The model is most sensitive to changing the fractions of manure that is going to storage and to land. Furthermore, the model is quite sensitive to the fraction of animals that is young and the mass of young animals. The model is not so sensitive to changes in storage time and temperatures in different seasons.
Table S8. Sensitivity analysis for all parameters except prevalence and excretion rates. Column 1 gives the variable name, column 2 the changed value, column 3 the baseline model value and column 4 explains the change in words. Column 5 and 6 show the results of the model run with that particular change. Column 5 shows the total global oocyst load to land, and column 6 shows the total oocyst load divided by the total oocyst load of the baseline model run, so the relative effect of the change.

| Variable name                        | Variable changed | Variable baseline | Explanation          | Total oocyst load | Total divided by baseline run |
|--------------------------------------|------------------|-------------------|----------------------|------------------|------------------------------|
| animal numbers (N)                   | 0.8              | 1                 | 20% decrease         | 2.60E+23         | 0.80                         |
| animal numbers (N)                   | 1.2              | 1                 | 20% increase         | 3.89E+23         | 1.20                         |
| fraction young (Fy)                  | 0.5              | varies per animal | halve                | 2.37E+23         | 0.73                         |
| fraction young (Fy)                  | 2                | varies per animal | double               | 4.99E+23         | 1.54                         |
| mass all                             | 0.8              | varies per animal | 20% decrease         | 2.73E+23         | 0.84                         |
| mass all                             | 1.2              | varies per animal | 20% increase         | 3.76E+23         | 1.16                         |
| mass young                           | 0.5              | varies per animal | halve                | 2.30E+23         | 0.71                         |
| mass young                           | 2                | varies per animal | double               | 5.14E+23         | 1.58                         |
| manure per1000kgmass                 | 0.8              | varies per animal | 20% decrease         | 2.73E+23         | 0.84                         |
| manure per1000kgmass                 | 1.2              | varies per animal | Storage +50%, land - 50% | 3.76E+23         | 1.16                         |
| fraction to storage (Fints, Fexts)   | 0.5              | 0                 | Storage +50%, land - 50% | 2.14E+23         | 0.66                         |
| fraction to land (Fintl, Fextl)      | 0.5              | 0                 | Land +50%, storage - 50% | 6.38E+23         | 1.97                         |
| storage time (t_j)                   | 183              | 274 days (9 months) | 6 months           | 3.61E+23         | 1.11                         |
| storage time (t_j)                   | 365              | 274 days (9 months) | 1 year             | 3.06E+23         | 0.94                         |
| storage time low (t_j)               | 15               | 30 days (1 month) | 2 weeks             | 3.26E+23         | 1.00                         |
| storage time low (t_j)               | 60               | 30 days (1 month) | 2 months            | 3.22E+23         | 0.99                         |
| temp par1                            | -1.2793          | -2.5586           | less steep           | 3.43E+23         | 1.06                         |
| temp par2                            | 239.26           | 119.63            | higher              | 4.30E+23         | 1.33                         |
| temp par1 & temp par2                | both doubled     | higher & steeper  | 3.98E+23            | 1.23             |
| temp par1 & temp par2                | both halved      | lower & less steep| 2.84E+23            | 0.88             |
| Temperature (T)                      | average January temperature | average annual temperature (°C) | Seasonal storage | 3.46E+23         | 1.07                         |
| Temperature (T)                      | average July temperature | average annual temperature (°C) | Seasonal storage | 3.05E+23         | 0.94                         |

S7.2 Sensitivity analysis for prevalence
The prevalence values used in this model are based on the mean cryptosporidiosis prevalence per animal species and age group found in a literature review published elsewhere. For this sensitivity analysis, we take the highest prevalence found per animal species and age group in this same literature review (Table S9, column 2). We did not do a sensitivity run for lowest observed prevalence, as this was zero in most cases and therefore not so meaningful.

Table S5 shows that the model is most sensitive to changes in prevalence among young cattle (defined as under three months old); the total oocyst load to land changes with a factor 2.17. After young cattle, the model is most sensitive to the prevalence among adult pigs, chickens, young goats and adult cattle. The effect size for these animal species is similar to the effect size observed in Table S8. Changing the prevalence to the upper end of the range for all animal species at the same time (last row of Table S9) changes the total oocyst load to land with a factor 3.69.

Table S9. Sensitivity analysis for prevalence (Pa and Py). Column 1 gives the variable name, column 2 the changed value and column 3 the baseline value (shown as %). Column 4 and 5 show the results of the model run with that particular change. Column 4 shows the total global oocyst load to land, and column 5 shows the total oocyst load divided by the total oocyst load of the baseline model run, so the relative effect of the change. First prevalence was changed per animal species, and the last row shows the effect when prevalence is changed for all animal species at the same time.

| Variable name   | Variable changed | Variable baseline | Total oocyst load | Total divided by baseline run |
|-----------------|------------------|-------------------|-------------------|------------------------------|
| prev cattle young | 80               | varies per region, average 25.8 | 7.05E+23          | 2.17                         |
| prev cattle adult | 73.3             | varies per region, average 14.5 | 3.77E+23          | 1.16                         |
| prev buffaloes young | 50.6             | 27                | 3.37E+23          | 1.04                         |
| prev buffaloes adult | 50.6             | 14.4              | 3.27E+23          | 1.01                         |
| prev pigs young | 80               | 25.4              | 3.29E+23          | 1.02                         |
| prev pigs adult | 80               | 19.8              | 4.70E+23          | 1.45                         |
S7.3 Sensitivity analysis for excretion rates

The excretion rates used in this model are based on the mean cryptosporidiosis excretion per animal species as found in a literature review published elsewhere. For each study a mean excretion rate was determined, and as model input we use the median of these means. For this sensitivity analysis, we change the excretion rate by one geometric standard deviation (SD) of the observed mean excretion rates of that animal species from this same literature analysis. For buffaloes, the same value as for cattle is used. For camels, donkeys and mules, the same value as for horses is used. For ducks, the geometric SD of the chicken studies was used (see Table S5).

Table S10 shows that the model is most sensitive to the excretion rate of young cattle. Adding one SD to the excretion rate leads to an increase in the total oocyst load to land by a factor 27.9. After young cattle, the model is most sensitive to changes in the excretion rate of young goats, young buffaloes, adult pigs, horses, chickens, adult cattle and camels. Decreasing the excretion rate with one SD for all animal species at once changes oocyst loads to land with a factor 0.07. Increasing the excretion rate with one SD for all animal species at once changes oocyst loads to land with a factor 39.8.

It can be seen from Tables S8-10 that the model is more sensitive to changes in the oocyst excretion rates than it is to changes in prevalence or other variables. This is not surprising, as oocyst excretion rates can vary over
several orders of magnitude. This means that the absolute size of oocyst loads to land, the relative importance of
the different animal species and the patterns on maps should be interpreted with this fact in mind.

**Table S10. Sensitivity analysis for excretion rates (Ra and Ry).** Column 1 gives the variable name, column 2 the changed value, column 3 the baseline value and column 4 an explanation in words. The values in column 2 and 3 are in $10^{\log}$ oocysts / gram manure, except for chickens and ducks, the value is in $10^{\log}$ oocysts / infected animal / day. Column 5 and 6 show the results of the model run with that particular change. Column 5 shows the total global oocyst load to land, and column 6 shows the total oocyst load divided by the total oocyst load of the baseline model run, so the relative effect of the change. First the excretion rate was changed per animal species, and the last two rows show the effect when excretion rates are changed for all animal species at the same time.

| Variable name | Variable changed | Variable baseline | Explanation | Total oocyst load | Total divided by baseline run |
|---------------|------------------|-------------------|-------------|-------------------|------------------------------|
| exc cattle young | 3.1              | 4.9               | 1 SD lower  | 1.86E+23          | 0.57                         |
| exc cattle adult | 0.7              | 2                 | 1 SD lower  | 3.13E+23          | 0.97                         |
| exc buffaloes young | 3.1              | 4.9               | 1 SD lower  | 3.10E+23          | 0.96                         |
| exc buffaloes adult | 0.7              | 2                 | 1 SD lower  | 3.23E+23          | 1.00                         |
| exc pigs young | 3.9              | 4.7               | 1 SD lower  | 3.23E+23          | 0.99                         |
| exc pigs adult | 2.9              | 3.9               | 1 SD lower  | 2.81E+23          | 0.87                         |
| exc sheep young | 3.3              | 4.4               | 1 SD lower  | 3.19E+23          | 0.98                         |
| exc sheep adult | 1                | 2.3               | 1 SD lower  | 3.23E+23          | 1.00                         |
| exc goats young | 3.6              | 5.3               | 1 SD lower  | 2.99E+23          | 0.92                         |
| exc goats adult | 1                | 2.2               | 1 SD lower  | 3.24E+23          | 1.00                         |
| exc horses | 1                | 3.1               | 1 SD lower  | 3.22E+23          | 0.99                         |
| exc camels | 1                | 3.1               | 1 SD lower  | 3.22E+23          | 0.99                         |
| exc donkeys | 1                | 3.1               | 1 SD lower  | 3.24E+23          | 1.00                         |
| exc mules | 1                | 3.1               | 1 SD lower  | 3.24E+23          | 1.00                         |
| exc chickens day | 6.1              | 6.8               | 1 SD lower  | 2.71E+23          | 0.84                         |
| exc ducks day | 4                | 4.7               | 1 SD lower  | 3.24E+23          | 1.00                         |
| exc cattle young | 6.7              | 4.9               | 1 SD higher | 9.05E+24          | 27.90                        |
| exc cattle adult | 3.3              | 2                 | 1 SD higher | 5.47E+23          | 1.69                         |
| exc buffaloes young | 6.7              | 4.9               | 1 SD higher | 1.22E+24          | 3.77                         |
| exc buffaloes adult | 3.3              | 2                 | 1 SD higher | 3.46E+23          | 1.07                         |
| exc pigs young | 5.5              | 4.7               | 1 SD higher | 3.37E+23          | 1.04                         |
| exc pigs adult | 4.9              | 3.9               | 1 SD higher | 7.54E+23          | 2.33                         |
| exc animal      | day (mean) | day (SD) | 1 SD | 1 SD lower | 1 SD higher | 1 SD higher |
|-----------------|------------|----------|------|------------|-------------|-------------|
| exc sheep young | 5.5        | 4.4      | 1 SD higher | 3.95E+23   | 1.22        |
| exc sheep adult | 3.6        | 2.3      | 1 SD higher | 3.44E+23   | 1.06        |
| exc goats young | 7          | 5.3      | 1 SD higher | 1.59E+24   | 4.90        |
| exc goats adult | 3.4        | 2.2      | 1 SD higher | 3.32E+23   | 1.02        |
| exc horses      | 5.2        | 3.1      | 1 SD higher | 6.71E+23   | 2.07        |
| exc camels      | 5.2        | 3.1      | 1 SD higher | 5.78E+23   | 1.78        |
| exc donkeys     | 5.2        | 3.1      | 1 SD higher | 3.38E+23   | 1.04        |
| exc mules       | 5.2        | 3.1      | 1 SD higher | 3.28E+23   | 1.01        |
| exc chickens day| 7.5        | 6.8      | 1 SD higher | 6.26E+23   | 1.93        |
| exc ducks day   | 5.4        | 4.7      | 1 SD higher | 3.25E+23   | 1.00        |
| exc all low     | varies per animal | varies per animal | 1 SD lower | 2.41E+22 | 0.07 |
| exc all high    | varies per animal | varies per animal | 1 SD higher | 1.29E+25 | 39.82 |
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