Quantification of exposure to fecal contamination in open drains in four neighborhoods in Accra, Ghana

TECHNICAL APPENDIX

Model parameters

Model parameters were generated in R 2.14.2 (Vienna, Austria). Justification and key assumptions are described below. Point estimates were used to describe the transfer efficiency of microbes from objects to hands (TE_{OC}, TE_{OEc}) and hands to mouth (TE_{HC}, TE_{HEc}) (Rusin *et al.* 2002). The estimated duration of time spent in a drain (T_D) was based on a competing hazards model. Hazard rates were estimated from observed durations of activities of young children in households and nurseries in Accra, Ghana, assuming a Weibull hazard model with shape factor adjusted to values greater than two. Hazard rate estimates were stratified by neighborhood. Using these estimated rates, 10,000 simulated durations of drain entry were generated selecting the durations of any activity in drains from randomly generated daily sequences of behaviors. It was assumed that the duration of time a child spent in a drain was independent of neighborhood and age.

For the remaining parameters, 10,000 Monte Carlo simulations were generated to describe the distribution of each parameter. A log-normal distribution was used to describe the initial coliphage (C_C) and *E. coli* (C_{Ec}) concentrations in drain water. The generated concentrations were transformed back from the log scale for the analysis. To describe the frequency of hand contact with drain water per drain entry event during deliberate entry (D_D), a Poisson distribution of the period of time spent in the drain multiplied by five drain contact events per hour was used. This produced a discrete distribution of the number of hand contact events. To describe the frequency of hand or object contact with drain water per drain entry event during accidental (D_A) and incidental (D_I) entry, a Poisson distribution with a value of one was used. To ensure at least one contact event occurred for each drain entry event, the distribution was zero truncated, discarding all zero samples.

To determine the volume of drain water loaded on hands, three parameters were used: (1) surface area of hands or object; (2) percentage of the hands or object in contact with drain water, hands, or mouth; and (3) thickness of the drain water film on hands or object. The surface area of children's hands (A_Y, A_M) was described by a uniform distribution with lower and upper bounds representing the 5th and 95th percentiles of surface area for male and female children (US EPA 2011). A non-porous sphere was assumed to represent the typical object retrieved, and the surface area of that object (A_O) was described by a uniform distribution with upper bound equal to the surface area of a regulation soccer ball and lower bound equal to the surface area of a ball half that diameter. The percentage of hands that contacted drain water (S_{HDW}) was given a uniform distribution based on observations of children contacting non-dietary water (AuYeung *et al.* 2008). The percentage of the surface area of an object contacting drain water (S_{ODW}) was given a uniform distribution, assuming that at least 25% of the object would come into contact with drain water. The percentage of hands contacting an object (S_{OH}) was given a uniform distribution with upper and lower bounds determined from observations of children playing with toys outdoors (AuYeung *et al.* 2008). The thickness of the film of drain water left on hands (V) was assumed to be the same as on objects, given the hydrophilic properties of hands and non-porous objects. This parameter was described by a uniform distribution with the upper bound representing immersion into water not followed by wiping afterwards and the lower bound representing immersion into water followed by partial wiping (US EPA 1987).

Finally, parameters used to describe transfer of microbes from hand to mouth included the percentage of the hand contacting the mouth, the frequency of hand mouthing by age group, and the time until hand washing. For any mouthing

activity, the percentage of the hand contacting the mouth (S_{HM}) was assumed to be uniformly distributed based on observations of child hand mouthing in an outdoor setting (AuYeung 2007). The dose resulting from all mouthing activities was assumed to be additive based on the frequency of hand mouthing events. The frequency of hand mouthing (HM_Y, HM_M) for all children was described by a Weibull distribution with equal mouthing frequencies for male and female children (Tulve 2002; Xue *et al.* 2007). Lastly, the time until hand washing occurred (T_{HW}) removing all microbes loaded on hands was given a uniform distribution based on the assumption that children are awake for 16 hours a day and wash their hands 3.9 times a day with hand washing equally likely to occur any time throughout the day (Freeman *et al.* 2001).

Model equations

The distribution of hand contamination (number of microbes transferred directly from drain to hand) is proportional to the initial concentration of microbes in drain water (C_x), the frequency of hand contact with the drain ($D_{Is} \times T_x$ for instrumental entry, D_{Ic} for incidental entry), the surface area of the hand contacting the drain water ($A_x \times S_{HDW}$), and the thickness of the water film left on the hand (V).

$$E_x = C_x \times \begin{bmatrix} D_D \times T_D \\ \text{or} \\ D_A \end{bmatrix} \times (A_x \times S_{HDW}) \times V \quad (1)$$

The distribution of hand contamination through an object (number of microbes transferred from drain to object to hand) is proportional to the initial concentration of microbes in the drain (C_x), the frequency of object contact with the drain (O_{Ic}), the surface area of the object contacting the drain water ($A_O \times S_{ODW}$), the thickness of the water film left on the object (V), the proportion of the object that the hand contacts ($A_x \times S_{OH}/A_O \times S_{ODW}$), and the transfer efficiency of microbes between the object and hand (TE_{Ox}).

$$E_x = C_x \times D_I \times (A_O \times S_{ODW}) \times V \times \left(\frac{A_x \times S_{OH}}{A_O \times S_{ODW}}\right) \times TE_{Ox} \quad (2)$$

The hand-to-mouth dose distribution is proportional to the number of microbes on the hand (as determined by the distribution of hand contamination, E_x, calculated in Equations (1) and (2)), the frequency of hand mouthing (HM_x), the percent of the hand contacting the mouth (S_{HM}), the transfer efficiency of microbes between the hand and mouth (TE_{Hx}), and the time until hand washing (T_{HW}).

$$D_x = E_x \times HM_x \times S_{HM} \times TE_{Hx} \times T_{HW} \quad (3)$$

This residual exposure dose distribution for instrumental entry is proportional to the initial concentration of microbes in drain water (C_x) and the volume of one droplet of water, which was assumed to have a fixed volume of 0.05 mL.

$$R_x = C_x \times 0.05\text{mL} \quad (4)$$

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