PSI Health Impact Estimation Model for a Basic Care Package for People Living with HIV/AIDS (PLWHA)

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PSI shares its models with all interested individuals or organizations. Please note that the models are updated periodically based on the latest available epidemiological, demographic, intervention effectiveness, and utilization data. As a result, numbers used in this document should be considered illustrative only. They show how the model works, but they are likely to have changed since the time of writing.

For more information or the latest model updates, contact Hongmei Yang at hyang@psi.org.

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Introduction

Background

Population Services International (PSI) is a social marketing organization that promotes healthy behaviors in low-income and vulnerable populations. PSI has programs in 65 countries (www.psi.org) and covers a wide range of health areas. PSI uses the disability-adjusted life year (DALY) as the metric for measuring the health impact of interventions in health areas. A DALY model has been developed for each of PSI’s product/services and behavior change communications (BCC) interventions. The DALY model presented here is the Basic Care Package (BCP) DALY model for prevention of specific diseases and conditions observed among people living with HIV/AIDS (PLHWA) and members of their household.

The PSI basic care package provides a range of materials, medications, and information designed to enable people living with HIV/AIDS to improve their life situation and, by extension, that of the members of their household. The contents of the basic care package vary from country to country, but typically include the following four components:

1. Male condoms to prevent transmission of HIV to sexual partners and to prevent unwanted pregnancies that can result in higher rates of morbidity and mortality among women and young children;
2. One or two insecticide-treated mosquito nets (ITNs) or long-lasting insecticide-treated mosquito nets (LLINs) to prevent the spread of the mosquito-borne parasite that causes malaria;
3. Household water treatment products (chlorine tablets) to prevent diarrhea caused by contaminated drinking water in the household; and
4. Oral rehydration salts (ORS) to treat diarrhea.

BCPs are provided to people who test positive for HIV. PSI distributes BCPs directly through its counseling and testing centers; it also provides BCPs to public and private sector health facilities for distribution to their HIV-positive clients. BCPs are also distributed by community outreach workers and peer educators.

The BCP DALY model developed by PSI provides an estimate of DALYs averted per BCP distributed to persons living with HIV/AIDS (i.e., DALY coefficient). It will be used to measure the impact of social marketing programs that promote the distribution of BCPs to PLHWA. The purpose of this report is 1) to describe the principles and structure of a simple deterministic model (in Excel) that estimates the health impact of a BCP program on PLHWA in DALYs averted per package distributed, and 2) to identify the parameters and assumptions used in the model.
DALY Model for Basic Care Package (BCP) for People Living with HIV/AIDS (PLWHA)

Section 1: Principles and Structure of the Model

1.1 General Principles of the DALY Model

Because individuals can have multiple diseases and/or conditions (including pregnancy among females) at the same time, new cases averted in the BCP DALY model is the sum of all possible cases. However, an individual can die only once, even though s/he may have multiple infections and/or conditions at the time of death; therefore, cause of death needs to be considered when calculating deaths averted. Similarly, when calculating DALYs averted, it needs to be taken into account that death is a one-time event and people die of one cause.

Because BCPs are distributed to people who already have HIV/AIDS (PLWHA), the condoms included in the package are intended for the protection of the sexual partners of the person with HIV (whether male or female), not the person with HIV/AIDS. If the person with HIV/AIDS (index case) is a male, the condoms protect his sexual partners from both HIV infection and pregnancy. If the index case is female, the condoms included in the basic care package protect her male sexual partners from contracting HIV and protect her from becoming pregnant. The primary mosquito net (1 of 2) in the basic care package protects the index case from being infected with malaria while the additional net protects other household members. The water treatment tablets (chlorine) in the package protect all household members, including the PLWHA, from general diarrhea. The oral rehydration salts (ORS) in the package are effective in treating diarrhea when it occurs, thereby reducing the risk of death for the person with HIV/AIDS (index case).

In the BCP DALY model, if the person with HIV/AIDS (index case) is male, it is assumed that a proportion of his female sexual partners will contract HIV and become pregnant, and that these women may die either from pregnancy and/or delivery-related causes or from HIV/AIDS. Because deaths from pregnancy and/or delivery-related causes typically occur earlier than deaths from HIV/AIDS – assuming no antiretroviral treatment and that death occurs after 10 years with HIV and two additional years with AIDS – in the DALY model these women are considered to have died from pregnancy and/or delivery-related causes, not from HIV/AIDS. Therefore, these deaths are subtracted from HIV/AIDS deaths to avoid double counting.

In the BCP DALY model, if the person with HIV/AIDS (index case) is female it is assumed that a proportion of the women will become pregnant and contract malaria, and that these women may die either from pregnancy and/or delivery-related causes or from malaria. The model assumes that pregnant women die from pregnancy and/or delivery-related causes at age 27.4 years (17 years for women age 15-19, 25 years for those age 20-29, and 37 years for women age 30 and above). The model also assumes that PLWHA die from malaria at age 28. This assumption is based on death data from the DCCP (World Bank/WHO, 2006), which reports that for sub-Saharan Africa there were 20,000 malaria deaths in age group 15 to 29 and 21,000 malaria deaths in age group 30 to 44. Because deaths from pregnancy and/or delivery-related causes typically occur earlier than deaths from malaria, these women are considered to have died from pregnancy and/or delivery-related causes. Therefore, these deaths are subtracted from malaria deaths to avoid double counting.

The sources of information for the BCP DALY model (cases averted, deaths averted, and life expectancies for each disease or condition) are listed below in Table 1.
Table 1. BCP DALY model sources of information for cases averted, deaths averted, and life expectancy, male and female persons living with HIV/AIDS (PLWHA)

<table>
<thead>
<tr>
<th>PLWHA</th>
<th>Cases Averted: Sources</th>
<th>Deaths Averted: Sources</th>
<th>Life Expectancy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>HIV: Female partners</td>
<td>HIV: Female partners</td>
<td>81.25</td>
</tr>
<tr>
<td></td>
<td>Pregnancy: Female partners</td>
<td>Pregnancy: Female partners</td>
<td>81.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Subtract HIV infected female partners who die of pregnancy related conditions from HIV deaths to avoid double counting of death</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Malaria: index case &amp; other household members, if another net is provided</td>
<td>Malaria: index case &amp; other household members, if another net is provided</td>
<td>38 or 81.25</td>
</tr>
<tr>
<td></td>
<td>Diarrhea: all household members</td>
<td>Diarrhea: all household members</td>
<td>38 or 81.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ORS reducing diarrhea death: index case</td>
<td>38</td>
</tr>
<tr>
<td>Female</td>
<td>HIV: male partners</td>
<td>HIV: male partners</td>
<td>81.25</td>
</tr>
<tr>
<td></td>
<td>Pregnancy: index case</td>
<td>Pregnancy: index case</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Malaria: index case &amp; other household members, if another net is provided</td>
<td>Malaria: index case &amp; other household members, if another net is provided</td>
<td>38 or 81.25</td>
</tr>
<tr>
<td></td>
<td>Diarrhea: all household members</td>
<td>Diarrhea: all household members</td>
<td>38 or 81.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ORS reducing diarrhea death: index case</td>
<td>38</td>
</tr>
</tbody>
</table>

**Note:** A life expectancy of 38 years is calculated for people living with HIV/AIDS (PLWHA) assuming that PLWHAs get infected at age 26, live 10 years with HIV, and live another two years with AIDS, before dying.

### 1.2 General Structure of the DALY Model

Unlike other PSI DALY models, the BCP DALY model does not estimate burden of disease (BOD); this is because 1) the burden of disease for HIV, malaria, unwanted pregnancy, and diarrhea has been estimated by other PSI DALY models, and 2) the study population is a sub-population, not the general population. The BCP DALY model is designed to estimate the health impact of PSI’s BCP program on the target audience, people living with HIV/AIDS (PLWHA). Health impact is measured by the number of new infections averted, deaths averted, and DALYs averted per BCP distributed to PLWHA.
Because the contents of a basic care package provide protection against several diseases and/or conditions, PSI designed a DALY submodel for each item in the package that produces a health impact. The complete BCP DALY model consists of the following five components (submodels):

1. **HIV/AIDS submodel** – estimates the impact of male condoms in preventing HIV transmission to sexual partners of index case
2. **Family planning submodel** - estimates the impact of male condoms in preventing pregnancy-related maternal conditions and/or deaths, and in reducing deaths among children under five years attributed to improper birth spacing (i.e., preceding birth interval too short) (DaVanzo et al., 2004; Koenig et al., 1990; Makepeace & Pal, 2006; Rutstein, 2005)
3. **Malaria submodel** - estimates the impact of LLIN/ITNs in preventing index case and other household members from contracting malaria
4. **Diarrhea (water treatment) submodel** - estimates the impact of water treatment products (chlorine tablets and Aquatabs) in preventing general diarrhea among household members and PLWHA
5. **Diarrhea (ORS) submodel** – estimates the impact of ORS in treating diarrhea in PLWHA

The principles and structure of the math models are detailed below for each component (submodel).

### 1.3 Principles and Structure of the HIV/AIDS Submodel

The HIV/AIDS submodel is based on Bernoulli probability theory (Gray et al., 2001; Mastro et al., 1994; Satten et al., 1994). The probability of HIV transmission within a discordant partnership, $\lambda$, is equal to $1-(1-\gamma)^n$, where $\gamma$ refers to per-act infectivity of HIV during unprotected vaginal intercourse and $n$ represents the number of sexual contacts with each partner. This assumes that the probability of HIV transmission during each sexual contact is independent. A person who is HIV positive is $(1-p)$ likely to have sexual intercourse with a partner who is HIV negative, where $p$ represents the prevalence of HIV in the general adult population. Additionally, a person who is HIV positive is assumed to have, on average, $m$ sexual partners in a year. Therefore, the probability of HIV transmission from an HIV-positive person to all his/her sexual partners through heterosexual contact during the study period (one year) is modeled as $P = (1-p) \times \lambda \times m$. Substituting the $\lambda$ with the above expression results in the equation,

$$P = (1-p) \times (1-(1-\gamma)^n) \times m,$$

which shows that the probability of transmission through heterosexual contact is associated with both the number of sexual partners and the number of contacts with each partner. Because it is probable that these behaviors are affected by type of sexual partner, the equation is modified to consider three types of sexual partners: regular, casual, and commercial. (The partner categories need to be exclusive and exhaustive and can be modified at the country level to be culture- or context-specific.) The modified full equation estimating the probability of infection through heterosexual contact is expressed as:

$$P = \sum_{i=regular}^{casual,commercial} (1-p_i) \times (1-(1-\gamma)^n) \times m_i$$
A number of factors may influence the per-act infectivity of HIV transmission including STD infection status within the partnership, HIV infection stage of the infected partner, baseline circumcision status of the male partner, and condom use during sexual intercourse. Per-act infectivity is therefore adjusted by considering the effects of such cofactors in various probabilistic combinations that a person who is HIV positive may encounter while having sexual intercourse with his/her sexual partners who are HIV negative.

Because of the diversity of sexual behaviors associated with HIV transmission during heterosexual intercourse, the study population (i.e., PLWHA) is divided into five risk groups (population categories) defined by the total number of partners in the past year. The cut-off points for the five risk groups were determined based on the distribution of the data. The health impact is estimated for each of the risk groups. The five risk groups are as follows:

- Low Risk (total partners in the past year = 1)
- Medium Risk (total partners in the past year = 2)
- High Risk (total partners in the past year = 3-4)
- Very High Risk (total partners in the past year = 5-9)
- Highest Risk (total partners in the past year ≥ 10)

The HIV/AIDS submodel is designed to estimate the reduction in risk of HIV transmission that occurs as a result of implementation of the PSI BCP program. For individuals in each of the five risk groups, the model runs a scenario in which the individual has \( x \) partners, \( y \) sexual contacts with each type of partner, and \( z \) sexual contacts protected by a condom.
The epidemic and sexual behavioral data remain the same in both scenarios. The condom use parameter varies depending on whether or not the PSI BCP program has been implemented. The BCP program aims to increase the percentage of sexual contacts protected by a condom (not necessarily a PSI branded condom), but the model measures the incremental impact of PSI condoms – the net increase in use of PSI condoms post-intervention compared with a baseline level of use. The likelihood of HIV transmission within each of the five risk groups (with the PSI BCP program present) is subtracted from the likelihood of HIV transmission (with the PSI BCP program absent) to obtain an estimate of reduced risk of HIV transmission per person per year. The number of PSI condoms used per person per year is estimated based on sexual activity and data on use of PSI condoms. Dividing the reduction in risk of HIV transmission per person per year by the number of PSI condoms used per person per year yields an estimated number of new infections averted per condom per year. For each risk group, the HIV/AIDS model runs as shown above in Figure 1:

The estimated number of new infections averted per condom per year is translated into an equivalent figure measured in DALYs averted per condom per year. In this step, the model assumes that sexual partners of PLWHA contract HIV at age 26. On average, an infected person lives 10 years with HIV and another two years with AIDS before death. This means that an infected partner loses 19.3 healthy life years, which are the sum of years of life lost due to diseases (i.e., being sick and disabled during the 10 years of HIV and 2 years of AIDS)
and the years of life lost due to premature death at age 38 (i.e., 43.25 years of life lost, discounted at 3% for future years), compared with people who are HIV negative.

Parameters in the HIV/AIDS submodel

The parameters in the HIV/AIDS submodel fall into three main categories: epidemic parameters, sexual behavioral parameters, and condom use parameters. Epidemic parameters include the male circumcision rate and the prevalence of HIV and STD in the population. Sexual behavioral parameters include the number of sexual partners in the past year, by type, and the number of sexual contacts with each partner. The condom use parameter is the percentage of sexual contacts with each partner that were protected by a condom.

Sexual behavioral data are not readily available for many countries so defaults were developed for the DALY model. The default values were obtained by combining data from three studies (PSI TRaC surveys) of women and men age 15 to 49 in Angola, Zambia, and Zimbabwe.

Similarly, epidemic data on HIV prevalence among commercial partners (data from sex workers are used as a proxy) and the prevalence of STDs in both the adult population and the commercial sex partner population are not readily available for most PSI countries. Therefore, functional relationships between these populations and HIV prevalence in the adult population, for use in the DALY model, were developed based on existing data. The data used for developing the function for HIV prevalence among commercial sex partners came from the WHO/UNAIDS Epidemiological Fact Sheets on HIV/AIDS and STIs (2007). Ratios of general adult to sex worker HIV prevalence rates were calculated for all countries that had data available. Then the ratios were used to simulate different functions according to WHO regions. The function with the best fit was chosen for each region. The function for the sub-Saharan region fit well the data reported in the article by Buve et al. (2001).

The function for HIV prevalence among commercial sex partners is shown below by region, where \( R_g \) is HIV prevalence in the adult population and \( R_c \) is HIV prevalence among female sex workers (FSWs):

- Sub-Saharan countries, \( R_c = R_g \times \left(0.625 + \frac{35.987}{R_g \times 100}\right) \);
- Asian countries, \( R_c = R_g \times 17 \);
- Latin America/Caribbean countries, \( R_c = R_g \times (2.198 + 2.715 \times R_g \times 100) \)

The data used to develop the function for STD prevalence in the general adult population include HIV prevalence in the general population by region (UNAIDS/WHO, 2006) and the STD prevalence rate for the general population by region (WHO, 2001). Ratios of STD to HIV were calculated for all regions. The ratios were then used to simulate different functions. The function with the best fit was chosen and is shown below, where \( R_g \) is HIV prevalence in the adult population and \( S_g \) is STD prevalence in the adult population:

\[
S_g = R_g \times 4.6 \times (100 \times R_g)^{-0.382}
\]

STD prevalence among commercial sex partners is set at 80% for PSI platforms lacking available data. For more information about parameter values and data sources, see Section 2.
1.4 Principles and Structure of the Family Planning Submodel

In the family planning submodel, the benefits of condom use are not limited to family planning (preventing unwanted pregnancies), they also have implications for the well-being of mothers and children under five years. The family planning submodel takes into consideration the health benefits of fewer pregnancies for mothers and the benefits of longer birth intervals on child survival (DaVanzo et al., 2004; Koenig et al., 1990; Makepeace & Pal, 2006; Rutstein, 2005).

The condom family planning submodel estimates the reduction in risk of health events associated with pregnancy and child birth by considering the burden of morbidity and mortality associated with pregnancy. It also uses multiple DHS data sets in a functional correlation model to examine the relationship between preceding birth interval (PBI) and child mortality and incorporates the impact of contraception (condom use) on the length of PBI.

The indicator, couple-years of protection (CYP), is a commonly used measure in family planning interventions. In the PSI family planning submodel, number of condoms used is first translated into CYP (i.e., years of effective contraceptive protection). This is done by estimating the utilization level of condoms, incorporating estimated wastage level, and protective efficacy, to obtain an index of units of condoms that is equivalent to one couple-year of protection, or 100% protection from pregnancy for one year.

CYP is then used with population-level morbidity and mortality rates from maternal conditions and complications to estimate the unwanted pregnancies averted and deaths averted which, in turn, are translated into DALYs. In addition, CYP is used to estimate a proportion shift in the average birth interval across subgroups defined by birth interval (<18 mo, 18-23 mo, 24-29 mo, 30-35 mo, 36 mo+). The distribution of birth intervals by subgroup is interpolated from DHS data for multiple surveys across a specific region (www.measuredhs.com). The results are used as a proxy for the countries within that region (Tanzania data for SSA, Vietnam data for South East Asia, and Uzbekistan data for Central Asia). Once the shift in the birth intervals is estimated, the data can be combined with country-specific population data and the function between birth intervals and the odds-ratio of death among children under five, to estimate the reduction in the absolute number of deaths in that age group due to changes in the average length of the birth interval (DaVanzo et al., 2004; Koenig et al., 1990; Makepeace and Pal, 2006; Rutstein, 2005).
EXAMPLE: Estimating the impact of selling 50 million condoms in rural Tanzania on under-five mortality

1. Calculate the increase in birth spacing (months)
   - Selling 50,000,000 male condoms in Tanzania yields 336,458 CYP
   - Total female population of reproductive age (15-44 years) is 8,586,007
   - Increase in birth spacing: 12 * 336,458 / 8,586,007 = 0.47 months

2. Calculate under-5 mortality rates by birth spacing intervals
   Using data from the 2004-05 DHS survey in Tanzania, obtain the following:
   - Distribution of birth intervals (in months) among rural reproductive women in Tanzania
   - Childhood mortality rates by birth spacing interval groups (<18, 18 to 23, 24 to 29, 30 to 35, 36 to 41, 42 to 47, 48 to 53, 54 to 59, 60+ months)

3. Estimate the number of births shifting to longer birth spacing interval groups
   - Selling 50,000,000 male condoms in Tanzania gives a birth interval of ΔB=0.47 months.
   - 0.47 * number of cases in the last category of each birth spacing group (<18 months, 18 to 23 months, 24 to 29 months, and 30 to 35 months) will move some cases to a new group

4. Calculate the total number of deaths averted
   Deaths averted = (the number of cases that change group) × (the difference in the childhood mortality rates)
   Total number of deaths averted among children under five years is 32.5.

This survey-based total is then divided by the number of births in the rural survey population (24,970), to obtain an estimate of under-five deaths averted per succeeding birth, which is 1.3*10⁻³.

Under-5 deaths averted per condom are then calculated using the following expression:

Under-5 deaths averted per condom = CYP per condom * 2 * rural Crude Birth Rate * 1.3*10⁻³.

1.5 Principles and Structure of the Malaria Submodel

The malaria submodel estimates the impact of using mosquito nets for sleeping on the likelihood of specific malaria disease outcomes: episodes, severe episodes, and death. Usually, two mosquito nets are provided in
each basic care package (BCP). One net is assumed to be used by the person with HIV/AIDS and the other is used by household members. The “consumption” of a mosquito net by a household is defined by its utilization (i.e., the number of people who slept under a net). The primary net is assumed to cover the person with HIV/AIDS.

Data from PSI and other surveys on the use of mosquito nets for malaria prevention were used to develop a proxy table on the use of mosquito nets by the average household. It should be noted that there is considerable variance in this parameter although there is currently only one linear form for the data in the model. The intention is to incorporate this variance into the model in two ways: first, the empirical variance will be incorporated into the stochastic version of the model later this year; second, individual countries will begin collecting their own survey data on household use of mosquito nets, which will be fed directly into the model. These activities will enable production of regional tables on mosquito net utilization (at a minimum) and, eventually, country-specific tables.

The next stage is to incorporate empirical evidence of the protective efficacy of the use of mosquito nets as bed nets. This information is drawn from the Cochrane Review referenced in the Disease Control Priority Project final document (Lengeler, 2004). The document provides estimates of the protective efficacy of treated mosquito nets across regions. The data are then incorporated into the model alongside the estimated burden of malaria, in terms of episodes of disease, episodes of severe disease, and death from malaria. These intermediate outcomes are then translated into DALY estimates. Finally, the effective lifespan of a mosquito net is incorporated into the model. For example, long-lasting, insecticide-treated nets (LLINs) have a lifespan of three years, compared with regular insecticide-treated nets (ITNs) that have a lifespan of two years.

1.6 Principles and Structure of the Diarrhea Submodel

The diarrhea submodel estimates the impact of point-of-use water treatment products (chlorine tablets) on the likelihood of two disease outcomes: diarrhea episodes and death.

Household-years-of-protection (HYP) per unit of product was estimated as follows:

\[
\text{Liter treated per unit product/[(household size) * (per capita usage per day) * 365].}
\]

Most studies report that in households without piped water, 3 liters of water per capita per day is the average (mean) consumption of water for drinking and cooking. Because the disease burden (diarrhea morbidity and mortality rates) is different across age groups, household members are broken down into three age groups: 0-4 years, 5-14 years, and 15+ years. The number of people in each age group who are protected by using per unit product is then estimated by multiplying the household-years-of-protection (HYP) per unit of product by the household size and by the proportion of age groups in the household. It is necessary to use generalized demographic inputs for this calculation because no information was available indicating that households that treat their water (or use PSI products) are demographically different from those that do not.

The number of people in each age group who will benefit from treated water for that year is then translated into an impact on the burden of diarrheal disease by the protective efficacy of the various treatments. The protective efficacy associated with use of chlorine tablets was obtained from the most recent Cochrane Review (Clasen et al., 2007). These studies report estimates of protective efficacy from episodes of diarrhea disease and death from diarrhea for treated and untreated water.
When oral rehydration salts (ORS) are included in the basic care package for PLWHA, the impact of treating diarrhea with ORS is estimated as well. ORS is assumed to be consumed by PLWHA when they develop diarrhea. ORS does not prevent the episode of diarrhea but it reduces the likelihood of death from diarrhea. The person-years-of-protection (PYP) per unit of ORS — the number of episodes of diarrhea that benefit from treatment with ORS — was estimated by multiplying diarrhea episode data (morbidity) by protective efficacy and then dividing by units of ORS needed per episode. The number of units of ORS needed per episode is assumed to be two, although this figure varies by cause of the diarrhea and by geographical location (primarily due to the abundance of co-morbid events). Protective efficacy was broken into two component parts, adherence to therapy and clinical efficacy, because some patients may not be compliant with treatment. Diarrhea deaths averted among people living with HIV/AIDS was estimated taking into consideration person-years-of-protection (PYP) and the likelihood that a case will result in death if left untreated (see Section 3 for presentation of the formulas).

1.7 Interaction between Diseases

Studies have shown that coinfection with HIV and malaria can accelerate the spread of both diseases (Abu-Raddad et al., 2006). Malaria infection was found to have an impact on transmission of HIV but not on progression of HIV (Whitworth & Hewitt, 2005). Acute malaria infection increases the HIV viral load by 0.25 log copies per milliliter for 42 days (Abu-Raddad et al., 2006; Kublin et al., 2005; Whitworth & Hewitt, 2005). The heightened viral load of HIV is associated with increased probability of transmission of the virus. Studies have reported that a log (base 10) rise in viral load leads to 2.45 units of increase in per-act infectivity of HIV (Quinn et al., 2000; Abu-Raddad et al., 2006).

People who are HIV positive are more likely to show clinical symptoms once they are infected with malaria; however, there is no evidence that HIV infection increases the incidence of severe malaria or malaria mortality in areas where malaria is endemic (stable) (i.e., transmission of malaria over the years is high without marked fluctuation, although seasonal fluctuations occur). (Korenromp et al., 2005; Abu-Raddad et al., 2006; Herrero et al., 2007; Hewitt et al., 2006; Whitworth & Hewitt, 2005).

Studies on the interaction of HIV and diarrhea and the interaction of malaria and diarrhea are limited, so these interactions are not considered in the modeling process presented here.
Section 2: Parameters and Data Sources

This section presents information on the deterministic data points for the parameters used in the BCP DALY model, and their sources.

2.1 Parameters in the HIV/AIDS Submodel

2.1.1 Risk group sexual activity data

Sexual behavior data shown in the table below include the number of sexual partners in the past year, by type, the number of sexual contacts with each partner, and the proportion of each of the five risk groups. The results were determined using the combined data from three PSI TRaC surveys of the general population age 15-49 in Angola, Zambia and Zimbabwe.

<table>
<thead>
<tr>
<th>Percent sexually active</th>
<th>Risk group</th>
<th>Percent among those sexually active</th>
<th>Type of partner</th>
<th>Average no. of partners/year</th>
<th>Average no. of sexual contacts/partner/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>82.2% (5297/7135)</td>
<td>Low risk (1 partner)</td>
<td>77.3%</td>
<td>regular</td>
<td>0.854</td>
<td>58.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>casual</td>
<td>0.139</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>commercial</td>
<td>0.0072</td>
<td>0</td>
</tr>
<tr>
<td>11.2%</td>
<td>Med risk (2 partners)</td>
<td>11.2%</td>
<td>regular</td>
<td>0.958</td>
<td>70.18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>casual</td>
<td>0.931</td>
<td>40.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>commercial</td>
<td>0.1112</td>
<td>24</td>
</tr>
<tr>
<td>5.3%</td>
<td>High risk (3-4 partners)</td>
<td>5.3%</td>
<td>regular</td>
<td>0.997</td>
<td>69.78</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>casual</td>
<td>1.763</td>
<td>25.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>commercial</td>
<td>0.5015</td>
<td>24</td>
</tr>
<tr>
<td>3.7%</td>
<td>Very high risk (5-9 partners)</td>
<td>3.7%</td>
<td>regular</td>
<td>1.054</td>
<td>55.89</td>
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<tr>
<td></td>
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<td>casual</td>
<td>2.769</td>
<td>21.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>commercial</td>
<td>2.269</td>
<td>25.2</td>
</tr>
<tr>
<td>2.5%</td>
<td>Highest risk (10+ partners)</td>
<td>2.5%</td>
<td>regular</td>
<td>4.092</td>
<td>31.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>casual</td>
<td>4.74</td>
<td>18.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>commercial</td>
<td>9.315</td>
<td>36</td>
</tr>
</tbody>
</table>
Baseline condom usage

Condom use rates by type of partner are as follows: regular partner (8%), casual partner (32%), and commercial relationship (48%). These rates are obtained based on available DHS data (www.measuredhs.com/hivdata/) and apply to all PSI countries.

2.1.2 Epidemic data


Male circumcision rate

Male circumcision rates were obtained from Williams et al., (2006). The male circumcision rate in Swaziland (8.2%) is obtained from 2006/2007 DHS data.

2.1.3 Biological information

In Europe and North America, studies of serodiscordant couples have typically reported a per-act infectivity of 0.001 (range: 0.0001-0.0015) (Boily et al., 2009; De Vincenzi, 1994; Downs and De Vincenzi, 1996; Leynaert et al., 1998; Peterman et al., 1988; Royce et al., 1997; Wiley et al., 1989). A study of monogamous couples in Rakai, Uganda found that the average per-act infectivity was 0.0011 (Gray et al., 2001).

Therefore, 0.0005 was selected as the transmission probability per sexual contact during the asymptomatic stage of HIV, with both partners negative for other STIs; and, 0.0047 was selected as the transmission probability per sexual contact during the acute infection stage of HIV, with both partners negative for other STIs (Hollingsworth et al., 2008; Pilcher et al., 2004; Wawer et al., 2005).

The effect of STD infection on HIV transmission is 5 (Rottingen et al., 2001 and Satten et al., 1994)

2.1.4 Disease-related information

Acute period of infection: 54 days (Pilcher et al., 2004)

Duration of HIV: 10 years; YLD weight: 0.135 (World Bank/WHO, 2006)

Duration of AIDS: 2 years; YLD weight: 0.505 (World Bank/WHO, 2006)

Age at infection: 26 years

Life expectancy: 81.25 years (World Bank/WHO, 2006)
2.1.5 Efficacy of product/services

Protective efficacy of condoms: 90% (Pinkerton et al., 1997)

Protective efficacy of male circumcision: 60% (Auvert et al., 2005; Bailey et al., 2007; Gray et al., 2007)

2.2 Parameters in the Family Planning Submodel

Demographic data by country (FP v50)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Kenya</th>
<th>Ethiopia</th>
<th>Uganda</th>
<th>Cote d’Ivoire</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Fertility Rate Rural (per 1000 live)</td>
<td>169.57</td>
<td>186.52</td>
<td>231.74</td>
<td>174.09</td>
</tr>
<tr>
<td>General Fertility Rate Urban (per 1000 live)</td>
<td>130.43</td>
<td>143.48</td>
<td>178.26</td>
<td>133.91</td>
</tr>
<tr>
<td>Crude Birth Rate Rural (per 1000 people)</td>
<td>44.09</td>
<td>46.35</td>
<td>53.13</td>
<td>42.96</td>
</tr>
<tr>
<td>Crude Birth Rate Urban (per 1000 people)</td>
<td>33.91</td>
<td>35.65</td>
<td>40.87</td>
<td>33.04</td>
</tr>
<tr>
<td>Maternal mortality rates rural</td>
<td>0.0098</td>
<td>0.0098</td>
<td>0.0098</td>
<td>0.0098</td>
</tr>
<tr>
<td>Maternal mortality rates urban</td>
<td>0.004</td>
<td>0.0098</td>
<td>0.00393</td>
<td>0.0098</td>
</tr>
</tbody>
</table>

Odds ratios for deaths among children under five years by preceding birth interval subgroup (months), according to region (Rutstein, 2005)

<table>
<thead>
<tr>
<th>Region</th>
<th>&lt; 18</th>
<th>19-23</th>
<th>24-29</th>
<th>30-35</th>
<th>36-41</th>
<th>42+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-Saharan Africa</td>
<td>2.99</td>
<td>1.83</td>
<td>1.65</td>
<td>1.36</td>
<td>1</td>
<td>0.97</td>
</tr>
<tr>
<td>South Asia</td>
<td>2.64</td>
<td>1.56</td>
<td>1.27</td>
<td>1.13</td>
<td>1</td>
<td>0.86</td>
</tr>
<tr>
<td>East Asia &amp; Pacific</td>
<td>2.37</td>
<td>1.64</td>
<td>1.57</td>
<td>1.38</td>
<td>1</td>
<td>0.89</td>
</tr>
<tr>
<td>Latin &amp; Central America</td>
<td>3.02</td>
<td>2.11</td>
<td>1.68</td>
<td>1.29</td>
<td>1</td>
<td>0.87</td>
</tr>
<tr>
<td>Former Soviet States</td>
<td>2.21</td>
<td>1.34</td>
<td>1.12</td>
<td>1.08</td>
<td>1</td>
<td>1.01</td>
</tr>
</tbody>
</table>

Product utilization (units required for full CYP) & Protective efficacy (Fu et al., 1999)

<table>
<thead>
<tr>
<th>Product</th>
<th>Units required for CYP</th>
<th>Protective efficacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condoms</td>
<td>114</td>
<td>88.65%</td>
</tr>
</tbody>
</table>
2.3 Parameters in the Malaria Submodel

Epidemiology by country (malaria v52; Hay et al., 2004; Snow et al., 2003; Snow et al., 2005; Smith et al., 2006).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Kenya</th>
<th>Ethiopia</th>
<th>Uganda</th>
<th>Cote d'Ivoire</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rural</td>
<td>Urban</td>
<td>Rural</td>
<td>Urban</td>
</tr>
<tr>
<td>morbidity rate 0-4</td>
<td>2.16</td>
<td>1.55</td>
<td>0.88</td>
<td>0.63</td>
</tr>
<tr>
<td>morbidity rate 5-14</td>
<td>0.34</td>
<td>0.24</td>
<td>0.14</td>
<td>0.0987</td>
</tr>
<tr>
<td>morbidity rate over 15</td>
<td>0.34</td>
<td>0.24</td>
<td>0.14</td>
<td>0.0987</td>
</tr>
<tr>
<td>mortality rate 0-4</td>
<td>0.0136</td>
<td>0.00978</td>
<td>0.00765</td>
<td>0.0055</td>
</tr>
<tr>
<td>mortality rate 5-14</td>
<td>0.000153</td>
<td>0.00011</td>
<td>0.000086</td>
<td>6.18E-05</td>
</tr>
<tr>
<td>mortality rate over 15</td>
<td>0.000153</td>
<td>0.00011</td>
<td>0.000086</td>
<td>6.18E-05</td>
</tr>
<tr>
<td>mortality rate preg women</td>
<td>0.00143</td>
<td>0.00103</td>
<td>0.00143</td>
<td>0.00103</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DALY weights (World Bank/WHO, 2006)</th>
<th>Length of Illness (yrs)</th>
<th>YLD Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Episode of malaria</td>
<td>0.03</td>
<td>0.105</td>
</tr>
<tr>
<td>Severe episode of malaria</td>
<td>0.08</td>
<td>0.611</td>
</tr>
</tbody>
</table>

Deaths from malaria (PSI default global estimates); Lifespan (yrs): 81.25 (World Bank/WHO, 2006)

<table>
<thead>
<tr>
<th>Age at death (yrs)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0-4 yrs</td>
<td>1.8</td>
</tr>
<tr>
<td>5-14 yrs</td>
<td>8.4</td>
</tr>
<tr>
<td>15+ yrs</td>
<td>28</td>
</tr>
</tbody>
</table>

Protective efficacy of insecticide-treated nets (Lengeler, 2004)

<table>
<thead>
<tr>
<th>Product</th>
<th>ITN versus no net</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITN</td>
<td>50%</td>
</tr>
</tbody>
</table>
Utilization of insecticide-treated nets (PSI survey)

<table>
<thead>
<tr>
<th>Age</th>
<th>Number of people per net</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-4 yrs</td>
<td>0.47</td>
</tr>
<tr>
<td>5-14 yrs</td>
<td>0.19</td>
</tr>
<tr>
<td>15+ yrs (including pregnant women)</td>
<td>0.76</td>
</tr>
</tbody>
</table>

2.4 Parameters in the Diarrhea Submodel

Epidemiology by country for diarrheal disease (diarrhea v28; WHO sources including “World Health Statistics 2007”)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Kenya</th>
<th>Ethiopia</th>
<th>Uganda</th>
<th>Cote d'Ivoire</th>
</tr>
</thead>
<tbody>
<tr>
<td>morbidity rate 0-4</td>
<td>4.65661</td>
<td>4.24488</td>
<td>4.41791</td>
<td>3.04056</td>
</tr>
<tr>
<td>morbidity rate 5-14</td>
<td>0.26022</td>
<td>0.23721</td>
<td>0.24688</td>
<td>0.24688</td>
</tr>
<tr>
<td>morbidity rate over 15</td>
<td>0.04109</td>
<td>0.03745</td>
<td>0.03898</td>
<td>0.03898</td>
</tr>
<tr>
<td>mortality rate 0-4</td>
<td>0.00587</td>
<td>0.00769</td>
<td>0.00692</td>
<td>0.00956</td>
</tr>
<tr>
<td>mortality rate 5-14</td>
<td>0.00025</td>
<td>0.00022</td>
<td>0.00023</td>
<td>0.00023</td>
</tr>
<tr>
<td>mortality rate over 15</td>
<td>0.00005</td>
<td>0.00005</td>
<td>0.00005</td>
<td>0.00005</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DALY weightings (World Bank/WHO, 2006)</th>
<th>Length of Illness (yrs)</th>
<th>YLD Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Episode of diarrhea</td>
<td>0.03</td>
<td>0.105</td>
</tr>
</tbody>
</table>

Death from diarrheal disease (Lifespan (yrs) 81.25)

<table>
<thead>
<tr>
<th>Age at death (yrs):</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-4 yrs</td>
</tr>
<tr>
<td>5-14 yrs</td>
</tr>
<tr>
<td>15+ yrs</td>
</tr>
</tbody>
</table>

Protective efficacy of chlorine (Clasen et al., 2007; Gavin et al., 1996): 46%

Protective efficacy of ORS (from death): 90%

Water usage (Tumwine et al., 2002; Thompson et al., 2000)

Liters of water per person per day for drinking and cooking in households (HH) with unpiped water: 3
### Regional water usage by age group (%)

<table>
<thead>
<tr>
<th>Region</th>
<th>0-4 yrs</th>
<th>5-14 yrs</th>
<th>15+ yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-Saharan Africa</td>
<td>16.0</td>
<td>28.1</td>
<td>55.9</td>
</tr>
<tr>
<td>South Asia</td>
<td>14.0</td>
<td>25.9</td>
<td>60.1</td>
</tr>
<tr>
<td>East Asia &amp; Pacific</td>
<td>10.4</td>
<td>22.6</td>
<td>67.0</td>
</tr>
<tr>
<td>Latin &amp; Central America</td>
<td>12.6</td>
<td>27.4</td>
<td>60.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product</th>
<th>Liters of water treated per unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waterguard C</td>
<td>1000</td>
</tr>
<tr>
<td>Pur</td>
<td>10</td>
</tr>
<tr>
<td>Aquatabs</td>
<td>20</td>
</tr>
</tbody>
</table>
Section 3: Selected Formulas in the Excel Model

3.1 HIV/AIDS Submodel

Columns M and N: probability of transmission of HIV from PLWHA to their sexual partners (with and without PSI BCP program):

\[
\text{Probability of transmission of HIV to HIV negative sexual partners} = \sum_{i=\text{reg, cas, com}} \left( (1 - p_{\text{hiv, partner}, i}) \times \left( 1 - \text{semi}_i \times (1 - PE_{\text{cdm}, i}) \right) \times \left( 1 - \text{semi}_i \times (1 - \text{act}_i) \right) \right) \times (\# \text{partners}_i)
\]

Where,

\[i = \text{reg, cas, com}: \text{Regular, casual, or commercial partners}\]
\[\% \text{cdm}_i: \text{Percentage of sex with regular (or casual or commercial) partners that were protected by a condom}\]
\[PE_{\text{cdm}, i}: \text{Protective efficacy of male condoms}\]
\[\text{act}_i: \text{Average number of sexual contacts with regular (or casual or commercial) partners in the past year}\]
\[\# \text{partners}_i: \text{Average number sexual partner by type (regular, casual or commercial) in the past year}\]
\[\text{semi}_i (i.e., \text{Column L}) \text{ refers to intermediate step of calculation. It is calculated as below:}\]

\[
\text{semi}_i = \left[ \left( p_{\text{std, partner}_i} \times Y_{\text{no, std}} \times E_{\text{std}} + \left( 1 - p_{\text{std, partner}_i} \right) \times Y_{\text{no, std}} \right) \times \left( 1 - \frac{D_{\text{acute}}}{365 + D_{\text{HIV/AIDS}}} \right) \right] + \left( p_{\text{std, partner}_i} \times Y_{\text{win, std, partner}_i} \times E_{\text{std}} + \left( 1 - p_{\text{std, partner}_i} \right) \times Y_{\text{win, std, partner}_i} \times \left( 1 - \% \text{MC} \times PE_{\text{mc}} \right) \right) \times \left( 1 - \% \text{MC} \times PE_{\text{mc}} \right)
\]

Where,

\[p_{\text{std, partner}}: \text{STD prevalence among partners}\]
\[Y_{\text{no, std}}: \text{Per-act transmission probability when neither partner has STD}\]
\[E_{\text{std}}: \text{Effect of STD infection on HIV transmission probability, which equals 5}\]
\[D_{\text{acute}}: \text{Duration of HIV acute infection stage, which is assumed to be 54 days}\]
\[D_{\text{HIV/AIDS}}: \text{Duration of HIV/AIDS infection, which is assumed to be 12 years}\]
\[Y_{\text{win, std, partner}}: \text{Per-act transmission probability when neither partner has STD but the infected female partner is in acute stage of HIV infection}\]
\[\% \text{MC}: \text{Baseline male circumcision rate (i.e., MC rate when there is no PSI NMC program)}\]
\[PE_{\text{mc}}: \text{Protective efficacy of male circumcision}\]

Column R: New infections averted (NIA) after considering wastage:

\[
\text{NIA} = \frac{\text{Reduction in risk of transmission}}{\# \text{PSI condoms used per person per year} \times (1 - \text{condom wastage rate})}
\]

3.2 Family Planning Submodel

Column F: Pregnancies averted per condom:

\[
Pregnancies \text{ averted per condom} = (CYP \text{ per condom}) \times (\text{age group splits}) \times (\text{general fertility rate by age groups}) \times (\text{pregnancy to live birth ratio})
\]
Column W: Child-under-five (CUS) deaths averted per condom:

\[ \text{CUS deaths averted} = (\text{CYP per condom}) \times 2 \times (\text{crude birth rate}) \times (\text{CUS death averted per succeeding birth}) \]

### 3.3 Malaria Submodel

Column H: Episodes averted per LLIN:

\[ \text{Episodes averted per LLIN} = (\# \text{ people slept under a net by population subgroups}) \times (\text{morbidity rate by subgroups}) \times (\text{effect of HIV on incidence of clinical malaria, if the subgroup is PLWHA}) \times (\text{protective efficacy of LLIN}) \times (\# \text{ of protective years of a LLIN, discounted at } 3\%) \times (1 - \text{wastage rate}) \]

### 3.4 Diarrhea Submodel

Column H: Episodes averted per unit of water treatment product:

\[ \text{Episodes averted per unit water treatment product} = (\text{household year of protection}) \times (\text{household size}) \times (\text{proportion of different age groups in a household}) \times (\text{morbidity rate by age group}) \times (\text{protective efficacy of water treatment product}) \times (1 - \text{wastage rate}) \]

Column I: Deaths averted per unit of ORS treatment:

\[ \text{Deaths averted per unit of ORS} = ((\text{diarrhea morbidity rate among PLWHA}) \times (\text{efficacy of ORS for preventing diarrhea death}) \times (1 - \text{wastage rate})) / (\text{number of units needed per year}) \]

### 3.5 HIV and Malaria Coinfection

Coinfection with malaria affects the per-act infectivity of HIV while PLWHA are in an acute episode of malaria. However, acute infection with malaria has no effect on the progression of HIV. The effect of acute malaria infection on HIV transmission will change the formula for \( S_{\text{emi}} \) to the following:

\[ S_{\text{emi}}' = S_{\text{emi}} \times (1 + \text{increased HIV viral load in log copies} \times \text{Relative risk of HIV per act infectivity per log rise in viral load}) \]

New HIV infections averted (NIA) when infected people (PLWHA) develop malaria:

\[ \text{NIA coefficient} = \text{Duration of increased viral load} \times \text{SUM}[\text{NIA coefficient while in acute malaria infection, by risk group}] \times (\text{proportion of PSI condoms used by risk group}) + (1 - \text{Duration of increased viral load}) \times \text{SUM}[\text{NIA coefficient while not in acute malaria infection, by risk group}] \times (\text{proportion of PSI condoms used by risk group}) \]

The effect of HIV infection on malaria is shown in the formula in the Section 3.3.
Section 4: Limitations of the BCP DALY Model for PLWHAs

1. The model is a simple deterministic model. It does not consider factors such as the viral load in the population. It also does not synergise the impact of a product across diseases. Taking condoms as an example, the model is designed to measure the health impact of condoms in preventing the transmission of HIV. The benefits of condoms in preventing the transmission of STIs and some cancers are not considered.

2. Health impact is calculated based on the number of primary infections averted during the 12-month period following the intervention. It does not include any secondary infections averted (or potential subsequent infections averted).

3. In the HIV submodel, the study population is grouped into five risk groups based on a single indicator of sexual behavior, i.e., the number of sexual partners in the past year. Because of the complexity of human sexual behavior, one parameter may not be sufficient to obtain a satisfactory risk profile of the study population.

4. The sexual behavior data used in the HIV submodel have necessarily been summarized (e.g., means) for use in the model. Summarized data inevitably loses some information. Most important for the model, many sexual behavior data are skewed. For this reason, the means may not be a good statistic to use in these cases.

5. The sexual behavior data in the HIV submodel are from a combined dataset (three African studies) covering just one region. Because of this geographic limitation, the data may not be applicable to countries in other regions.

6. STD prevalence rates among general population in the HIV submodel were calculated based on formulas of HIV prevalence in the general population of that region.

7. The coinfection effect between HIV and diarrhea cannot be easily quantified; therefore, it is not considered in the modeling.

8. In the diarrhea submodel, the population is broken down into just three age groups (0-4 yrs, 5-14 yrs, and 15+ yrs) and there is no group for the elderly. This is partly because PSI’s diarrhea programs focus mainly on children but also because parameter values are difficult to obtain for the elderly in developing countries.

9. In the family planning submodel, the relationship between preceding birth interval and under-five mortality rate is determined based on DHS surveys in three countries (in three regions). The relationship is then used to proxy relationships in other countries in the three regions.
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