Zinc deficiency and DALYs in India: impact assessment and economic analyses [*]

Alexander J. Stein, Matin Qaim and Penelope Nestel

Abstract

Although less obvious than outright lack of sufficient food, micronutrient malnutrition represents an economic and public health problem in many countries. Over the last years zinc deficiency has emerged as another major micronutrient deficiency, with a large proportion of the population being at risk, especially in the developing world. However, simple quantification of the number of people who suffer from a condition fails to take account of the depth of the problem. For comparison, monitoring or impact assessment purposes as well as cost-effectiveness or more general economic analyses, the health loss of a condition needs to be measured in a more comprehensive index.

In this chapter the concept of disability-adjusted life years (DALYs) is explained and a framework for its application to zinc deficiency is provided. DALYs were developed by the World Bank in collaboration with the WHO and are today used by many relevant organizations and for analyses in very different fields, in particular at the global level or in developing countries. By weighting the loss of an individual's functioning due to ill health – relative to death and complete health – DALYs allow measuring morbidity and mortality in a single index that can be aggregated and compared across different conditions. The methodology is explained and discussed, and general data and parameters to calculate the loss of DALYs due to zinc deficiency are reported for the example of India.

Summary points

- Zinc deficiency is a recognized public health problem in India and many other developing countries.
- Zinc deficiency is among the top five risk factors for the loss of healthy live in developing countries with high mortality rates.
- Zinc deficiency causes diarrhea, pneumonia and stunting in children under five years old; it also results in death.
- Disability-adjusted life years (DALYs) are a major unit of measurement in health economics.
- One DALY lost is equivalent to the loss of one year of healthy life.
- DALYs are units of ill health that measure the health loss due to both mortality and morbidity.
- DALYs capture both the extent and severity of a disease.
- DALYs allow summing up the burdens to society of different diseases.
- DALYs can be used to quantify the health loss of each of the outcomes of zinc deficiency.
- Calculating the impact and cost-effectiveness of zinc interventions can be based on DALYs.
- First projections support the idea that zinc biofortification could be a viable approach to reduce DALY losses.
- In the context of India, the estimated cost-effectiveness of zinc biofortification of rice and wheat compares favorably with other public health interventions.

[*] Manuscript for: Stein A.J., Qaim M., Nestel P. (2010). "Zinc deficiency and DALYs in India: impact assessment and economic analyses." In: Preedy V., Watson R.R. (eds). Handbook of Disease Burdens and Quality of Life Measures. Heidelberg: Springer-Verlag. ISBN: 9780387786643 and 9780387786650.
http://www.springer.com/medicine/book/978-0-387-78665-0

List of abbreviations

AADO	average age of death or onset of disease
cf.	confer
DALY	Disability-Adjusted Life Year
FAO	Food and Agriculture Organization
GBD	Global Burden of Disease
GDP	gross domestic product
IZiNCG	International Zinc Nutrition Consultative Group
N/A	not applicable
QALY	Quality-Adjusted Life Year
r	discount rate
RDI	recommended dietary intake
SEAR-D	countries in the WHO's South-East Asia region with high child and high adult mortality
t	time
UN	United Nations
US$	United States Dollar
WHO	World Health Organization
WTP	willingness-to-pay
YLD	years lived with disability
YLL	years of life lost
yr	year
ZnD	zinc deficiency

Introduction

Micronutrient deficiencies

Over 800 million people in developing countries are undernourished because they do not eat enough to meet their daily energy requirements (FAO 2005). Moreover, many of these people go to bed hungry. The social and economic costs of inadequate food intake directly affect those who endure this hunger, and indirectly society at-large, which is acknowledged by academics, policy makers and the general public (Strauss and Thomas 1998; UN 2000; Arcand 2001; McGovern 2001; WHO 2001; Sachs et al 2004).

A monotonous diet that is insufficient in quantity and does not meet energy requirements will invariably be inadequate in quality too, but increasing energy intake through increased consumption of staple foods will not necessarily ensure adequate quality. The notion of good diet quality is especially pertinent for intakes of vitamins and minerals that are collectively known as micronutrients. Micronutrients are essential for cell functioning and survival. Prolonged low micronutrient intakes result in recognized and documented clinical outcomes, and in some cases death, but these outcomes reflect the extreme end of the sequelae that ensues as an individual goes from being replete to deplete.

The prevalence of florid clinical micronutrient deficiencies has greatly fallen over the last 50-70 years due to both improved agricultural production and access to health care (World Bank 2006). While the prevalence of clinical deficiencies declined, and the diagnostic tools improved, it became increasingly apparent that there were very large numbers of individuals with subclinical micronutrient deficiencies in which no signs and symptoms were present. The latter is important because even subclinical deficiencies can impact on morbidity and mortality (World Bank 2006), hence the notion of hidden hunger.

As the link between micronutrient deficiencies and child survival became increasingly apparent, policy makers have been compelled to consider the public health ramifications – including the economic implications – of controlling micronutrient deficiencies (Behrman et al 2004; FAO 2005; World Bank 2006). Partly because they were relatively easy to diagnose, the focus has been on controlling iodine, iron and vitamin A deficiencies (ACC/SCN 2000). Because the underlying causal factors for iron deficiency are similar to that for zinc deficiency, and the fact that zinc is needed in nearly all metabolic pathways in the body, it soon became apparent that zinc deficiency was also very likely to be a public health problem of enormous proportions in developing countries (Prasad 2003). And indeed the World Health Organization identified zinc deficiency as one of the top five risk factors contributing to the burden of disease in developing countries with high mortality rates (WHO 2002).

Zinc deficiency, its causes and its extent

One third of the global population is estimated to be zinc deficient (Hotz and Brown 2004). Zinc deficiency can develop due to inadequate intakes, increased requirements, malabsorption, impaired utilization or increased losses (Box 1). Zinc intakes will be inadequate if the zinc content of food is low or it is bound to some other compound (notably phytates) that makes it unavailable for absorption. Zinc requirements are increased in during pregnancy. Diseases such as diarrhea and some drugs can result in reduced absorption of zinc. Other drugs can bind zinc, thus impairing its utilization. Infections in general result in the sequestration of zinc in the liver, thus decreasing circulating levels of this trace mineral in the body. Finally, disease or other conditions that are associated with bone or muscle atrophy can also increase the losses of endogenous zinc from the body; furthermore, conditions that perturb intestinal functions may affect the body's ability to maintain zinc status (Hotz and Brown 2004).

Box 1. *Key facts on zinc in nutrition and health*

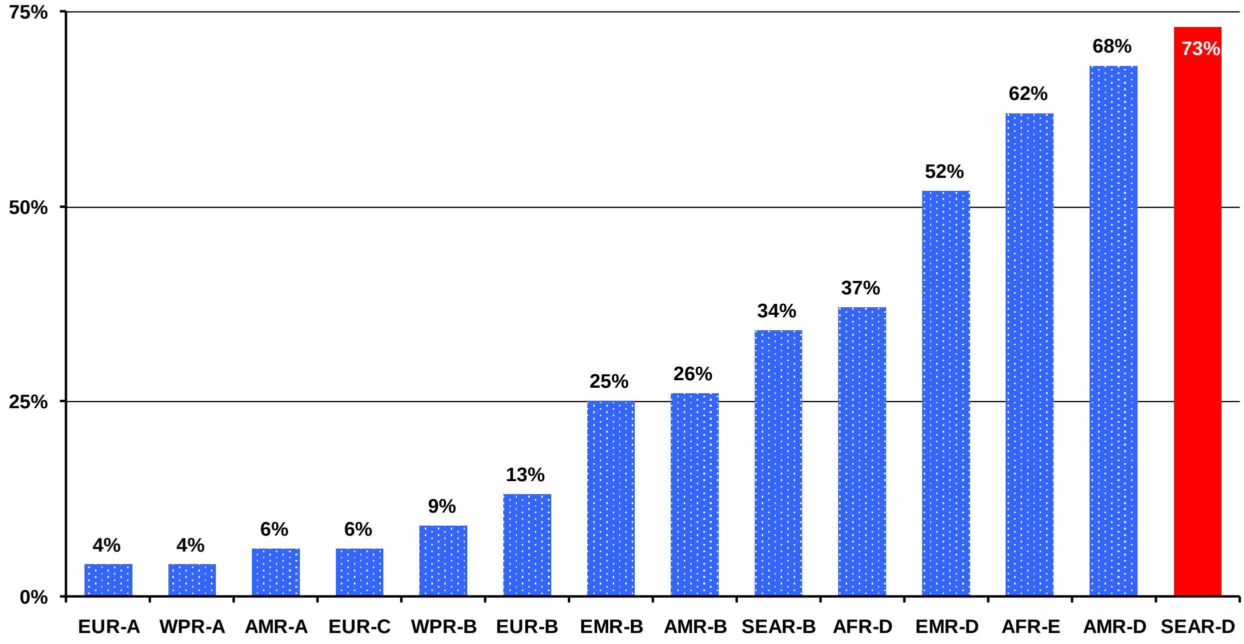
Zinc is present in virtually every tissue in the body and plays a central role in the correct functioning of the immune system, growth and development. Consequently, infants and young children who are growing rapidly are most vulnerable to becoming deficient. Deficiency results when there is an inadequate intake of absorbable zinc that can develop from inadequate dietary intakes, increased requirement (during pregnancy and lactation), as well as malabsorption, impaired utilization or increased losses of zinc as a result of pathological conditions that affect the integrity of the gut. Deficiency causes stunting, poor appetite, recurrent infections (especially diarrhea and pneumonia) and delayed wound healing due to low immune function. About one third of the global population is estimated to be zinc deficient, with deficiency most widespread in South and Southeast Asia. Poor health related to zinc deficiency also affects economic productivity in later life. For instance, estimates for India indicate a lower bound for the economic loss due to zinc deficiency of US$ 1.74 billion – or 0.25 percent of gross domestic product.

In absolute terms zinc deficiency is most widespread in Asia because of the large number of people living in this region. Indeed, just under three-quarters of the population in the WHO SEAR-D region – i.e. India, Bangladesh, Myanmar, North Korea, Nepal, Bhutan and the Maldives – were calculated to consume less than the US recommended dietary intakes (RDIs) for zinc (WHO 2002; Figure 1). More specifically Hotz and Brown (2004) estimated that one-quarter of the Indian population were at-risk of inadequate zinc intakes, putting India in the “high” risk category for zinc deficiency (Table 1). Hence, zinc deficiency in India clearly warrants further analyses, from both the biological and economic perspectives.

The need to measure the burden of zinc deficiency correctly

Knowing how many people are at risk of zinc deficiency is a first and important step to ascertain the extent of the problem. However, a head-count approach can neither show the depth or severity of the problem – as encountered with head-count measurements in the poverty literature (cf. Sen 1976) – nor does it allow for *comparisons* to be made between the severity of ill health from zinc deficiency and other public health problems. Likewise, summing up the magnitude of various health problems to obtain an overall burden of disease is not possible with a head-count approach alone.

Figure 1. *Zinc deficiency worldwide*



This figure shows for different regions in the world the percentage of people having insufficient zinc intakes (by US standards); India belongs to the SEAR-D region where this share is highest. Region code: AFR: African Region, AMR: Region of the Americas, EMR: Eastern Mediterranean Region, EUR: European Region, SEAR: South-East Asia Region, WPR: Western Pacific Region. Mortality strata: A: very low child, very low adult, B: low child, low adult, C: low child, high adult, D: high child, high adult, E: high child, very high adult. RDIs: recommended dietary intakes. Source: After WHO (2002).

Table 1. *Zinc deficiency in India and its neighbors*

Country	Total population (millions)	At risk of ZnD (%)	At risk of ZnD (millions)
India	982	25.9	254
China	1,263	14.1	178
Pakistan	148	11.1	16
Bangladesh	125	50.4	63
Myanmar	44	34.6	15
Nepal	23	21.3	5
Sri Lanka	18	44.7	8
Total	2,604	20.8	540

This table shows the total population size of India and its neighbors and the percent of the population of each of these countries that is at risk of zinc deficiency, as well as the absolute number of people in this region who are at risk of zinc deficiency (by the standards of IZiNCG). ZnD: zinc deficiency. Source: Hotz and Brown (2004).

In *assessing the impact* of a public health program – or in continuous *monitoring* – it may be misleading to simply look at the change in the prevalence of zinc deficiency: the intervention may reduce the severity of the ill-health outcomes of the deficiency although the absolute number of cases may remain the same.

In establishing the *cost-effectiveness* of a public health program, using the effect of zinc deficiency on mortality rates (e.g. to express the cost per death averted) may also be misleading: a disease or deficiency may result in many cases with severe but non-lethal health outcomes, while another may result in fewer but more severe health outcomes or even deaths. In the first case the program may improve the lives of many people considerably (e.g. reduce morbidity) but not save any lives, while in the latter case the program may prevent a few deaths but not affect the severity of the morbidity.

Finally, to carry out purely *economic analyses*, e.g. by assessing the productivity loss due to a deficiency, merely knowing the number of people who are zinc deficient does not say anything about the extent to which their productivity may be affected. Hence, simply looking at the prevalence or incidence of zinc deficiency or at mortality rates is not very informative.

The forgoing has shown that zinc deficiency is a global public health problem, particularly in India. It has explained the need for a better economic indicator that captures both the extent and severity of the problem. The rest of this chapter explains the concept of *disability-adjusted life years* (DALYs) and puts forward a framework for its application to zinc deficiency in India.

Zinc deficiency and DALYs

The DALY methodology

Application and strengths of the methodology

As explained above, head-count approaches to measure ill-health are not satisfactory because they do not capture the severity of a condition. One concept that addresses this issue is the disability-adjusted life years (DALYs) approach that builds on the idea of quality-adjusted life years (QALYs). The World Bank, in collaboration with the WHO, developed the DALYs methodology and introduced DALYs as a measure for the global burden of disease (GBD) (World Bank 1993). The use of DALYs was further popularized following the work of Murray and Lopez (1996); nowadays, the approach is also often used by other international organizations (e.g., FAO 2004; UN-SCN 2004) and in a diverse set of contexts, e.g., civil war and sanitation infrastructures (Collier and Hoeffler 2004; Rijsberman 2004). DALYs are used particularly in global or developing country settings (c.f. Fox-Rushby 2002). In the context of dietary deficiencies in India, DALYs were used to determine the cost-effectiveness of biofortification (Stein et al 2006; 2007; 2008) and the human and economic cost of micronutrient malnutrition (Stein and Qaim 2007).

The strength of the DALY methodology is that it includes both the severity – what economists may refer to as its depth – and the incidence – or width – of a condition. This is done through the use of disability weights that define the extent of the loss of an individual’s function with each adverse health outcome relative to death (100 percent loss) and complete health (no loss). This relative weighting means that the combined health losses due to morbidity and mortality can be measured in one single index, and the latter is comparable across different conditions. The duration of the adverse health outcomes are counted in life years. With this, the burden of disease, or of a particular dietary deficiency, can be expressed as the aggregate number of DALYs that are lost due to the condition(s) of interest, i.e. as the sum of the *years of life lost* (YLL) due to the condition-related mortality and the sum of *years lived with disability* (YLD) that is due to the condition (Murray and Lopez 1996).

The calculation of DALYs

Because the severity – or the level of disability – is weighted in the YLD (relative to the YLL), the basic rationale underlying the DALY concept can be represented as:

$$Burden\ of\ disease = DALYs_{lost} = YLL + YLD_{weighted}$$

This burden of disease needs to be calculated and aggregated for each target group (i.e. each relevant age and gender group) that is affected by the condition – as incidence and severity may differ between different groups – and future health losses need to be discounted. Following Zimmerman and Qaim (2004) and Stein et al (2005), the revised formula can then be represented more formally as:

$$DALYs_{lost} = \sum_j T_j M_j \left(\frac{1-e^{-rL_j}}{r} \right) + \sum_i \sum_j T_j I_{ij} D_{ij} \left(\frac{1-e^{-rd_{ij}}}{r} \right)$$

Where $\boldsymbol{T_j}$ is the total number of people in target group j, $\boldsymbol{M_j}$ is the mortality rate associated with the condition in target group j, $\boldsymbol{L_j}$ is the average remaining life expectancy for target group j (i.e. if persons in that target group live one year shorter they lose one DALY), $\boldsymbol{I_{ij}}$ is the incidence rate of condition i in target group j, $\boldsymbol{D_{ij}}$ is the disability weight for condition i, in target group j (ranging from 1 to 0, with 1 representing a complete loss of functioning and 0 perfect health), $\boldsymbol{d_{ij}}$ is the duration of the condition i in target group j (for permanent conditions d_{ij} equals the average remaining life expectancy L_j), and $\boldsymbol{r}$ is the discount rate for future life years.

General criticism of DALYs and methodological differences

The DALY approach has not been without criticism (e.g. Anand and Hanson 1998; Arnesen and Nord 1999; Groce et al 1999; Richardson 1999; Olsen et al 2002; Allotey et al 2003; Lyttkens 2003). In this section the main points of critique are discussed and the modifications that have been made to the original methodology to address some of the issues are explained. A more detailed discussion can be found in Murray (1996) and Fox-Rushby (2002).

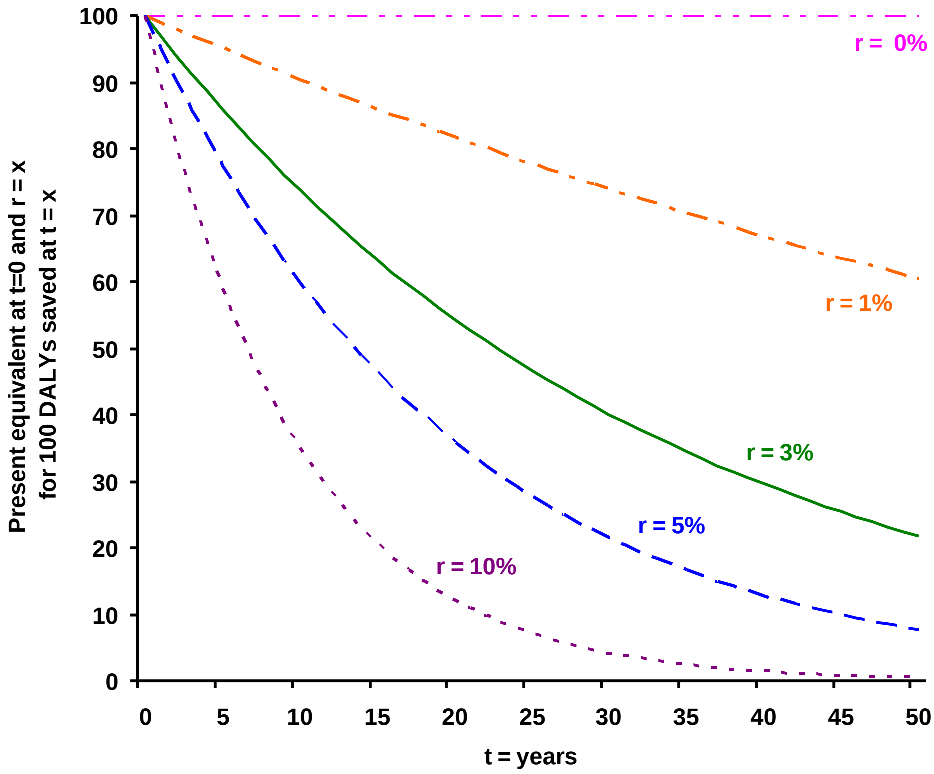
Discounting of DALYs and future life and health

Discounting DALYs (and thus future life and health) is a contentious issue in the literature. The main reproach to discounting DALYs is that it is unfair toward future generations because, with discounting, saving one DALY next year is worth less than saving one DALY today and saving one DALY in 20 years is – at present – worth even less (Figure 2). This issue has been discussed by Murray (1996) and Tan-Torres Edejer et al (2003: 67) who explained succinctly:

> The logic for discounting costs is that the value of a unit of consumption to individuals and society decreases over time, for three possible reasons. First, individuals take into account the fact that they might not be alive to benefit from future consumption, and society takes into account the possibility of catastrophe – the possibility that any or all interventions might at some point in the future become valueless due to the technology becoming obsolete, climate change or social chaos, for example. Second, people and society might simply prefer consumption now to consumption in the future – called the pure rate of time preference or, sometimes, myopia. Third, if it is expected that incomes will increase, the marginal welfare gain from an additional unit of consumption will be lower in the future, when people are richer, meaning that any given increase in consumption is more valuable now than in the future. Accordingly it is standard practice to discount future costs to their present values to allow for differences in the value of one extra unit of consumption over time.

It is now usual practice to use a discount rate of three percent in DALY calculations (World Bank 1993; Murray and Lopez 1996; WHO 2002; Tan-Torres Edejer et al 2003; Stein et al 2005). Nevertheless, when calculating DALYs it is considered good practice to carry out sensitivity analyses in which the discount rate is varied and includes a zero percent rate (Murray and Lopez 1996; Stein 2006). Sensitivity analysis can be used both to illustrate the impact of the choice of discount rate on the final results and to facilitate comparisons across different programs and studies.

Figure 2. *The impact of discounting DALYs*



This figure illustrates the impact of discounting DALYs by showing how the *present* value of 100 DALYs diminishes the higher the discount rate (*r*) and the more years the saving of these DALYs lies ahead in the future (*t*); without discounting (*r* = 0%) the current equivalent of 100 DALYs that are saved in the future is also 100 DALYs. DALYs: disability-adjusted life years. Source: Adapted from Stein (2006).

The use of disability weights

The use of disability weights has also been criticized because they neither value the intrinsic value of the life of a person suffering from a condition, nor question their potential contribution to society or their capacity to realize individual achievements and to have a fulfilled life. Disability weights merely measure the loss of function of individuals, i.e. the degree to which they are unable to achieve their full physical and cognitive potential.

The disability weights used in the GBD project were derived at a meeting convened at the WHO, in which a rigorous consultative protocol was followed; the results matched closely the pooled results of similar previous exercises (Murray 1996; Arnesen and Nord 1999). Subsequent studies have found that the approach of putting person trade-off questions to a group of experts is sufficiently robust and can yield comprehensive and coherent disability weights (Baltussen et al 2000; Stouthard et al 2000). As most decisions in public health imply a certain trade-off between one treatment or group of patients against another, disability weights contribute to greater transparency and objectivity. Allotey et al (2003), however, note that it may be necessary to assess their general validity and to adapt disability weights to particular settings. The disability weights reported below for India are the outcome of a workshop – with experts from the Indian subcontinent – in which the disability weights used in the GBD project (Murray and Lopez 1996) were used as benchmarks to set the appropriate disability weights to use in a developing country context (Stein et al 2005).

One of the more serious reproaches to the use of disability weights is that they discriminate against the disabled because they imply that saving the lives of disabled people saves fewer DALYs than that of fully functional individuals (Anand and Hanson 1998; Arnesen and Nord 1999). Yet this problem does not actually arise because when calculating the YLL no disability weights are applied, i.e. one year of life lost from premature mortality counts the same for all people irrespective of whether they are disabled. A more detailed discussion of the use of disability rates, including a justification for the use of disability weights is given by Stein (2006), and the concept as such is explained well by Tan-Torres Edejer et al (2003).

The basis for calculating the average remaining life expectancy

In the GBD project a hypothetical general life expectancy was used to derive the average remaining life expectancies ($\boldsymbol{L_j}$). This general life expectancy was based on the longest observed life expectancy of 82.5 years for Japanese women – adjusted to 80 years for men because of the biological difference in survival potential (Murray 1996). The use of a standardized approach was necessary because the GBD project undertook to measure the burden of *all* diseases and injuries at once at a given point in time, i.e. for the average remaining life expectancies a world without diseases and accidents had to be assumed. Moreover, because the GBD was calculated for the entire world, this approach ensured inter-regional equality: no matter where a premature death occurred – be it in a rich country with a long-living population or in a poor country with a low national average life expectancy – general life expectancy counted the same in terms of the number of DALYs lost. However, the gender differentiation has provoked criticism because of the inherent inequality and the potential ethical implications if decisions in the field of health are based on biological – or genetic – factors (Lyttkens 2003).

For analyses of individual conditions at a national level, such as zinc deficiency in India, the issue of which life expectancy to apply (the national one or a theoretical maximum life expectancy, possibly differentiated between men and women) can be circumvented because eradicating the condition probably only has a minor impact on national average life expectancy and, therefore, national life tables can be used (Stein 2006). More details are given in the section on "Calculating the loss of DALYs due to zinc deficiency ".

The exclusion of age weights

A departure from the DALY formula used by Murray (1996) is that no age weights are included in the formula presented here, which is taken from Zimmermann and Qaim (2004). Murray had proposed age-based weights to value the lives of young, productive adults higher than the lives of infants and the elderly, i.e. more DALYs are lost if a disease is suffered by a 33 year old person than if the same disease is suffered by a 11 year old child or a 66 year old individual, and more DALYs are saved if the life of a 33 year old person is extended by 5 years than if the life of either the child or the elder individual is extended by 5 years. Murray justified this approach based on studies on the social and individual willingness to pay for health care, and the contribution of young adults to social welfare and their role as "care-givers" for their children and perhaps also their parents.

Age weights have been criticized on various grounds (Anand and Hanson 1998; Richardson 1999; Williams 1999), not least because weighting an individual's social importance implies an ethical value judgment and could represent an opening of Pandora's Box (Lyttkens 2003) that leaves the question where to stop with the weighting (Stein 2006): are doctors or film stars more important than other people, or orphans less? By not using age weights (or using unity weights for all individuals) this problem can be reduced. Because even if Musgrove (2000) rightly points out that treating all age groups equally is not a value-free judgment either, the ethical ramifications of not using age weights are less far reaching. Given the concerns outlined here, it is also noteworthy that in their sensitivity analyses of the GBD calculations Murray and Lopez (1996) had changed the age-weighting assumptions.

Arguments in favor of the DALY approach

As explained above, the DALY formula presented here is a modification of the original one to counter some of the general criticisms of the DALY methodology. While quantifications in the field of public health will inevitably be controversial, it is nevertheless often expedient to do the calculations – and DALYs are a transparent and widely used way of doing so. In particular, DALYs differ from other economic measures of disease because – unlike, for instance, the cost-of-illness or willingness-to-pay (WTP) approaches that aim at approximating the impact of ill-health through monetary quantification – they are not influenced by the earnings of individuals (or the national product). Hence, DALYs are more equitable. (In the case of cost-of-illness analyses higher incomes of individuals increase the benefit of avoiding or curing a disease that affects them – e.g. against controlling a disease that affects poorer individuals. Hence, one result of such analyses may be that curing the more affluent members of a society (or the citizens in richer countries) should take precedence over saving the lives of the poor. Similar outcomes are possible with WTP approaches, as health typically has a positive income elasticity of demand, i.e. the more individuals earn the more they are willing to pay for health.)

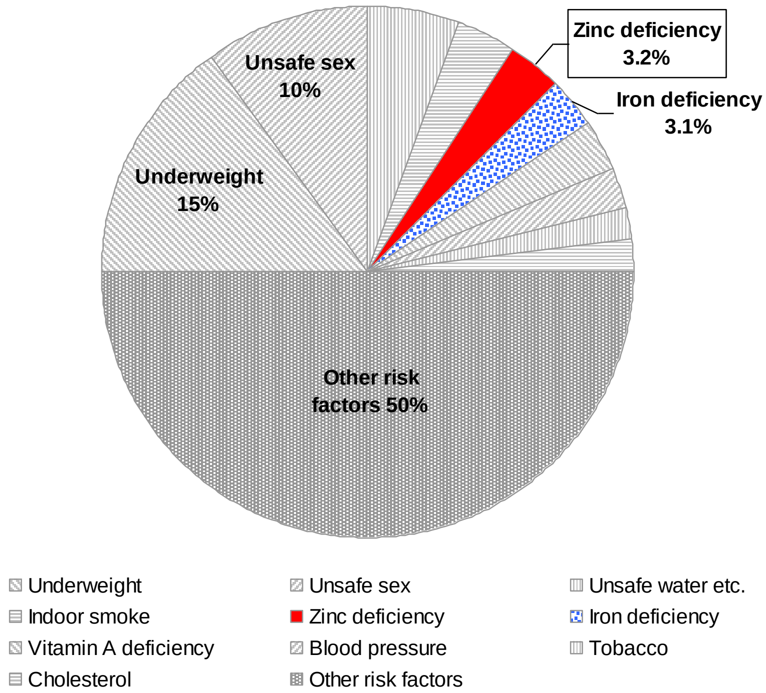
While standardization can help to reduce the equity issue of these alternative approaches, it cannot quantify the actual burden of ill-health. DALYs, however, can be used for both: they measure the burden of ill-health directly and, by attaching a standard monetary value to a DALY, they can also be used for monetary approximations of the economic burden of a disease (see "Using DALYs for impact assessment and economic analyses").

Calculating the loss of DALYs due to zinc deficiency

In its World Health Report 2002 the WHO reported the number of DALYs that are lost due to various risk factors. According to this report it was estimated that in 2000 worldwide over 28 million DALYs were lost due to zinc deficiency; 9.6 million of which were in the countries in South-East Asia that have high child and high adult mortality rates, including India. In terms of DALYs lost, zinc deficiency was ranked among the top five risk factors that contribute to the burden of disease in high mortality developing countries; these were underweight (15 percent of the burden), unsafe sex (10 percent), unsafe water, sanitation and hygiene (5.5 percent), indoor smoke from solid fuels (3.7 percent) and zinc deficiency (3.2 percent) (Figure 3).

In an application of the methodology outlined above and largely based on the data presented below, Stein el al (2007) calculated that zinc deficiency in India resulted in 2.8 million DALYs lost in 2004. This is less than the WHO estimated loss of 9.6 million DALYs in South-East Asia – where India is the biggest country. It is important to note, however, that the World Health Report reported the burden of zinc deficiency at the regional level and not the country level. Moreover, apart from the methodological differences explained above, and the perhaps more conservative assumptions presented in this section, the World Health Report did not directly calculate the loss of DALYs for zinc deficiency. Instead, the burden of zinc deficiency was based on attributing a share of the DALYs lost due to other, related conditions. ("Worldwide, zinc deficiency is responsible for approximately 16% of lower respiratory tract infections, 18% of malaria and 10% of diarrhoeal disease." WHO 2002: 55.)

Figure 3. *The ten leading risk factors that contribute to the burden of disease in high mortality developing countries*



This figure illustrates the importance of zinc deficiency as a public health problem in high mortality developing countries by showing its contribution to the burden of disease in percent, together with the contribution of the other nine leading risk factors (including iron deficiency, another micronutrient deficiency) that contribute to the burden of disease in these countries. Source: After WHO (2002).

This section describes the data required for calculating the number of DALYs lost due to zinc deficiency. While special reference is made to India, the requirements would be essentially the same also in other country contexts. Much of the information presented here draws on Stein et al (2005) who summarize the outcomes of a series of workshops held in 2003 and 2004 at which nutritionists and economists discussed and substantiated the scientific basis for the recommendations. An overview of the data requirements and data sources is given in Table 2, and an illustration of how DALYs are lost with different health outcomes is given in Figure 4.

Outcomes and target groups

Zinc deficiency increases the risk of young children contracting diarrhea, pneumonia that is a severe acute respiratory infection, and growth faltering manifested as stunting or short stature. The increased susceptibility to diarrhea and pneumonia affects both infants – defined as children below one year old – and young children – age 1 through 5 years, while the onset of stunting affects only infants. Thus, the incidence rates of the above three conditions in the two age groups are needed. Furthermore, it is assumed that both diarrhea and pneumonia result in a certain percentage of fatalities.

Size of the relevant target groups

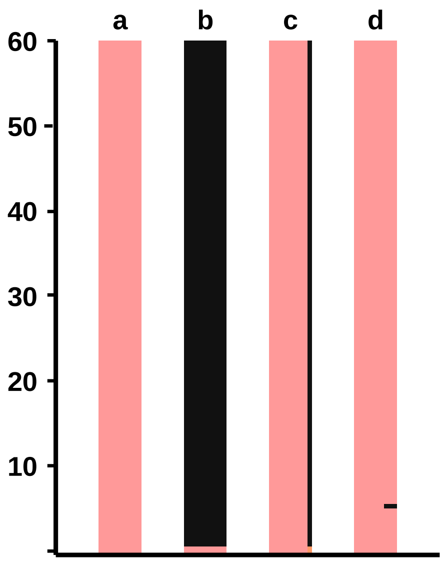
The size of the two target groups – infants and young children – can be derived from population and demographic statistics of international organizations or official national sources. For India updated national census data is available online (Census 2007).

Table 2. *Data requirements and data sources to calculate DALYs for zinc deficiency in India*

Condition i	Target group j	T_j	M_j or I_{ij}	D_{ij}	AADO	L_j or d_{ij}	r
Diarrhea	infants <1 yr	Use census data	0.47	0.20	N/A	3/365	3%
	children 1-5 yrs		0.23	0.15		4/365	
Pneumonia	infants <1 yrs		0.12	0.30		4/365	
	children 1-5 yrs			0.20		4/365	
Stunting	infants <1 yr		derive from (i) ZnD, (ii) stunting	(i) 0.001 (ii) 0.0001	< 1 year	Calculate from AADO* and standard life tables	
Increased mortality	Use data on live births		0.04 * under five mortality rate	(1.00)	< 1 year		

This table shows what data are needed to calculate DALYs for zinc deficiency in India, suggesting possible sources where the data are not provided. DALYs: disability-adjusted life years. T_j: total number of people in target group j. M_j: mortality rate associated with zinc deficiency in target group j: L_j: average remaining life expectancy for target group j. I_{ij}: incidence rate of condition i in target group j. D_{ij}: disability weight for condition i in target group j. AADO: average age of death or onset of disease. d_{ij}: duration of the condition i in target group j. r: discount rate for future life years. yr: year. N/A: not applicable. Source: Adapted from Stein et al (2005).

Figure 4. *Illustration of how the loss of DALYs is calculated*



This figure illustrates how the loss of DALYs is calculated by showing this loss on columns that represent the duration of a theoretical life. The 60 "rows" of each column represent life years; light/pink rows represent healthy life years, black rows represent DALYs lost. In case (a) the individual has a healthy life of 60 years with no DALYs lost. In case (b) the individual dies prematurely at the age of one and, thus, loses 59 DALYs. In case (c) the individual suffers from stunting from the age of one year onwards, but as the disability weight for stunting is very small, the individual loses only a fraction of a DALY in each of the remaining years (altogether 0.06 DALYs). In case (d) the individual suffers a 4-day-bout of pneumonia at the age of five years. During these four days the individual is disabled to 20% (disability weight of 0.2). If these four days, in which a partial loss of good health occurs, are put in relation to a year, 0.002 DALYs are lost. (This is for illustration purposes only, therefore neither are DALYs discounted to the present, nor is it considered that live expectancy increases over an individual's life span (see Figure 5) but it is assumed to be fix at 60 years.) DALYs: disability-adjusted life years.

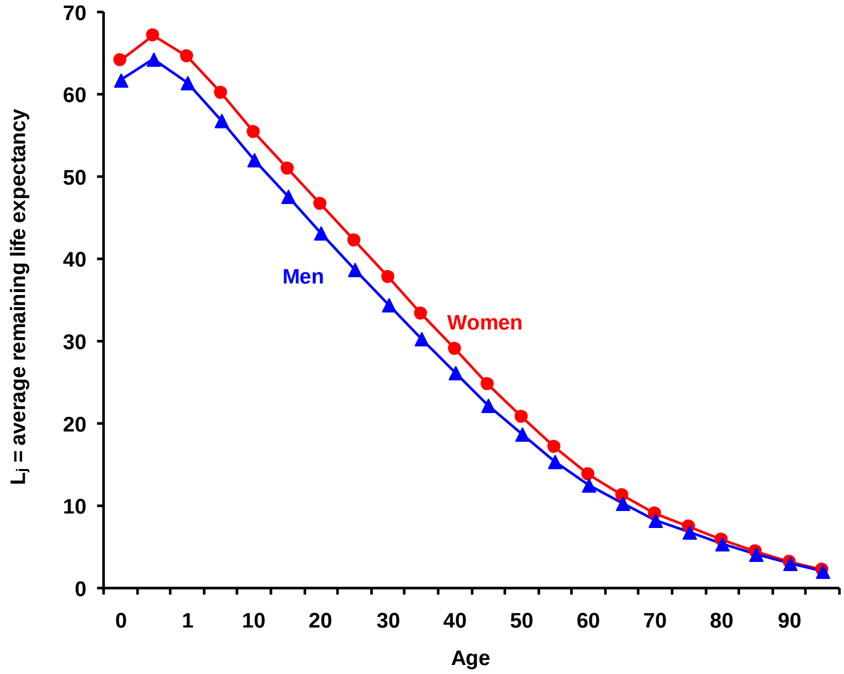
Mortality rates

The mortality due to zinc deficiency *per se* is unknown, but both diarrhea and pneumonia result in a certain percentage of fatalities. Jones et al (2003) estimated that at least four percent of mortality among children under-five years old in low-income countries could be prevented if the intake of zinc was adequate. Hence, mortality due to zinc deficiency in children under five years old in India can be approximated by multiplying the overall mortality rate of children under five years old by 0.04. The under-five mortality rate for India in 2005 was 74 per 1,000 live births (UNICEF 2007; WHO 2007a; UNDP 2007; World Bank 2007a). Because mortality rates for children under-five years old are given as the number of deaths per 1,000 live births, the target group for which the mortality rate needs to be applied is the number of live births and not the number of children under five years old.

Remaining life expectancy

Of the three adverse functional outcomes caused by zinc deficiency, only stunting is permanent. This means that the duration of stunting d_{ij} equals the average remaining life expectancy L_j. Standard life tables are used to calculate the average remaining life expectancy, and thus also to calculate the DALYs lost due to mortality. These tables are available from the WHO (2007b) and are shown graphically in Figure 5. In zinc deficiency stunting is assumed to start at the age of six months (Stein et al 2005). Most of the deaths among children under five years old in India is among infants (Census 2007); thus, the age of death for children under-five years old can be set before the first birthday (Stein 2006). This means that the duration of stunting and the average remaining live expectancy for zinc deficiency-related child mortality in 2005 was on average 63 years for both sexes.

Figure 5. *Average remaining life expectancies in India in 2005*



This figure illustrates how the average remaining life expectancy rises directly after infancy and then slowly falls again, indicating for each age and gender group the average remaining life expectancy. For those people who survive the various risks to their life at various ages, when they get older their average remaining life expectancy diminishes at a slower rate, thus explaining why, for instance, males have a remaining life expectancy of about 65 years when they are 1 year old, but on average can still expect to live over 12 years when they are 65 years old. Source: After WHO (2007b).

Incidence rates

Incidence rates of the sequelae of zinc deficiency

Because the incidence rates of diarrhea, pneumonia and stunting due to zinc deficiency are not known, a share of the general incidence rates has to be attributed to zinc deficiency. By combining information on the average number of diarrhea episodes per year and the share of zinc deficiency therein, Stein et al (2005) calculated that the incidence rate for diarrhea due to zinc deficiency was 0.47 for infants and 0.23 for young children. Similarly, the incidence rate for pneumonia due to zinc deficiency was estimated to be 0.12 for both infants and young children.

For stunting two approaches can be used to determine the incidence rate due to zinc deficiency. First, assume that all infants with zinc deficiency are at-risk of being stunted. In other words, the incidence rate of zinc deficiency is used as the incidence rate of stunting. Second, assume that without zinc deficiency all stunted infants become one centimeter taller than otherwise, that is the incidence rate of stunting is used as the incidence rate of zinc deficiency (Stein et al 2005). The approach chosen determines the disability weights used, as explained in the next section.

Incidence rates and prevalence rates

A potential problem in using the first approach is that zinc deficiency is usually reported as a prevalence rate rather than incidence rate. However, the two rates are connected. Given the assumption that stunting is permanent and sets in during infancy, the incidence rate can be derived from the prevalence rate for zinc deficiency because the reference period in each case is one year: as many infants as are stunted (i.e. the prevalence rate) became so during the same year (i.e. the incidence rate). Where the prevalence rate is not specifically given for infants, an approximation is still possible: because stunting is permanent, the prevalence rate for a group comprising several age groups can also be used for each age group alone, i.e. also for infants. (For instance, if 45 percent of children under-five years old are stunted then 45 percent of those aged four years are stunted, and 45 percent of those aged three years, and two years, and one year are stunted as well – and so are 45 percent of the infants.) This approach, however, neglects demographic changes (like lower birth rates over time), which is why it is only an approximation. Prevalence data on stunting among children in India are available in the National Family Health Surveys, and the most recent survey gives the prevalence rate of stunting among children under the age of three years to be 38 percent (IIPS 2007).

Disability weights

The 2003-2004 expert consultation (Stein et al 2005) assigned a disability weight for diarrhea of 0.2 for infants and 0.15 for young children, and 0.3 and 0.2 for pneumonia among infants and young children, respectively. For stunting, two sets of disability weights were agreed upon, depending on the approach used to determine incidence. If the incidence rate of stunting is derived from the incidence of zinc deficiency, and if it is assumed that with adequate zinc intake zinc-related stunting will disappear, then the disability weight is 0.001. If it is assumed that adequate zinc intakes will reduce all stunting by one centimeter then the disability weight is 0.0001.

Duration of the relevant diseases

The experts at the workshop set the average duration of diarrhea among infants in a developing country like India at three days, and that for young children at four days. For pneumonia the average duration was set at four days for both infants and young children (Stein et al 2005). The annual figures were derived by dividing these durations, which are expressed in days, by 365 days to obtain the duration of the diseases as fractions of a year. Because stunting is permanent its duration was simply calculated from standard life tables as described in the section on “Remaining life expectancy”.

Using DALYs for impact assessment and economic analyses

General issues

Once the loss of DALYs due to zinc deficiency has been calculated the result can be used both to illustrate the burden of disease provoked by the deficiency and to assess the impact of a zinc intervention. The latter is done by comparing the number of DALYs lost with and without the intervention – although care must be taken to control for possible confounding factors.

Going one step further, the number of DALYs that could be saved through an intervention can be juxtaposed on the cost of its implementation to arrive at the cost per DALY saved. For an *ex ante* analysis, the impact of the intervention can be simulated and then compared with its expected cost. In this case the uncertainty associated with *ex ante* analyses should be taken care of, for example, by calculating the impact of the intervention based on a pessimistic and an optimistic scenario and also by using pessimistic and optimistic assumptions for projecting the development of the related costs. To approximate the economic burden of a disease on society, or to carry out a cost-benefit analysis, DALYs can also be valued monetarily. Then, by adding up the loss of DALYs in monetary terms, the total corresponding financial loss can be off-set against suitable parameters, like the gross domestic product (GDP), to illustrate the magnitude of the problem (Stein and Qaim 2007).

The example of biofortification in India

Biofortification refers to the use of plant breeding to accumulate essential micronutrients in the edible parts of staple crops. Using the framework described in this chapter and using a pessimistic and an optimistic scenario, Stein et al (2007) projected that zinc biofortification of rice and wheat could reduce the burden of zinc deficiency in India by 20-50 percent. Furthermore, contrasting the corresponding gain of DALYs with the costs of this intervention, they indicated that the cost-effectiveness of this approach falls into the range of 1-7 US$ per DALY saved – whereas similar projections for zinc fortification of wheat flour produced a range of 5-7 US$/DALY saved (Table 3), and zinc supplementation, which could be necessary in rice-eating regions of India, was projected to cost at least 17 US$/DALY saved (Tan-Torres Edejer et al 2005; converted from international dollars). Based on these results Stein and Qaim (2007) calculated that a lower bound for the economic loss caused only by zinc deficiency in India in 2004 was US$ 1.74 billion – or 0.25 percent of the Indian GDP.

Table 3. *Impact and cost-effectiveness of zinc biofortification of rice and wheat in India*

Scenario	Pessimistic	Optimistic
DALYs lost in the status quo (million)	2.8	
Reduction of burden of ZnD (%)	20	51
Cost-effectiveness (US$/DALY saved)	7.31	0.73

This table shows the results of an analysis of the impact and cost-effectiveness of zinc biofortification on the burden of zinc deficiency in India; the burden of zinc deficiency is expressed in million DALYs lost, the impact is expressed in a percent reduction of this burden and the cost-effectiveness ratio is given in US$/DALY saved, i.e. it indicates how much it costs to save one DALY through this particular intervention. DALYs: disability-adjusted life years. ZnD: zinc deficiency. Source: Stein et al (2007).

Definitions, synonyms and acronyms

Micronutrient malnutrition, also micronutrient deficiencies, vitamin and mineral deficiencies, or hidden hunger: Micronutrient malnutrition results from an inadequate intake or uptake or excessive loss of essential vitamins and minerals that are essential for health and survival. This term is often used synonymously with “micronutrient deficiencies”.

Zinc deficiency: Zinc deficiency is an inadequate intake of absorbable zinc. Not all zinc consumed in absorbed because it is bound to other complexes in food and is not released during digestion. Zinc deficiency is a form of micronutrient malnutrition.

DALYs, disability-adjusted life years: DALYs are a measure of ill health at the population level. It weights the duration of a disease relative to its severity and then sums the years lost due to the disease-related premature mortality (where applicable), thus indicating the equivalent of healthy – or disability-adjusted – life years lost due to the disease. This aggregate figure is the burden of disease to society.

QALYs, quality-adjusted life years: QALYs are a concept similar to DALYs, with some methodological differences (also see “DALYs”). QALYs are a measure of ill health that reflects the quality and length of life that can be gained through a health intervention.

GBD, global burden of disease: The total number of DALYs that are lost world-wide due to disease and injury. (Also see “DALYs”.)

Prevalence, colloquially also spread, extent, or commonness: The prevalence of a disease is the number of *existing* cases of the disease in a population at *any* point in time, i.e. the proportion of individuals within a population with the disease. (Also see “incidence”.)

Incidence, colloquially also occurrence or frequency: The incidence of a disease is the number of *new* cases of the disease in a population in a *given* period of time, i.e. the percentage of individuals within a population who get the disease in a specified period of time. The incidence rate also indicates the risk of individuals in a population getting the disease. (Also see “prevalence”.)

Cost-effectiveness, also efficiency: Cost-effectiveness expresses the cost per unit of measured outcome of an intervention relative to the corresponding costs of alternative interventions. By spending resources on the most cost-effective interventions, i.e. on those with the lowest cost per unit of measured outcome, this outcome can be maximized. Or, cost-effectiveness is the extent to which the desired impact is achieved at a lower cost compared with alternatives. More colloquially: cost-effectiveness measures how much bang one gets for the buck.

Discounting: Discounting means calculating the present value of an amount (e.g. of money or DALYs) that materializes in future. (Because of uncertainty regarding future events, i.e. the recipients do not live to see, the amount does not materialize or it becomes less useful, the present value is usually lower than the expected amount. The present value is also lower when the recipients would simply have the amount sooner rather than later – the longer they have to wait, the less value they attach to it.)

Biofortification, also genetic fortification: Biofortification refers to the use of plant breeding to accumulate nutrients in the edible parts of staple crops.

References

ACC/SCN (2000) Fourth report on the world nutrition situation. UN ACC, Sub-Committee on Nutrition, Geneva. www.unsystem.org/SCN/Publications/rwns/4RWNS.html

Allotey P, Reidpath D, Kouamé A, Cummin R (2003) Soc Sci Med 57: 949-958. http://dx.doi.org/10.1016/S0277-9536(02)00463-X

Arcand JL (2001) Undernourishment and economic growth. Economic and Social Development Paper No. 147. FAO, Rome. www.fao.org/DOCREP/003/X9280E/X9280E00.HTM

Anand S, Hanson K (1998) World Dev 26: 307-310. http://dx.doi.org/10.1016/S0305-750X(97)10019-5

Arnesen T, Nord E (1999) Brit Med J 319: 1423-1425. www.bmj.com/cgi/content/extract/319/7222/1423

Baltussen RMPM, Sanon M, Sommerfeld J, Würthwein R (2002) Health Econ 11: 155-163. http://dx.doi.org/10.1002/hec.658

Behrman JR, Alderman H, Hoddinott J (2004) Hunger and malnutrition. Copenhagen Consensus, Copenhagen. www.copenhagenconsensus.com/Default.aspx?ID=223

Census (2007). Census of India. New Delhi: Registrar General & Census Commissioner. www.censusindia.gov.in/

Collier P, Hoeffler A (2004) The challenge of reducing the global incidence of civil war. Copenhagen Consensus, Copenhagen. www.copenhagenconsensus.com/Default.aspx?ID=221

FAO (2004) The state of food insecurity in the world 2004. FAO, Rome. www.fao.org/sof/sofi/

FAO (2005) The state of food insecurity in the world 2005. FAO, Rome. www.fao.org/sof/sofi/

Fox-Rushby JA (2002) Disability adjusted life years (DALYs) for decision-making? An overview of the literature. Office of Health Economics, London. ISBN 978-1899040377

Groce NE, Chamie M, Me A (1999) Int Rehabil Rev 49: 12-15. www.rehab-international.org/publications/rehabilitationreview.html

Hotz C, Brown KH (eds) (2004) Food Nutr Bull 25: S91-S204. www.unu.edu/unupress/food/fnb25-1s-IZiNCG.pdf

Jones G, Steketee RW, Black RE, Bhutta ZA, Morris SS, Bellagio Child Survival Study Group (2003) Lancet 362: 65-71. http://dx.doi.org/10.1016/S0140-6736(03)13811-1

Lyttkens CH (2003) Eur J Health Econ 4: 195-202. http://dx.doi.org/10.1007/s10198-003-0169-2

McGovern G (2001) UN Chronicle 38: 24-27. www.un.org/Pubs/chronicle/2001/issue3/0103p24.html

Murray CJL (1996) In: Murray and Lopez (1996), pp. 1-98

Murray CJL, Lopez AD (eds) (1996) The Global Burden of Disease. Global Burden of Disease and Injury Series, Vol. 1. Harvard Univ, Cambridge, MA. www.hup.harvard.edu/catalog/MURGLO.html

Musgrove P (2000) Health Policy Plann 15: 110-115. http://dx.doi.org/10.1093/heapol/15.1.110

IIPS (2007) National Family Health Survey (NFHS-3), National Fact Sheet: India. International Institute for Population Sciences, Mumbai. www.nfhsindia.org/

Olsen JA, Richardson J, Dolan P, Menzel P (2002) The moral relevance of personal characteristics in setting health care priorities. Working Paper No. 17. Oslo Univ, Oslo. www.hero.uio.no/publications.html

Prasad AS (2003) Brit Med J 326: 409-410. http://dx.doi.org/10.1136/bmj.326.7386.409

Richardson J (1999) Age Weighting and Discounting: What Are the Ethical Issues? Working Paper No. 109. Monash Univ, West Heidelberg. www.buseco.monash.edu.au/centres/che/che-publications.html#1999

Rijsberman F (2004) The water challenge. Copenhagen Consensus, Copenhagen. www.copenhagenconsensus.com/Default.aspx?ID=228

Sachs JD, McArthur JW, Schmidt-Traub G, Kruk M, Bahadur C, Faye M, McCord G (2004) Brookings Pap Eco Ac 1: 117-240. www.brookings.edu/press/Journals/2004/brookingspapersoneconomicactivity12004.aspx

Sen AK (1976) Econometrica 44: 219-232. http://dx.doi.org/10.2307/1912718

Stein AJ (2006) Micronutrient malnutrition and the impact of modern plant breeding on public health in India. Hohenheim Univ, Stuttgart. www.uni-hohenheim.de/ub/opus/volltexte/2006/157/

Stein AJ, Meenakshi JV, Qaim M, Nestel P, Sachdev HPS, Bhutta ZA (2005) Analyzing the health benefits of biofortified staple crops by means of the disability-adjusted life years approach. HarvestPlus Technical Monograph No 4. IFPRI, Washington. www.ifpri.org/publication/analyzing-health-benefits-biofortified-staple-crops-means-disability-adjusted-life-years

Stein AJ, Sachdev HPS, Qaim M (2006) Nat Biotechnol 24: 1200-1201. http://dx.doi.org/10.1038/nbt1006-1200b

Stein AJ, Nestel P, Meenakshi JV, Qaim M, Sachdev HPS, Bhutta ZA (2007) Public Health Nutr 10: 492-501. http://dx.doi.org/10.1017/S1368980007223857

Stein AJ, Meenakshi JV, Qaim M, Nestel P, Sachdev HPS, Bhutta ZA (2008) Soc Sci Med 66: 1797-1808. http://dx.doi.org/10.1016/j.socscimed.2008.01.006

Stein AJ, Qaim M (2007) Food Nutr Bull 28: 125-134. http://dx.doi.org/10.1177/156482650702800201

Stouthard MEA, Essink-Bot M-L, Bonsel GJ (2000) Eur J Public Health 10: 24-30. http://dx.doi.org/10.1093/eurpub/10.1.24

Strauss J, Thomas D (1998) J Econ Lit 36: 766-817. www.aeaweb.org/journal/contents/june1998.html

Tan-Torres Edejer T, Baltussen R, Adam T, Hutubessy R, Acharya A, Evans DB, Murray CJL (2003) Making choices in health: WHO guide to cost-effectiveness analysis. WHO, Geneva. www.who.int/choice/book/

UN (2000) United Nations Millennium Declaration. General Assembly Resolution 55/2 of 8 September. United Nations, New York. www.un.org/millennium/declaration/ares552e.htm

UN-SCN (2004) 5th report on the world nutrition situation. United Nations System, Standing Committee on Nutrition, Geneva. www.unsystem.org/SCN/Publications/html/RWNS.html

UNDP (2007). Statistics of the Human Development Report. UNDP, New York. http://hdr.undp.org/en/statistics/

UNICEF (2007). Monitoring and statistics. UNICEF, New York. www.unicef.org/statistics/

WHO (2001) Macroeconomics and health: investing in health for economic development. WHO, Geneva. http://whqlibdoc.who.int/publications/2001/924154550X.pdf

WHO (2002) The World Health Report 2002. WHO, Geneva. www.who.int/whr/2002/en/

WHO (2007a). WHOSIS (WHO Statistical Information System). WHO, Geneva. www.who.int/whosis/

WHO (2007b). Life tables for WHO member states. WHO, Geneva. www.who.int/whosis/database/life_tables/life_tables.cfm

Williams A (1999) Health Econ 8: 1-8. http://dx.doi.org/10.1002/(SICI)1099-1050(199902)8:1<1::AID-HEC399>3.0.CO;2-B

World Bank (1993) World Development Report 1993. World Bank, Washington. http://go.worldbank.org/J6RBXR2BM0

World Bank (2006) Repositioning nutrition as central to development. World Bank, Washington. http://go.worldbank.org/UGPWFYHNU0

World Bank (2007a). Development Data & Statistics, World Bank, Washington. www.worldbank.org/data/

Zimmermann R, Qaim M (2004) Food Policy 29: 147-168. http://dx.doi.org/10.1016/j.foodpol.2004.03.001