



Research article

An economic analysis of malaria elimination program in Nepal

Uttam Paudel^{a,*}, Krishna Prasad Pant^b^a Tribhuvan University, Kathmandu, Nepal^b Kathmandu University, Kathmandu Nepal

ARTICLE INFO

Keywords:

Economics
 Infectious disease
 Public health
 Cost-benefit analysis
 Malaria elimination
 Willingness to pay
 Sensitivity analysis
 Curative and preventive interventions
 Nepal

ABSTRACT

Background: Governments have committed to eliminate malaria. But a decline in government investment in malaria interventions, particularly in developing countries such as Nepal, reveals a limited emphasis on malaria elimination that may be due to lack of strong evidence on benefits of the investment. This paper empirically analyses curative and preventive costs and benefits of Nepal's malaria elimination program from the perspectives of both service providers in the public sector and people who are at risk.

Methods: Cost benefit analysis of both curative and preventive interventions for malaria elimination was conducted using case and non-case household survey data. Secondary data were obtained from government sources. Ingredient approach and step-down methods were used to estimate costs of malaria elimination interventions, and willingness to pay (WTP) method and case averted approach to estimate benefits.

Results: Curative intervention of malaria elimination program is economically viable in Nepal with a net present value (NPV) of USD 23 million, benefit cost ratio (BCR) of 1.58 and internal rate of return of 63%. Malaria preventive intervention is highly beneficial with NPV of USD 435 million and BCR of 2.13. An annual investment of USD 36.59 million is required to continue the current pattern of malaria reduction that can generate societal benefits of USD 92.81 million. From this investment, the government can save USD 132 million by the end of 2025. The maximum WTP of case households for the intervention is USD 57 per household which is 63% higher than that of non-case households.

Conclusion: Malaria elimination program in Nepal is economically viable and investment worthy. As the preventive intervention generates much higher net benefits than the curative intervention, the government should emphasize on preventive intervention while continuing the curative interventions.

1. Introduction

Malaria elimination is a key global health priority across the tropical areas of developing world [1, 2]. Low- and middle-income countries in tropical areas have endeavored to control malaria through research, policy and interventions. Recent literatures focus primarily on biological and technical aspects of case management with less emphasis on malaria management at various risk rates [3, 4, 5]. A few studies have examined socioeconomic factors linked to malaria prevalence [2, 6]. However, research on economic analysis of malaria elimination program in developing countries is yet to be prioritized to quantify social welfare of the malaria elimination [3].

Several literatures emphasized on evidence-based interventions to tackle acute illness and systemic deficiencies to reduce malaria-related disease cost [7, 8]. Use of long-lasting insecticide-treated bed nets (LLINs) and installation of a robust surveillance systems are commonly

recommended in order to achieve the vision of malaria-free Asia-Pacific region [9]. Scaling up of supply chain management, improving referral systems and implementing evidence-based interventions such as rapid diagnostic tests (RDTs), artemisinin combined therapies (ACTs), LLINs, and indoor residual insecticide spraying (IRS) are major interventions implemented in Asia [10, 11, 12, 13]. However, interventions in Nepal are limited by a single round of LLINs, IRS, little access of ACTs and RDTs, and free curative system for managing malaria in highly affected districts; heavily depending on development partners' assistance [14]. Such initiatives are not getting enough research related evidence of any cost-benefit analysis.

Nepal is divided into 77 districts which comprises of low laying plain Terai region in the south, undulating hills in the middle and Himalayas in the North. Malaria cases caused by *Plasmodium vivax* are reported from 25 low lying Terai and hill districts, but no case is reported from 16 Himalayan districts. Rest of the hill districts have reported zero

* Corresponding author.

E-mail addresses: uuupaudel22@gmail.com, uttampdl12@gmail.com (U. Paudel).

indigenous cases in the last three years [15]. Nevertheless, some of these hill districts are also highly receptive and vulnerable due to the proliferation of vector mosquitoes suitable temperature, environmental and socio-economic factors for malaria [16]. In spite of widespread malaria cases in the large parts of Nepal, there has been a decline in public investment on malaria interventions in the country, and this decline can be attributed to insufficient evidences about the potential future benefits of present spending on the disease elimination. Government investment on malaria interventions accounts for just 8 percent of overall expenditure allocated for infectious disease interventions in Nepal [17]. Declining public investment aimed at eliminating malaria (Figure 1) is in contradiction with the government's malaria elimination strategy. This may be due to the fact that Nepal's government does not have access to credible evidence on the non-traded benefits of eliminating malaria [18], especially due to limited information on the cost saved from averted cases.

Interventions to eliminate malaria are directly related to reducing the risks of morbidity and mortality, and improving health. Cost benefit analysis (CBA) is a standard tool for economic assessment of disease elimination to quantify real social benefits and non-use advantage of removing diseases [19, 20]. The CBA approach includes costs and benefits in monetary terms but finding price of many cost and benefit items are not so easy. Willingness to pay (WTP) technique is robust methodology to capture the true value of non-marketed goods and services with value of statistical life (VSL) [21]. Many studies have used WTP for avoiding the disease mortality/morbidity risk, concentrating the VSL in terms of years adjusted disability/quality [21, 22]. However, this study relies mainly on CBA using WTP and case-averted approach to assess the value of eliminating malaria in terms of monetary measures without considering the age of people at risk [23, 24, 25]. Consequently, this paper explores household benefits of eliminating malaria by applying willingness-to-pay method [26, 27], which expresses a part of VSL from malaria elimination in monetary terms. Finally, this paper compares economic costs and social benefits of malaria interventions by using CBA to evaluate economic viability of malaria elimination interventions in Nepal.

2. Method

2.1. Study areas

The study was conducted in a malaria endemic district in far-west Nepal. According to 2015 annual report of Department of Health Services (DoHS), the districts of Kanchanpur and Kailali in far-west Nepal are the most prevalent districts of malaria, responsible for about 30 percent of Nepal's total cases in 2014 [14,17]). Because of population heterogeneity and underreported malaria cases found during a pilot survey conducted in these two districts in March 2016, the district of Kanchanpur was selected for a case household census survey and non case household sample survey. Kanchanpur District Public Health Office

provided comprehensive information about 2014 malaria-affected households that served as the sampling frame. On the basis of this information, Punarbas and Belauri villages in Kanchanpur were identified for the local reality check.

2.2. Data sources

The study employed both primary and secondary data. Cost data for malaria interventions were obtained from publications of Epidemiology and Disease Control Division (EDCD), Center for Disease Control, Department of Health Services (DoHS), Ministry of Health and Population (MoHP), World Health Organization (WHO) and United Nations Children's Fund. The costs of malaria interventions were compiled from adjusted annual government expenditures on malaria and household survey data. Benefits were estimated using household's maximum WTP survey and case averted approach of VSL.

2.3. Household data collection

Professional public health graduates performed the face to face in-depth interview of 117 case households and 176 non-case households using a pretested semi-structured questionnaire. The survey was conducted from April 1 through April 12, 2016. Of the district's total of 124 cases of malaria in 2014, 117 case households were interviewed to cover all cases in the presence of malaria patients and care givers. During the data collection, written informed consent was obtained from all participants ensuring ethical issues.

In addition, two more checklists were employed. First checklist was developed to get curative costs and preventive costs of government. Second checklist containing some validation questions was also developed for a focus group discussion (FGD) among the government officers working in the malaria intervention program in the study area. Some unanswered cost of the medicines in the field were retrieved from the office of EDCD in Kathmandu.

The maximum willingness to pay of non-case households to avoid the risk of malaria through intervention was assessed using stratified purposive sampling technique with insightful household member from moderate risks villages (Punarbas and Belauri) in Kanchanpur district.

2.4. Analytical framework

The survey data were complementary to the secondary data for estimating curative, preventative and aggregate net societal benefits of the malaria interventions. The actual data were from 2004 to 2014 and projections were made using SPSS until 2025. Additionally, effectiveness of malaria elimination interventions is measured using case averted approach and work efficiency loss of malaria affected persons was estimated using loss of work due to the disease. The data analysis was performed using MS Excel and SPSS. The functional relationship between the inputs and outputs of the malaria interventions is expressed in the conceptual framework (Figure 2) as a logical relationship.

2.5. Empirical strategy

Empirical strategy is divided into three parts: (A) cost and benefit estimation using survey data; (B) intervention-wise total cost and benefit estimation; and, (C) cost benefit analysis.

A. Cost and benefit estimation using survey data

For a given year, the costs of the intervention to manage malaria include the resources used for malaria interventions such as personnel, supplies, facilities, infrastructure, medications vehicles, buildings, and the time of patients and caretakers. The costs of each intervention are calculated using the ingredients approach (summation of cost components) through review of literatures, direct interviews, and focus group

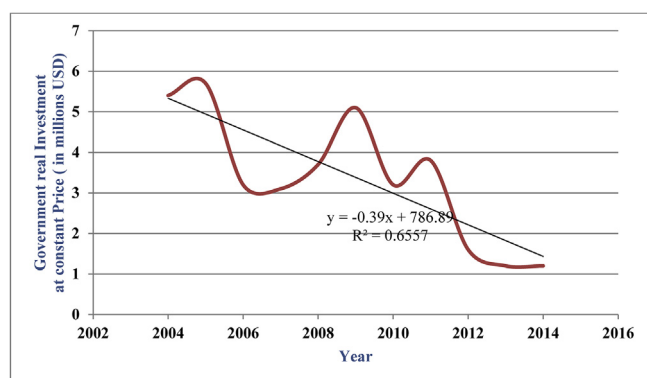


Figure 1. Trend of government investment in malaria control and elimination.

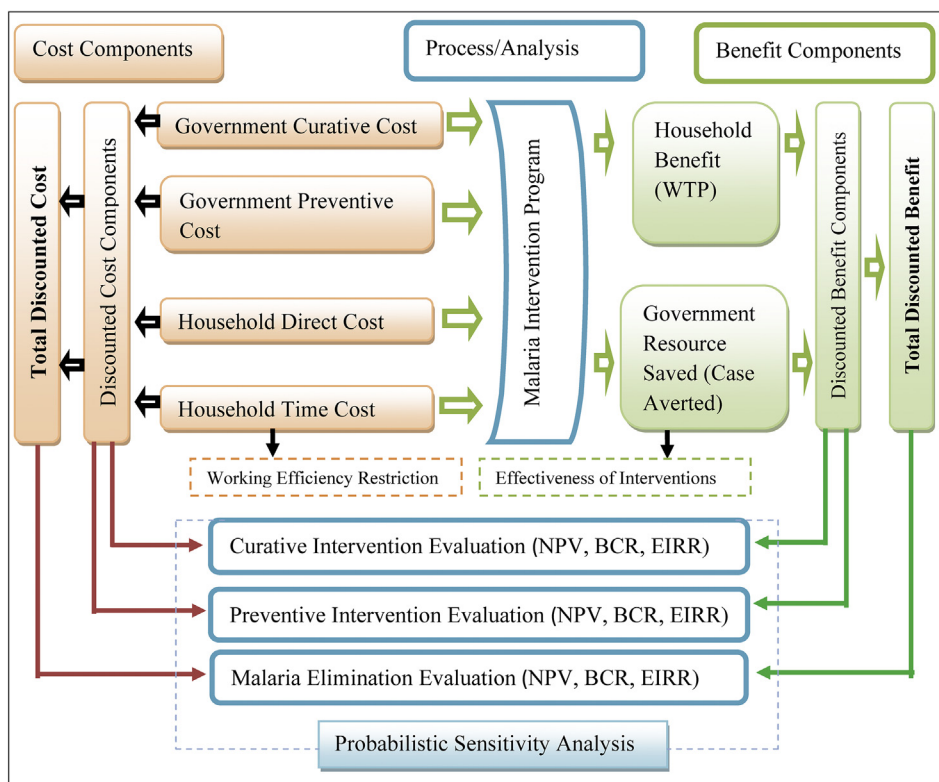


Figure 2. Analytical framework of the study.

discussions. The costing viewpoint accounts for the costs of services both to the provider and the consumer of the health services. Therefore, costs of interventions are broadly classified into four categories: curative and preventive costs of the government, and direct out of pocket costs and time costs of the households.

2.5.1. Cost estimation

- i. **Curative cost:** Government expenses for curative interventions include salary and allowances of health professionals, training for frontline staffs, first-line and second-line diagnosis and medications, equipment employed, capital costs, maintenance, administrative and curative health services utilities. Using a step-down method, these information were identified and used to estimate unit cost per malaria case management (a_1) for recovery including hospital and outpatient cost.
- ii. **Preventive cost:** Government's preventive cost of malaria control in the endemic area was estimated using ingredient approach, which comprises cost incurred on IRS and LLINs. Government cost on preventive services include salaries, fieldwork costs, vehicle repairs and depreciation, fuel, insecticides, spraying equipment, maps and stationery goods, monitoring and supervision, and training. Per household government preventive cost (b_1) is the sum of cost for IRS and LLINs (one net per 1.6 people in rule) [14] per household.
- iii. **Household direct cost:** Direct costs of case households are the private cost of getting preventive and curative care from the government. The direct curative cost of households (a_2) comprises travel expenses, additional food and lodge, related medicines not provided by the government and fees for admission to health establishments. Similarly, household direct preventive expense of purchasing mosquito nets, insecticides and so on (b_2). The average household direct costs are calculated by adding the average value of both direct preventive and direct curative costs, using the ingredient approach. Considering that the antimalarial

medications are free of government charges, household extra expenditure on such medication are only included in the household costs to prevent double counting.

- iv. **Household time cost:** The household direct time costs include curative time cost (travel time, hospitalized days, home bed rest during symptomatic period, recovery time, restricted time and time of caregiver) (a_3) and preventive time cost (IRS time, time for participation in awareness program, filling drainages to prevent mosquitos, daily net fitting time) (b_3). These costs are estimated by the average of government pay rate and market wage rate (i.e. USD 2.4 per day) for estimating the household's average total time cost.

The total cost of the interventions is given by the sum of all the above costs. Total cost (TC) of malaria intervention is estimated using mathematical equation (Equation 1).

$$TC = (a_1 + a_2 + a_3) X + (b_1 + b_2 + b_3) Y + Management Costs \quad (1)$$

Where, a_1 : Government unit cost per case management, a_2 : Household direct curative cost, a_3 : Household curative time cost, X : Number of cases in the reference year, b_1 : Average annual government cost of IRS and LLINs per household, b_2 : Household direct preventive cost, b_3 : Household preventive time cost, Y : Number of risk households in the malaria-endemic area.

2.5.2. Benefit estimation

Benefits generated from malaria intervention are separately estimated through the perspective of service providers (government) and payers (households). The benefit of the government is estimated by the number of averted malaria cases due to intervention (resources saved), using data from time series. Benefits from the malaria intervention generated by households are estimated using WTP method. As suggested by Viscusi (2011) [28], the WTP method is one of the best approaches to elicit benefits from disease mitigation risk of mortality/morbidity.

Viscusi also argued that the maximum WTP could capture the VSL's true value, either in terms of DALY/QALY or in terms of money. The total benefit from malaria elimination is aggregated by adding up household benefits and government benefits.

a) Government benefit estimation through cases averted approach:

The number of averted cases of malaria for a given year is calculated in Eq. (2):

$$\text{Averted cases of malaria} = C - C_i \tag{2}$$

C = Number of cases of malaria without interventions,

C_i = Number of cases of malaria with interventions.

i) **Identification of cases of malaria with intervention:** Number of malaria cases with interventions (C_i) focuses on actual data published by DoHS for the years 2004–2014 and projections for 2015 to 2025. Here, malaria cases are expected to decrease exponentially to hit one case per 10,000 risk population by 2025. Estimates of malaria cases and risk population for 2014 to 2025 have been adjusted with the current population growth rate in the endemic districts.

ii) **Estimation of possible malaria cases without intervention:** Malaria cases without intervention (C) are sensitive to several factors such as population growth rate, efficacy of IRS and LLINs, contemporary incidence rate, climate and environmental factors, vector density, transmission rate, pre-intervention recorded cases and household behavior among others. Reported cases of malaria from 1963 to 2014 are accessible on DoHS publications, but government expenditures attributing to the sharp reduction in the number of malaria cases from 2004 to 2014 are hardly available. Consequently, the incidence of malaria without interventions was assessed using reported malaria cases of 11 consecutive years prior to 2004. Reported malaria cases over the period 1993–2003 seem to be similar to each other without any major substantive change. Therefore, an average of cases over this 11 year period is presumed to be a representative constant case of malaria for the study period without any intervention. With regard to this statement, one can argue that cases that may be in increasing rate due to climate change and at least with population growth rate (1.35%) [29], but there are also some possibilities to decrease cases of malaria along with improved education and improving life style of people at risk.

And finally, the unit cost per case management of malaria borne by households and government for the base year multiplied by number of the cases prevented from the year gives money saved at the base year level. This information also helps to estimate the effectiveness of Nepal's malaria intervention program.

b) Household benefit estimation through the maximum WTP

The maximum WTP was elicited using a hypothetical scenario with the explanation of household benefits after the malaria elimination in terms of reducing morbidity risk and other direct/indirect cost savings. Three steps were taken to estimate the WTP of case and non-case households.

Step - 1: Reduction of possible starting point bias: Among the contingent valuation methods (CVM) some studies argued that the WTP is an insignificant indicator of real WTP with starting point bias problem [30]. Studies also reported, however, that CVM is a reliable method for estimating the maximum WTP [31, 32] by setting a robust bid starting point. The bid starting point of case households for the maximum WTP was validated by a pretest of the questionnaire and triangulation of three aspects: i) average of the maximum amount that obtained during pretest of the questionnaire conducted among 12

case households (USD 47), ii) amount premeditated from total cost of interventions divided by the number of households at risk in the district (USD 55), and iii) the maximum amount estimated from FGD conducted in Punarbas Municipality Office in the district among the frontline workers (USD 63). The maximum WTP of case households was elicited with support of necessary conjectural background and the starting point of the bid (United States Dollars, USD 56).

The starting point for bids of non-case households (USD 22) was also fixed by triangulation of the three aspects: i) average of the maximum WTP of 12 non-case households obtained during the pretest of the questionnaire (USD 20), ii) amount obtained from the total cost of the intervention divided by the number of households at risk in the district (USD 24), and iii) maximum amount acceded from a FGD in Local Government Office of Punarbas among the frontline workers of three political party members (USD 23).

Step - 2: Administrating the questionnaire: The questionnaire was pretested before the administration. Before starting the bid, the respondents were encouraged to refer their family members [33].

Step - 3: Shaping average maximum WTP: The average maximum WTP of case households and non-case households were separately elicited by taking an average of the responses of the respective households.

Applying these three steps, the household maximum WTP for malaria elimination was elicited as the benefit of the malaria elimination at the risk community. The average WTP of case and non-case households were calculated separately, and used for estimating respective benefits.

B. Intervention-wise Total Cost and Total Benefit Estimation

Benefits and costs of the malaria intervention estimated using survey data and time series data are used as complementary information to estimate the discounted total benefits and total costs from a national perspective.

The costs and benefits of both the curative and preventive interventions were estimated and analyzed based on the estimated costs and benefits from the survey. The total cost for both the interventions is the government's separate annual cost of malaria intervention at a constant price from 2004 to 2014. Meanwhile, estimation of the curative benefit depends only on the number of case households, while estimation of the preventive benefit depends on the number of households at malaria risk. This is because the curative cost differs with cases of malaria and the preventive cost be the same for all the people at risk.

1. Curative cost and benefit estimation in relation to case households

The curative costs are the money, time and other resources forgone for the country's total case management, and estimated as given in Eq. (3). It is assumed that this cost declines proportionately, as the numbers of cases declines. Benefits generated by the country's malaria curative campaign have been estimated by accumulating saved government resources and saving curative cost for the households (Eq. 4).

$$\text{Curative cost} = (\text{Unit cost of case management} \times \text{Total number of cases in the country}) + \text{Household curative cost} (a_2 + a_3) \tag{3}$$

$$\text{Benefit from curative intervention} = \text{government resources saved} + \text{household curative cost saved.} \tag{4}$$

2. Preventive cost and benefit estimation in relation to total household at risk

The preventive cost of the intervention is directly estimated by adding up household preventive cost (number of household at risk × per

household cost on preventive intervention) and government preventative cost (total annual expenditures less the aforementioned curative cost) (Eq. 5). The government preventive cost of the intervention is almost indifferent with malaria case reduction because the preventive measures are necessary until no parasite survives in the country. However, it is true that the preventive cost would absolutely be reduced after maintaining zero case up to certain reference period in the previously affected areas. Benefits obtained from the preventive measures have been estimated by multiplying the total number of households at risk in the country in a particular year with per household WTP (Eq. 6). It is also assumed that the risk of malaria to all the households in the endemic area is almost equal in absence of individual preventive measures; therefore the maximum WTP for preventive measures is assumed alike for all the case and non-case households.

$$\text{Total preventive cost} = \text{Household preventive cost} + (\text{total annual government expenditure on malaria} - \text{curative cost of the government}) \quad (5)$$

$$\text{Total benefits from preventive intervention} = (\text{Total number of households at risk in a particular year} \times \text{average WTP}) + \text{household preventive cost saved} \quad (6)$$

C. Cost Benefit Analysis

The discounted benefits were compared to the discounted malaria elimination intervention costs, at an annual discount rate of 10 percent [9]. The curative and preventive cost benefit analyses were performed separately, followed by a combined CBA of the both interventions with cost and benefit projected by 2025.

A sensitivity analysis was conducted consistently in the precepts of formal decision-theory which affects determination of the optimal instant decision [34, 35], without fully mentioning utility approach in case of the projecting scenario. In order to assess the sensitivity, incidence growth rates are assumed to be -1.35 percent and 1.35 percent of the base rate (as the current population growth rate in Nepal is 1.35 percent) for curative services and, -10 percent and 10 percent of the base rate of the maximum WTP for preventive services.

3. Results

3.1. Effectiveness of interventions

Effectiveness of the malaria intervention in a given time period is reflected by the number of averted cases due to the intervention within the analysis horizon. Figure 3 exhibits the number of cases averted owing to the malaria intervention in one year. The result reveals that in Nepal,

there should be no more than 468 cases per year to reach the target of malaria elimination by 2025.

3.2. Efficiency loss of malaria-infected persons

On an average, 1.7 h (variance = 0.84) a day is restricted for one year due to malaria-induced weaknesses relative to before the disease infection, which means that in aggregate malaria infection will theoretically decrease a person's work performance by about 21 percent for one year.

3.3. Cost and benefit estimation in household perspective

3.3.1. Government Cost

A malaria patient in Nepal on average requires USD 4 to have curative service from a government hospital or a health-post. IRS covers only 36% [20] of total households at risk. The unit cost of IRS is USD 2.87 per household per annum. The cost of LLINs is USD 2.00 per household per annum. Therefore the government's preventive cost to control malaria per household per year in the study area is USD 4.87.

3.3.2. Household cost

Although diagnostic and treatment services for malaria are freely available in government hospitals, malaria-affected households must incur a direct cost of USD 17 and a total time cost of USD 30 per household to receive such curative services. The average time cost per household for access to preventive services such as LLIN and IRS is estimated at USD 5. Thus, the average opportunity cost per household is estimated at USD 35. A substantial share of the total time cost (83.59%) is for accessing the curative services. On average; an adult affected loses about 4 days in the malaria case management, 2 days by care-takers and about 3 days of absence in school for student.

3.3.3. Benefit estimation

The maximum WTP average for malaria elimination of case households and non-case households are elicited at USD 57 and USD 21 respectively. The key determinants of case household WTP are the severity of disease's pain, followed by income level and the number of small children in the family, but the major determinant of non-case household WTP is the number of small children in the family, followed by the respondent's income level and age. Marital status and level of education did not affect households' WTP.

As shown in Table 1, the total amount of government resources saved as a result of malaria intervention in the country from 2004 to 2014 is estimated at USD 60.07 million.

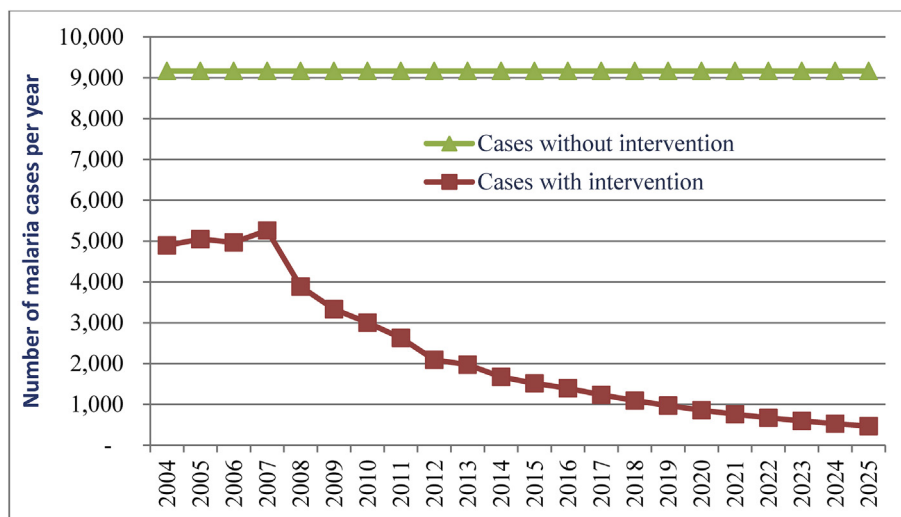


Figure 3. Projected cases with and without the intervention.

Table 1. Cases prevented and government resource saved during the year 2004–2014 (in million USD).

Year	Cases with intervention	Cases without intervention*	Government curative cost at 2014 price	Government resource saved
2004	4895	9167	5.40	4.71
2005	5050	9167	5.65	4.60
2006	4969	9167	3.17	2.68
2007	5261	9167	3.08	2.29
2008	3888	9167	3.72	5.05
2009	3335	9167	5.04	8.83
2010	3004	9167	3.21	6.58
2011	2631	9167	3.80	9.45
2012	2092	9167	1.59	5.39
2013	1974	9167	1.28	4.68
2014	1674	9167	1.28	5.75
Total				60.07

Note: * Following Kim et al. (1997) [31], it is also assumed that the number of malaria cases per year does not change without intervention. Further, epidemiological studies would be required to confirm any change in the cases of malaria without interventions.

3.4. Cost benefit analysis at national perspective

3.4.1. Curative cost benefit analysis for case households

Table 2 indicates that the annual average discounted net benefit of the malaria curative intervention is around USD 2.07 million. The total net discounted benefit (NPV) amounts to USD 22.78 million and internal economic rate of return (EIRR) is 62.76%. The benefit-cost ratio (BCR) of the malaria curative interventions is 1.58. The standard deviation shows that having discounted benefits is at greater risk than the discounted costs of intervention.

3.4.2. Sensitivity analysis

The above findings are based on a key assumption that the annual incidence of 9167 malaria cases remains constant in absence of the intervention. The findings from the sensitivity analysis show that with a ±1.35 deviations from the rate of change on malaria cases over years, NPV ranges from 16.62 million to 29.44 million US dollars and EIRR from 49.58 percent to 75.92 percent (Table 3). This shows that an increase in the gap with malaria case reduction greatly increases the economic returns from the intervention. For example, if malaria infection rises as a result of population growth; the gap between the incidence without intervention and with the intervention will widen, and resource savings will increase. Eventually the economic returns would be higher than the base case. This shows significance of the malaria curative interventions against rising cases of malaria.

3.5. Preventive cost benefit analysis for population at risk

The total net discounted benefit (NPV) of preventive interventions at 10% discount rate is USD 435.18 million with an annual average net discounted benefit of USD 39.56 million as shown in Table 4. The

Table 2. Summary results of cost benefit analysis of the curative intervention of malaria (in million USD).

Results	Discounted cost	Discounted benefit	Discounted net benefit
Sum	39.03	61.82	22.78
Mean (per year)	3.55	5.62	2.07
S.D.	1.61	2.10	2.43
Kurtosis	-1.06	0.13	-1.75
Skewness	-0.051	0.57	-0.17
Minimum	1.36	2.53	-1.04
Maximum	5.88	9.57	5.65
Range	4.51	7.04	6.37

resulting benefit-cost ratio (BCR) is 2.13. As estimated by the sensitivity analysis, the discounted benefits are more sensitive than the discounted costs means that NPV ranges from USD 119.45 million to USD 1014.32 million and BCR from 1.31 to 3.63.

3.6. Combined Cost benefit analysis of Malaria Interventions with Projection from 2004 to 2025

3.6.1. Total costs and benefits from interventions

The total costs and benefits of the 2004 to 2014 intervention are estimated from the reported data. Based on the cost benefit pattern during the period, the intervention's costs and benefits are projected exponentially over the 2015 to 2025 period, assuming investment pattern remains normal. The total cost of intervention is projected at USD 826.79 million over the entire projected period. For sustaining an annual parasite incidence rate of malaria below 0.12 for a thousand populations after 2015, at least USD 36.59 million discounted cost per year will be required.

Benefit components in Figure 4 reveal that government curative cost savings due to case averted from intervention comprise about 7 percent of total discounted benefit. Within the project timeframe, the households produce welfare equivalent to 37 percent of the total societal benefit from malaria intervention valued at USD 1900 million. Within the forecasted period from 2015 to 2025, at least USD 92.81 million discounted benefit will be generated per year.

3.6.2. Benefit-cost analysis of malaria interventions

Table 5 reveals that the discounted net societal benefit of the intervention is expected to be USD 1.08 billion over the entire projected period. This result of the interventions communicates the economic viability of the elimination of malaria via the expansion of malaria interventions in Nepal's endemic areas. The estimated annual net discounted benefits is around USD 48.92 million. Discounted benefit to cost ratio is 2.3.

Table 3. Sensitivity of NPV and EIRR: Annual incidence without intervention Project Horizon: 2004 through 2014.

Growth in Annual Incidence	NPV @10% (in million USD)	BCR	EIRR (%)
-1.35%	16.62	1.42	49.58
Base case	22.78	1.58	62.76
1.35%	29.44	1.75	75.92

Table 4. Summary results of cost and benefit of preventive intervention of malaria (in million USD).

Result	Discounted cost	Discounted benefit	Net Discounted Benefit
Sum (2004–2014)	385.32	820.50	435.18
Mean (per year)	35.02	74.59	39.56
S.D	1.48	3.31	4.12
Kurtosis	-1.45	-1.19	-0.82
Skewness	0.40	0.05	0.14
Minimum	33.48	69.69	33.60
Maximum	37.48	79.69	45.77

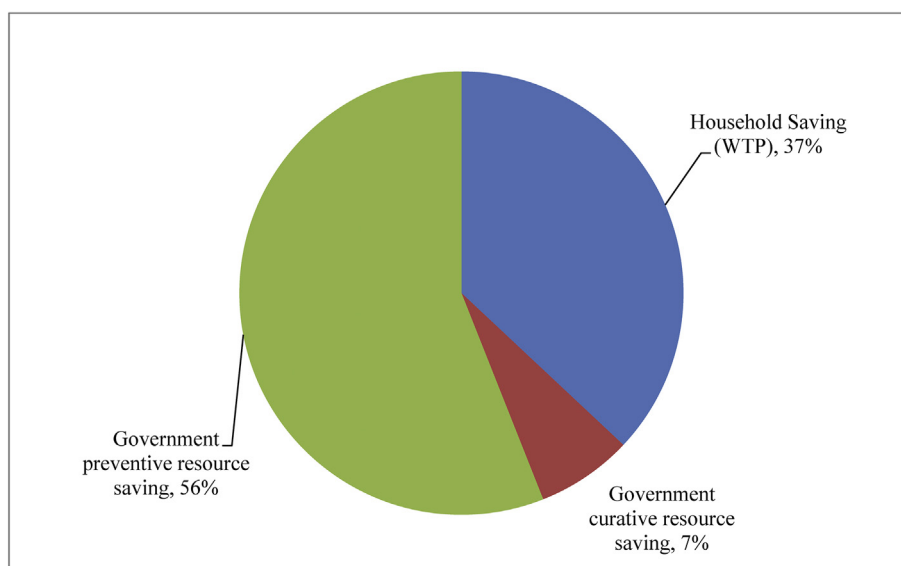


Figure 4. Estimated benefit components of the intervention.

3.6.3. Sensitivity analysis over the projected parameters

Sensitivity analysis is used to delineate the spectrum of possible values for the economic effects of the malaria interventions (Table 6). The findings from the sensitivity study that discounted net societal benefits range from 815 million to 1253 million USD with benefit-cost ratio from 2.25 to 2.51.

4. Discussion

This research shows that public investment in eliminating malaria has the potential to make significant difference to societal welfare. The EIRR value of the curative intervention observed in this study (62%) is almost double of that calculated by Kim et al. (1997) [35], and by Adhikari and Supakankunti (2010) [36]. This large disparity may be attributed to variation in study designs and various medical techniques used in malaria care in different countries. Estimation of EIRR of the preventive intervention is not possible because of the positive net benefit created

right from the start (year 2004). Benefit cost ratio of the preventive intervention (2.13) is between 1.45 by Ginsberg et al. (1993) [37] and 4.12 by Wutzler et al. (2002) [38].

This study's net discounted societal benefit of malaria intervention is higher than the estimates of Global Dracunculiasis Eradication Campaign reported by Kim et al. (1997) [35] and nearly consistent with another similar study in Thailand [39]. The government's projected annual discounted net cost savings is smaller than that reported by Chu's (2010) [40]. The average days missed by person infected by malaria along with caregivers and school children are greater than those reported by Salihu and Sanni (2013) [21] and nearly identical to that recorded by Tawiah et al. (2016) [41].

Apart from biological and methodical effectiveness, the deciding factor in the epidemic elimination system is an economic viability [42]. Economic viability provides clear proof for restricted resource distribution for full net societal benefit [43]. As stated in EDCC (2010) studies, malaria elimination is technically and politically feasible but they have

Table 5. Cost and benefits of malaria intervention throughout the project horizon 2004 to 2025 (in million USD).

Results	Discounted Cost	Discounted benefit	Net discounted Benefit	NPV	BCR
Sum	826.78	1903.24	1076.44	1076.44	2.30
Mean (per year)	37.58	86.51	48.92		
S.D	10.45	21.80	11.43		
Kurtosis	-1.91	-1.87	-1.77		
Skewness	0.304	0.316	0.367		
Minimum	34.86	74.27	32.53		
Maximum	42.71	98.75	60.80		
Range	7.85	24.48	28.27		

Table 6. Sensitivity analysis of NPV and BCR for Project horizon: 2004 through 2025.

Parameters	Extremes of Values	NPV @ 10% Discount (USD in Millions)	BCR
Average household preventive cost	Increase by 10%	1005	2.29
	Decrease by 10%	1147	2.50
Average household curative cost	Increase by 10%	1076	2.30
	Decrease by 10%	1077	2.30
Average household WTP	Increase by 10%	1253	2.51
	Decrease by 10%	899	2.08
National Population at malaria risk	Increase by 1.35%	1076	2.30
	Decrease by 1.35%	815	2.25
Average cases without intervention	Increase by 1.35%	1102	2.43
	Decrease by 1.35%	1055	2.27

Note: Extreme values of household preventive and curative cost and household WTP are around less than 10% of the average values and, the population at risk and malaria possible cases without intervention are supposed with national population growth rate; accordingly the extremes are assigned.

only sufficient power to mobilize enough resources for the action. Economic evaluation is a single, ever robust technique for generating self-motivation from local to national level to mobilize resources, but political engagement can mobilize resources. Thus, malaria intervention without economic evaluation can generate information on short term benefits but with economic evaluation, self-motivation makes the intervention eternally successful in expanding the additional interventions for elimination of malaria through national agenda growth.

Public spending on the malaria control and elimination has positive spillover effects and leads to achieving the Sustainable Development Goals 3 [44]. Sri Lanka and Azerbaijan were active in recording zero indigenous cases of malaria before 2015 [45,46]. Similarly, between 2000 and 2015, 17 nations including Iraq and Oman have managed to sustain zero indigenous cases through government investment in anti-malarial interventions [47]. Since 2012 Nepal has recorded zero malaria death, reporting a pre-elimination phase. However, Nepal's attempts to eliminate malaria do need to consider India's efforts, with whom Nepal shares a land border. With 384 annual deaths [40], more than 1.16 million people in India still suffer from malaria each year. In 2014, 95 imported cases of malaria were registered in Sri Lanka, having maintained zero indigenous cases since 2012, with infections acquired mainly by travelers using route via India [40]. Nearly all of Nepal's malaria-endemic districts have open border with India where malaria prevalence prevails strongly due to diverse socio-environmental conditions [48].

This research is not free of limits. This study has covered cost-benefit analysis of malaria interventions within the borderline irrespective of any possibility of the disease's trans-boundary contact. In fact, this analysis does not consider adverse effects, such as environmental impacts of insecticide spraying, alcohol toxicity, painful diagnostic testing, etc. However, this study estimated economic value of malaria elimination which directly helps in the improvements of health financing framework of evidence based future health programs in developing countries [49]. This research has significant policy implications for resolving the existing investment in infectious diseases for potential gains, taking this malaria CBA study's findings and recommendations. Likewise, malaria CBA is a strong evidence for governments.

5. Conclusions

This study provided a framework for assessing the costs and benefits of malaria elimination by comparing with and without antimarial health interventions, from the experiences of case households and the whole population at risk. The economic analysis concludes that investment in malaria programs has been producing net welfare gain to the economy. Consequently, threefolds increase in societal benefit within years of study and twentyfolds more projected benefit from incurred cost before the project horizon proves that government investment in malaria

intervention is pragmatically sustainable, reliable, efficacious and equitable as well as economically viable. Therefore, malaria elimination is a highly potential investment opportunity in Nepal. As the preventive intervention generates much higher net benefits than the curative intervention, the government should emphasize on preventive intervention while continuing the curative interventions. The findings will be useful for policy architects of malaria intervention in Nepal and other concomitant international agencies fervent to invest in malaria intervention in Nepal. This economic analysis is highly important and useful in understanding the generation of societal benefits from government investment for current malaria intervention programs in countries aimed at malaria elimination. It is necessary to persuade state policy-makers that public investment in the malaria elimination is worthwhile from a societal perspective.

Declarations

Author contribution statement

Uttam Paudel: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Krishna Prasad Pant: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

Authors acknowledge comments and suggestions from faculty members of Central Department of Economics, Tribhuvan University and Bimala Baral, co-worker in research.

References

- [1] R. Shretta, A.L.V. Avanceña, A. Hatefi, The economics of malaria control and elimination: a systematic review, *Malar. J.* 15 (2016) 593.

- [2] P.E. Anyanwu, J. Fulton, E. Evans, T. Paget, Exploring the role of socio-economic factors in the development and spread of anti-malarial drug resistance: a qualitative study, *Malar. J.* 16 (2017) 203.
- [3] S. Incardona, E. Serra-Casas, N. Champouillon, C. Nsanzabana, J. Cunningham, I.J. González, Global survey of malaria rapid diagnostic test (RDT) sales, procurement and lot verification practices: assessing the use of the WHO-FIND Malaria RDT Evaluation Programme (2011–2014), *Malar. J.* 16 (2017) 196.
- [4] R. Wang, S. Tang, J. Yang, T. Shao, P. Shao, C. Liu, et al., Improving local health workers' knowledge of malaria in the elimination phase—determinants and strategies: a cross-sectional study in rural China, *Malar. J.* 16 (2017) 210.
- [5] E. Sicuri, D.B. Evans, F. Tediosi, Can economic analysis contribute to diseases elimination and eradication? A systemic review, *PLoS One* 10 (6) (2015), e0130603.
- [6] D. Cutler, W. Fung, M. Kremer, M. Singhal, T. Vogl, Early-life malaria exposure and adult outcomes: evidence from malaria eradication in India, *Am. Econ. J. Appl. Econ. 2* (2) (2010) pp72–94.
- [7] R. Shretta, S.P. Silal, O.J. Celhay, et al., Malaria elimination transmission and costing in the Asia-Pacific: developing an investment case, *Wellcome Open Res.* 4 (2019) 60.
- [8] R. Maccario, R. Rouhani, T. Drake, et al., Cost analysis of a school-based comprehensive malaria program in primary schools in Sikasso region, Mali, *BMC Publ. Health* 17 (2017) 572.
- [9] J.K. Baird, Asia-pacific malaria is singular pervasive and diverse and invisible, *Int. J. Parasitol.* 47 (2017) 371–377.
- [10] M.T. Hambisa, T. Debelu, Y. Dessie, et al., Long lasting insecticidal net use and its associated factors in Limmu Seka District, South West Ethiopia, *BMC Publ. Health* 18 (2018) 124.
- [11] C.B. Mandayata, L.K. Olowski, W. Mutale, Challenges of implementing the integrated disease surveillance and response strategy in Zambia: a health worker perspective, *BMC Publ. Health* 17 (2017) 746.
- [12] Bhatt S, Weiss DJ, Cameron E et al. The effects of malaria control on *Plasmodium Falciparum* in Africa between 2000 and 2015. *Nature.* vol. 526, 207–211.
- [13] D.J. Kyabayinze, J. Achan, D. Nakanjako, et al., Parasite-based malaria diagnosis: are health systems in Uganda equipped enough to implement the policy? *BMC Publ. Health* 12 (2012) 695. <http://www.biomedcentral.com/1471-2458/12/695>.
- [14] Ministry of Health and Population, Annual Report 2015, Department of Health Services, Kathmandu, Nepal, 2015, pp. 86–92.
- [15] Ministry of Health and Population, Annual Report of Micro Stratification of Malaria Control Activities 2013, Department of Health Services, Government of Nepal, Kathmandu, Nepal, 2013, pp. 12–37.
- [16] World Health and Research Centre, Micro-stratification of Malaria Risk in Nepal, Nepal, Kathmandu, 2013. <http://www.edcd.gov.np/malaria-control-program>.
- [17] Ministry of Health and Population, Annual Report 2015, Department of Health Services, Kathmandu, 2015, pp. 1–6.
- [18] E.V.K. Fitzgerald, Public Sector Investment Planning for Developing Countries, Macmillan Publishers limited, Houndmills, Basingstock, Hampshire RG212XS, 1978.
- [19] S. Russell, The economic burden of illness for households in developing countries: a review of studies focusing on malaria, tuberculosis, and human immunodeficiency virus/acquired immunodeficiency syndrome, *Am. J. Trop. Med. Hyg.* 71 (2004) 147–155.
- [20] K.P. Pant, Cheaper fuel and higher health costs among the poor in rural Nepal, *AMBIO* 41 (3) (2012) 271–283.
- [21] N.A. Braathen, H. Lindhjem, S. Navrud, Valuing Lives Saved from Environmental, Transport and Health Policies: A Meta-Analysis of Stated Preference Studies, OECD, Paris, 2000.
- [22] GoN-The Treasury, Guide to Social Cost Benefit Analysis, Government of New Zealand, 2015. <http://www.treasury.govt.nz/publications/guidance/planning/costbenefitanalysis/guide>.
- [23] H. Lindhjem, et al., Meta-analysis of Stated Preference VSL Studies: Further Model Sensitivity and Benefit Transfer Issues, OECD, Paris, 2010.
- [24] G. Atkinson, S. Mourato, Environmental cost-benefit analysis, *Annu. Rev. Environ. Resour.* 33 (1) (2008) 317–344.
- [25] A.A. Schmid, Economic Analysis and Efficiency in Public Expenditure. Working Paper, 04-05, Department of Agriculture Economics, Michigan State University, East Lansing MI, 2004.
- [26] W.K. Viscusi, The heterogeneity of the value of statistical life: introduction and overview, *J. Risk Uncertain.* 40 (2010) 1–13.
- [27] L. Lindholm, M. Rosen, G. Hellsten, Are people willing to pay for a community-based preventive program? *Int. J. Technol. Assess. Health Care* 10 (1994) 317–324.
- [28] W.K. Viscusi, What's to know? Puzzles in the literature on the value of statistical life, *J. Econ. Surv.* (2011) 1–8.
- [29] Central Bureau of Statistics, Nepal Living Standards Survey 2010/11: Statistical Report, Kathmandu, National Planning Commission Secretariat, 2011. http://cbs.gov.np/wp-content/uploads/2012/02/Statistical_Report.
- [30] D. Kahneman, A. Tversky, Prospect theory: an analysis of decision under risk, *Econometrica* 47 (1979) 263–291.
- [31] P.R. Portney, The contingent valuation debate: why economists should care, *J. Econ. Perspect.* 8 (1994) 3–18.
- [32] E.J. Mishan, The plain truth about consumer surplus, *Zeit-schrift fur Nationalökonomie.* 37 (1997) 1–24.
- [33] O. Onwujekwe, J. Ojukwu, N. Ezumah, B. Uzochukwu, N. Dike, E. Soludo, Socio-economic differences in preferences and willingness to pay for different providers of malaria treatment in southeast Nigeria, *Am. J. Trop. Med. Hyg.* 75 (2006) 421–429.
- [34] B. Balo, A.P. Dawid, Probabilistic sensitivity analysis in health economics, *Stat. Methods Med. Res.* (2011).
- [35] A. Kim, A. Taddon, E. Ruiz-Tiben, Cost Benefit Analysis of the Global Dracunculiasis Eradication Campaign, The World Bank, Washington DC, 1997.
- [36] S.R. Adhikari, S. Supakankunti, A cost benefit analysis of elimination of kala-azar in Indian subcontinent: an example of Nepal, *J. Vector Borne Dis.* 47 (2010) 127–139.
- [37] O.M. Ginsberg, I. Kassis, R. Dagan, Cost benefit analysis of Haemophilus influenzae type b vaccination programme in Israel, *Br. Med. J.* 47 (6) (1993) 485–490.
- [38] P. Wutzler, A. Neiss, K. Banz, A. Goertz, H. Bisanz, Can varicella be eliminated by vaccination? Potential clinical and economic effects of universal childhood varicella immunization in Germany, *Med. Microbiol. Immunol.* 19 (2002) 89–96.
- [39] P. Sudathip, D. Kongkasuriyachai, R. Stelmach, et al., The investment case for malaria elimination in Thailand: a cost benefit analysis, *Am. J. Trop. Med. Hyg.* 100 (2019) 1445–1453.
- [40] B.K. Chu, P.J. Hooper, M.H. Bradley, D.A. McFarland, E.A. Ottesen, The economic benefits resulting from the first 8 years of the global program to eliminate Lymphatic Filariasis (2000-2007), *PLoS Neglected Trop. Dis.* (2010) 20532228.
- [41] T. Tawiah, K.P. Asante, R.A. Dwommoh, A. Kwarteng, S. Gyaase, E. Mahama, et al., Economic costs of fever to households in the middle belt of Ghana, *Malar. J.* 15 (68) (2016), 2016.
- [42] S.K. Bhattacharya, D. Sur, P.K. Sinha, J. Karbwang, Elimination of Leishmaniasis from the Indian subcontinent is technically feasible and operationally achievable, *Indian J. Med. Res.* 123 (2006) 195–196.
- [43] R.C.W. Hutubessy, L.M. Bendib, D.B. Evans, Critical issues in the economic evaluation of interventions against communicable diseases, *J. Acta Trop.* 78 (2001) 191–206.
- [44] RBM Partnership: to End Malaria, Global Health Campus, Geneva, 2018. http://endmalaria.org/sites/default/files/RBM%20Annual%20Report%202018_EN.pdf.
- [45] G. Vries, S. Tsolova, L.F. Anderson, et al., Health system factors influencing management of multidrug-resistant tuberculosis in four European Union countries - learning from country experiences, *BMC Publ. Health* 17 (2017) 334.
- [46] R. Newman, Malaria control beyond 2010, *Br. Med. J.* 341 (7765) (2010) pp182–183.
- [47] World Malaria Report 2018. <http://www.who.int/malaria/publications/>.
- [48] K. Wangdi, M.L. Gatton, G.C. Kelly, C. Banwell, V. Dev, A.C.A. Clements, Malaria elimination in India and regional implications, *Lancet Infect. Dis.* 16 (10) (2016) e24–e224.
- [49] A.A. Hyder, G. Bloom, M. Leach, et al., Exploring health systems research and its influence on policy processes in low income countries, *BMC Publ. Health* 7 (2007) 309.