Climate and Development

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tcld20

Cost effective adaptation to flood: sanitation interventions in the Gandak river basin, India

Purnamita Dasgupta , Samraj Sahay , Anjal Prakash & Arthur Lutz

To cite this article: Purnamita Dasgupta , Samraj Sahay , Anjal Prakash & Arthur Lutz (2020) Cost effective adaptation to flood: sanitation interventions in the Gandak river basin, India, Climate and Development, 12:8, 717-729, DOI: 10.1080/17565529.2019.1682490

To link to this article: https://doi.org/10.1080/17565529.2019.1682490

CLIMATE AND DEVELOPMENT
2020, VOL. 12, NO. 8, 717–729
https://doi.org/10.1080/17565529.2019.1682490

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

OPEN ACCESS Check for updates

Cost effective adaptation to flood: sanitation interventions in the Gandak river basin, India

Purnamita Dasgupta [a], Samraj Sahay[b], Anjal Prakash[c] and Arthur Lutz[d,e]

[a]Environmental & Resource Economics Unit, Institute of Economic Growth, New Delhi, India; [b]Independent Researcher, New Delhi, India; [c]TERI School of Advanced Studies, Hyderabad, India; [d]FutureWater, Wageningen, Netherlands; [e]Department of Physical Geography, Utrecht University, The Netherlands

ABSTRACT
The Hindu Kush Himalayan (HKH) region comprises of areas which are highly vulnerable to flood risks. The region faces challenges from multiple non-climate stressors such as poverty, environmental and climate shocks, and inadequate infrastructure. Addressing these deprivations in ways that reduce vulnerability associated with a changing climate are critical for the communities that live here. This paper combines data on flood risks derived from a climate–hydrology model under two future scenarios of RCP 4.5 and 8.5, with socio-economic data from communities in the Gandak basin, to demonstrate how mainstreaming climate change impacts into decision-making for sanitation interventions can reduce socio-economic vulnerability to flooding. A Cost-effectiveness analysis of the alternative interventions for sanitation reveals that gains are substantially higher under an intervention that takes note of climatic events, both for the present and in the future. Substantial health costs and inconvenience losses that are particularly acute for women during floods can be averted by investing in climate-friendly options. Climate adaptation (SDG goal 13 on climate action) can be synergistic with the achievement of other SDGs (Goal 6 on sanitation, goal 3 on health and well-being, goal 5 on gender).

ARTICLE HISTORY
Received 29 July 2018
Accepted 16 October 2019

KEYWORDS
Climate change; flood; cost-benefit analysis; sanitation; adaptation; Gandak River Basin; RCPs; cost-effectiveness analysis

1. Introduction

The Hindu Kush Himalayan (HKH) region is a global climate hotspot (Cochrane et al., 2017) and faces multiple risks from climate and weather conditions (Khadka, Babel, Shrestha, & Tripathi, 2014). A major concern is the current occurrence and future risks associated with floods (Elalem & Pal, 2015; Nibanupudi, Gupta, & Rawat, 2015). In an RCP4.5 scenario, loss of glacial mass (Kraaijenbrink, Bierkens, Lutz, & Immerzeel, 2017), and the occurrence of more frequent, wetter days in the HKH over shorter time periods leading to floods and landslides (Lutz et al. 2016a) could be significant risks.

Widespread poverty, lack of access to water, sanitation, clean energy and health care facilities, unemployment, poverty and inequity (Hunzai, Gerlitz, & Hoermann, 2011; Shrestha, Grabs, & Khadgi, 2015) create complex situations in which climate change impacts amplify existing vulnerabilities. Diarrheal diseases could become more prevalent with changes in freshwater and the frequency of flood events (Ebi, Woodruff, von Hildebrand, & Corvalan, 2007) while landslides and floods can adversely impact vulnerable groups such as the poor, women and children (Eriksson, Fang, & Dekens, 2008). Thus, to be effective in addressing deprivations, developmental interventions need to be adaptive, taking cognizance of the climate-related risk and mainstreaming it into decision-making.

At the household level, access to sanitation and water becomes a critical concern during floods in the region (Mukherji, Scott, Molden, & Maharjan, 2018). The provision of sanitation, in particular, has important welfare implications with positive externalities for individual health status, women's well-being and public health (Minh & Hung, 2011; UN, 2018). However, access to sanitation remains a challenge.

The Indian government has had various rural sanitation programmes since the 1950s, with the Swachh Bharat Mission (GoI, 2018), launched in 2014, being the most recent one. Its objectives include eliminating open defecation, accelerating sanitation coverage, encouraging cost-effective and appropriate technologies for ecologically safe and sustainable sanitation, creating positive impact on gender and promoting social inclusion through improved sanitation. An incentive amount of up to INR 12000 is provided for construction of a toilet by a household. Although the guidance on technologies mentions that the appropriateness of technology differs by hydrological conditions and geology, there appears to be a clear preference on the ground to implement a particular technology where the construction costs are well within the standard incentive amount offered.

Given the acute deficits in sanitation in the region, we choose technology options to demonstrate how climate risk management can be integrated with development targets for poor and marginalized households. The study presents evidence that the cost-effectiveness of the technology options changes substantially when the costs of current and future flood events are incorporated, including the intangible benefits

CONTACT Purnamita Dasgupta purnamita.dasgupta@gmail.com

that can be crucial for the poor and the women in the area. Our approach reveals that engineering or construction cost-based norms can under-estimate the benefits of integrating climate risks into infrastructure design, and the importance of capturing non-marketed benefits in such assessments. It clearly establishes the need to assess the costs arising from floods in the study area while choosing technology. The findings indicate that policy interventions that promote sanitation at the community and household level need to be sensitive to these specificities and the interaction effects between technology and climate change, in their pursuit of national and international development targets. Making climate adaptation (SDG goal 13 on climate action) synergistic with the achievement of other SDGs (Goal 6 on sanitation, goal 3 on health and well-being, goal 5 on gender) is feasible.

The paper is organized as follows. Following the introduction in Section 1, Section 2 provides a brief rationale for the study and describes its methodology. Section 3 presents data and assumptions, Section 4 presents the results while Section 5 concludes with a discussion on the relevance of these findings for implementing ecological sanitation as an effective adaptation response.

2. Methods of the study

An extensive review of the literature on climate risks and vulnerabilities in the HKH region, and interactions with experts on public health, gender and climate were used to design the study. The key elements of the design are – [1] collection of data on flood events, socio-economic characteristics and sanitation through focus group discussions, key informant interviews and household survey; [2] analysis of survey data using techniques of cost–benefit analysis (CBA) and [3] simulation of future climatic scenarios and the potential for gains from improved sanitation.

2.1. Collection of primary information and data

A mixed method approach, with qualitative and quantitative methods, was adopted for gathering primary information. Interviews were conducted with semi-structured questionnaires and checklists were used for focus group discussions (FGDs). A structured questionnaire was used for the household survey. The tools, FGDs and interviews were mostly in the local language (variants of Hindi). A mix of audio recordings and hand-written verbatim notes of the proceedings was taken, depending on whether a participant felt comfortable with the recording process.

The household survey included questions on household and demographic characteristics, income by sources and occupation, access to water and sanitation, utilization and costs of construction and maintenance of toilets as applicable, economic and social costs and benefits from sanitation, details of losses incurred during flood events, coping and adaptation measures. The major domains for data collection for the key informant interviews and FGDs were: village-level characteristics (geographical, biophysical, land use, demography, livelihoods and occupational profile, public and community institutions, connectivity, access to water and sanitation); experience of extreme events and natural disasters (including changes observed over the last 5–10 years in timing, frequency and intensity of events); village-level adaptation responses to floods across sectors including agriculture, water and sanitation (embankments, early warning systems, flood-resistant infrastructure, institutional community response mechanisms).

Key informant interviews were held with staff of NGOs and government agencies actively involved with implementation of public health programmes, disaster management, flood and irrigation departments, water and sanitation departments. Village heads, other Panchayat members, anganwadi (child health) workers, religious and social leaders (such as *Vikas Mitra*), and school teachers were also interviewed. FGDs were conducted with both men and women. Every effort was made to ensure equal representation from men and women, however, this ratio varied, with the share of women participants being over 60% in the FGDs. The FGDs had representation from both general and *backward* communities (as in certain castes, tribes, and disadvantaged sections of society identified through government lists: GOI, 2016a).[1] The FGDs lasted for approximately 60–90 min and consisted of a minimum of 5 and a maximum of 10 persons per village.

2.2. Cost benefit analysis from household survey data

Selection of the most appropriate technology options calls for evaluating the avoided costs of available alternatives and their effectiveness in achieving the desired reduction in climate impacts (Girard, Pulido-Velazquez, Rinaudo, Pagé, & Caballero, 2015; Mckinsey, 2009a). A CBA exercise can contribute in ensuring that decision-makers have information relevant to this community of flood-prone households, whose values are not otherwise adequately accounted for in monetized estimates (Chambwera et al., 2014; Dasgupta, 2016; USAID, 2016).

We conduct a cost–benefit analysis for choosing between two sanitation interventions, both of which have the potential to help India progress in achieving SDGs. In designing the CBA, the study makes a serious attempt to address some of the commonly perceived concerns with the CBA exercise. Specifically, concern with CBA has been (a) its inability to capture non-monetary values (as in the case of say ecosystem services), (b) a lack of dimensions of well-being that are normative (for instance gendered differences), (c) aggregation of multiple values that can ignore winners and losers if distributional criteria are not explicitly built into the design and (d) the choice of the appropriate discount rate, particularly when climatic events are being analysed (Atkinson, Bateman, & Mourato, 2012; Kolstad et al., 2014). The approach adopted here does the following. First, it is designed and conducted in the specific context of the marginalized community. Second, the study innovates to include the values of an intangible labelled as '(in)convenience'. Third, the methodology explicitly brings in the gendered perspective in the design. Fourth, it presents findings for the future in terms of cost-effectiveness under future climate scenarios with a sensitivity analysis as recommended in the literature (Chambwera et al., 2014; Kolstad et al., 2014).

The available options in sanitation for the selected sample were identified through the focus group discussions and key informant interviews, while data from the household survey were analysed to conduct a quantitative evaluation of the benefits and costs of the available options in terms of their potential to reduce losses while explicitly factoring in the impacts of climate change which poses flood risks to the sample population. The approach used is standard,[2] and two alternative criteria are computed: the benefit-cost ratio and the net present value. Costs include Capital costs and Operation and Maintenance (O&M) costs while the monetized benefits include health, convenience and fertilizer usage benefits. The assumptions and data aspects are discussed in Section 3.

The interventions discussed here, namely building toilets, are subsidized and targeted at the poor and disadvantaged. In such situations, a cost curve analysis that can compare across alternative measures to deliver the desired outcome provides valuable insights for policy (Mckinsey, 2009b). Note though that in the present case, the averted costs have been expressed directly in monetary terms. The cost curve is derived by plotting the benefit-cost ratio for the two sanitation measures against the cumulative averted costs, with the width of each bar representing the potential for averting losses.

2.3. Methodology for projecting flood events and future losses

Projected changes in precipitation extremes are used as a proxy to project future risks of flooding due to climate change. This study uses the Representative Concentration Pathways (RCPs) (van Vuuren et al., 2011) for projecting the future risk. Eight representative climate change scenarios are considered; four for RCP4.5 and four for RCP8.5. (Lutz et al., 2016a; Lutz et al., 2019). RCP4.5 is a scenario assuming stabilization of radiative forcing resulting from greenhouse gases halfway into the twenty-first century, whereas RCP8.5 can be referred to as a business as usual scenario with a continuing increase in greenhouse gas concentrations throughout the twenty-first century. We use these two RCPs, and four different downscaled climate scenarios for each RCP, to cover a large range of possible futures in terms of climate change.[3] Details on the climate dataset used can be found in Lutz et al. (2016a). It spans a 30-year reference period (1981–2010) and covers the period 2011–2100 for eight downscaled climate scenarios. All data is at a 10 × 10 km spatial resolution and daily temporal resolution. The grid cells in and around the catchment are considered for the analysis and the average of these grid cells is taken to increase the reliability of the results. Since residents reported that floods occurred historically 2–3 times per year, the daily sum of precipitation events that recur on average 1.5 times per year during the historical period (1981–2010) has been analysed. Subsequently, for events, the changes in their frequencies in the future are computed. This is done for all eight projections for multiple future time slices separately (Figure 3). There is substantial variation in the full range of the ensemble results. As residents reported up to 3 flood events in a year, with an increase in the flood events in recent years, to project flood events in the future, the difference between the ensembles reference year value (1981–2010) and the actual reported flood events was used to scale the projected values obtained from the ensembles.

3. Data and assumptions

3.1. Study area

The study area is in West Champaran, a district in the state of Bihar in India (Figure 1).

The selected district has low literacy levels and limited infrastructure and connectivity. Both regular and flash floods affect the district, which shares an international border with Nepal in the North. Villages in Bettiah and Narkatiaganj sub-division were selected for the study. FGDs and key informant interviews

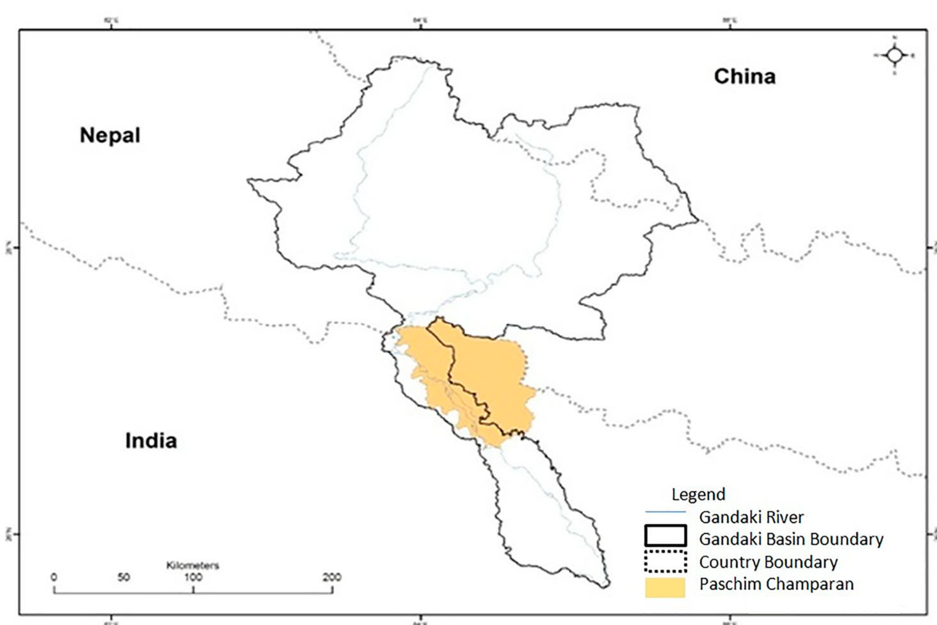

Figure 1. Map of the study area.
Source: ICIMOD, 2018

were conducted with officials at Bettiah headquarters and respondents from these villages. Two villages were purposively chosen for the study – Charkhi Viswambharpur (Charkhi) and Kairi. In all five formal FGDs[4] were conducted, two in Charkhiand three in Kairi, during the first phase of the study for understanding the issues and piloting the tools. The second phase involved the detailed household survey. The household survey was carried out in Kairi where both types of toilet designs were available, and data could be collected on all the required variables. However, there were data and other constraints in valuing the convenience benefits in Kairi. The information gained from the FGD and key informant interviews done in Charkhi in the first phase of the study, were used for quantification of the convenience benefits that could be associated with sanitation interventions during floods. The village is subject to regular floods, does not have access to a formal early warning system, most households are below the poverty line, and has huge deficits in terms of access to sanitation. It thus provided a baseline for understanding the averted costs of not having access to sanitation for the households. Kairi village consists of three settlements (locally called *tolas*): Khekaria, Kairi and Amarahawa and was a natural choice for the CBA since it is the only village in the area that has more than one functional toilet of alternative designs, each with varying implications for cost-effectiveness. The village is also highly prone to flooding from the Pandai River, following heavy precipitation events.

3.2. Sample characteristics: Kairi village

Kairi had 167 households (as per village records), all of which were covered in the initial enumeration. The detailed survey followed for all households which had a toilet along with a sub-sample from those who did not have any toilets. The door to door exercise for complete enumeration led to classification of households into three types – those practising open defecation, households with DPF toilets and households with ES toilets. The village had 4 households with ES toilets and 11 households with DPF toilets; all 15 were included in the costing exercise. In addition, as controls, households that did not have toilets, but matched these 15 households in terms of certain criteria were included in the household survey. The criteria were (a) Economic status – determined by the size distribution of landholding (b) Social status – ensuring representation of all the castes, tribes and religions in the village (c) Geographic location – representation from the three settlements in Kairi was required as the level of vulnerability to flooding differs across these, with two being closer to the river and experiencing complete inundation during floods, and one being less affected. Data on these three aspects was collected during the initial enumeration of the entire village. Shortlists of households meeting overlapping criteria that matched with those that had toilets were created. The selection of a household without a toilet from among the short-listed ones was done randomly.

Thirty households without toilets were selected (see Table 1 for the socio-economic characteristics of the sample) providing a 1:3 ratio between households with and without toilets. Inclusion of households practising open defecation (i.e without toilets) provided a basis for comparison of the reported differentials in the incidence of illness and convenience with and without toilets. Intensive interactions with these households provide insights on the reasons for not having a toilet till the time of the survey. As shown in table 2, administrative issues and lack of awareness were the top two factors explaining the lack of toilets (column 1). Local officials, however, felt that

Table 1. Socio-economic characteristics of the sample households.

		Percentage distribution of households[a]
1. Social category		
Scheduled Tribes[b]	Tharu	82.22
	Oraon	8.89
Scheduled Castes[c]	Pasi	2.22
Other Backward Classes (OBC)[d]	Nai	4.44
	Churihar	2.22
2. Land holdings	Landless	42.22
	Less than 1 Acre[e]	40.00
	More than 1 Acre	17.78
3. Type of structure	Kuccha[f]	40.00
	Semi-Kuccha	33.33
	Pucca	26.67
4. Source of drinking water	Dug well	26.67
	Hand pump	51.11
	Hand pump with filter	22.22

Source: Authors survey and calculations.
[a]Total households (sample) – 45.
[b]Scheduled Tribes (ST) – Article 366(25) of the Constitution of India defines scheduled tribes as 'such tribes or tribal communities or part of it, or group within such tribes, or tribal communities as are deemed under Article 342 to be scheduled tribes for the purpose of this constitution'. The criteria for specification include their historical background, geographical isolation, shyness and social, educational & economic backwardness (GOI, 2016b).
[c]Scheduled Castes (SC) – In accordance with Article 341 of the Constitution of India, the President, in consultation with the State Governor, notifies the status of SC. The criteria for specification include extreme social, educational and economic backwardness arising out of traditional practice of untouchability (GOI, 2015).
[d]Other Backward Classes (OBC) – These are the communities and castes which have been included in the central list of OBCs on the advice of National Commission for Backward Classes (NCBC) as envisaged in Section (9) of NCBC Act, 1993. The criteria for specification includes social, educational, economic backwardness and inadequate representation in the Central Government posts and services (GOI, 2015).
[e]1 Acre = 0.4046 ha
[f]Kuccha indicates the use of locally available and non-permanent materials such as thatch, bamboo and mud, while Pucca indicates the use of permanent and durable materials in the construction such as bricks and cement.

Table 2. Sanitation status of sample households.

Households having a toilet		
Number of households with a toilet	15	
Type of toilet used		
Double-pit pour flush	11	
Eco-san	4	
Households practising open defecation		
Number of households without a toilet	30	
Reason stated for not having a toilet[a]	Initial response	Final response[b]
High construction cost/initial investment	20	33
Never thought of it	24	44
Space constraints	23	23
Administrative glitches: the baseline list erroneously lists the household as one with a pre-existing toilet	33	0

Source: Authors survey and calculations.
[a]Percentage distribution amongst households which did not have a toilet.
[b]Response received under the condition that the administrative glitches will be removed.

these issues were being sorted out and would be taken care of soon. A follow-up probe on whether they would build toilets if administrative glitches were taken care of, led to an interesting change in the reasoning, with the maximum numbers saying they had not thought seriously about it as a need while cost considerations were the second most important reason.

3.3. Types of sanitation: Ecosan (ES) and double-pit pour-flush (DPF) toilets

ES toilets are among the more sustainable form of sanitation among available options. The advantages cited are low water usage as compared to flush toilets, environment-friendly on-site disposal, avoidance of costs of large infrastructure for treatment and disposal of waste, segregation of urine and faecal matter facilitating its subsequent use as manure and liquid fertilizer, and reduced faecal contamination of groundwater. The toilets are built on a raised platform ensuring accessibility in areas prone to floods and water-logging and the design varies depending on local factors (Chariar & Saktivel, 2011; Tilley, Luthi, Morel, Zurbrugg, & Schertlenberg, 2008).

DPF toilets have soak pits under the ground. The soak pit should be at least 15 m from any groundwater source (GOI, 2014). In most villages in the district, including Kairi, the water table is high and soak pits were found located very close to the source of water, the latter being usually a hand-pump (*Chapakal*) for pumping out groundwater, which is subsequently used for cooking and drinking purposes. The distance between the source of water for the households and a cluster of closely built soak pit latrines ranged from 12 to 40 feet (3.6–12 m). These conditions create a very real threat of contamination of groundwater due to its proximity to soak pits. These toilets were also constructed at a height of less than one foot (0.31 m) above the ground, as a consequence these were unusable during and after flood events till the pit and the toilet dried up. The cost–benefit analysis incorporates that the expected reduction in diarrhoeal incidence would be lower while the inconvenience associated with non-functionality would be higher with DPF than with ES for these flood prone areas.

3.4. Assumptions for cost-benefit analysis

The data for costs and benefits was mostly based on actuals reported during the survey in Kairi village. The key assumptions are described here while notes on calculations are provided in Table 3.

Costs: Capital including land and O & M costs varies substantially, the former being higher for ES and the latter being higher for DPF. Land is valued at the price at which residential land could be purchased in the village, as reported in the FGD. For DPF higher O&M costs occur since the emptying of the toilet's pit is done by hiring trained personnel with requisite equipment. Floodwaters inundate the DPF toilets, as these are constructed less than one foot (0.31 m) above ground level. The underground soak pits, often fill up with flood waters, creating spillage and associated inconveniences. The toilet is thus unusable during and after a flood, till it is emptied and dry. Based on the responses from the household members, on average such toilets cannot be used for at least 9 days in a year due to this reason. An additional component of an inconvenience cost is added to the DPF to reflect this. There is little variation in the reporting of the basic costs of building toilets and in the health-related data across households, except in terms of specific choices regarding additional features and non-essential materials used in the construction.

Benefits: Three types of benefits from the toilets are considered based on the literature and the discussions in the FGD: health benefits in terms of averted wage loss and averted treatment costs attributable to reduced diarrhoeal illness; convenience in terms of number of days of access to the toilet and avoidance of expenses on alternatives; and manure for agriculture from liquid and solid wastes. These are explained in some detail below as the assumptions made are important for the results of the CBA.

Incidence of illness and sanitation in flood-prone areas: The present study focuses on morbidity from acute diarrhoeal illness, which is a major health concern as stated by the survey respondents. There have been no deaths attributable to diarrhoeal episodes during the last 5 years. Studies have found a positive association between diarrhoeal incidence and flooding in developing countries, although the strength of the association varies (Ahern, Kovats, Wilkinson, Few, & Matthies, 2005; Hashimoto et al., 2014; Hara et al., 1998; Liu et al., 2016; Schwartz et al., 2006). While estimates are context-dependent, estimates suggest that a reduction in diarrhoeal incidence of upto 36% is achievable through improved sanitation interventions (Cairncross & Valdmanis, 2006; Fewtrell et al., 2005; Waddington, Snilstveit, White, & Fewtrell, 2009; WHO, 2011).

Calculations of the reduced cost of illness (from averted wage loss and avoided treatment costs) are based on the assumption of a 36% reduction in illness with access to an ES, and 10% for a DPF, as compared to not having a toilet. In ES toilets, the vaults for storing faeces are above ground and thereby the risk of contamination of groundwater is less compared to toilets with underground pits. Since the faecal matter is also kept dry with ash being added to it, it helps kill the pathogens. This considerably reduces the risk of occurrence of diarrhoea from transmission of pathogens through groundwater contamination. For DPF, although the benefits can go up to 20% reduction under ideal conditions (Uneze, Tajudeen, & Iweala, 2013; Whittington, Hanemann, Sadoff, & Jeuland, 2009), in the study area, there is a failure to comply with the regulations for maintaining minimum distance between the soak pit and the water source and experts felt that even a 10% reduction in illness may be difficult to achieve. This study, therefore, attributes a 10% decrease in incidence of illness from DPF as a benchmark.

Duration and episodes of illness: for rural India the average number of diarrhoeal episodes and the average number of days of illness reported vary across studies (Bern, 2004; Lakshminarayanan & Jayalakshmy, 2015; Lamberti, Walker, & Black, 2012). In the present sample, households typically report two children below 5, while the rest are treated as adults since self-reporting of illness episodes shows that there is no difference between adults and children above 5 years of age. Assuming 6 members on average per household, the weighted average

Table 3. Annual benefits and costs of ecosan (ES) and double-pit pour flush (DPF) toilet.

	Item	Eco-san		Double-pit pour flush		Data source
		Quantity/ unit	Value (INR)	Quantity	Value (INR)	
Costs						
Capital	Land area (including stairs)	44.58 sq.ft	2140	34	1632	Survey
	Construction (materials and labour cost)		17,000		7257	Survey
	Total		19,140		8889	
O & M						
	Minor repairs to structure, labour for emptying manure from vault		200		–	Survey
	Cost of emptying pit		–		600	Survey
	Inconvenience cost[a]				540	Survey
	Total		200		1140	
	Total Costs		**19,340**		**10,029**	
	Total costs in USD		**297.54**		**154.29**	
Benefits						
Health	Average number of diarrhoeal episode/person/year	3		3		Survey
	Average number of days ill during each diarrhoeal episode/person/ year	3.98		3.98		Calculated (Based on literature)
	Average number of days ill per person per year	11.94		11.94		
	Reduction in number of days ill	36% (4.298)		10% (1.194)		Based on literature
	Daily wage rate	200		200		Survey
	Average Treatment cost per episode of illness (INR)	500		500		Survey
	(i)Wage loss averted for the household[b]		2579		716	
	(ii) Treatment cost averted for the household[c]		1620		450	
	Total Health Benefit for a household of 6 person (i + ii)		**4199**		**1166**	
	Total Health Benefit in USD		**64.60**		**17.94**	
Convenience	(i) Benefit of using Eco-san during flood events (@ INR 60 per day/ household/flood event): Avoided cost	3 events	180			Survey and FGDs
	(ii) Convenience benefit from using toilet on regular basis @INR 1/ day[d]	365 days	2190	356 days	2136	
	Total convenience benefit (i + ii)		**2370**		**2136**	
	Total convenience benefit in USD		**36.46**		**32.86**	
Manure/ Fertilizer	(i) Fertilizer from Urine:					Based on Literature
	Nitrogen (@4.01 kg/person/year)	24 kg	216			
	Phosphorus (@0.40 kg/person/year)	2.4 kg	67			
	Potassium (@1 kg/person/year)	6 kg	120			
	(ii) Fertilizer from Faeces:					
	Compost generated per year	100 kg				Survey
	Market price of compost (INR /kg)	2.5				Survey
	Benefits from compost		250			
	Total benefits from manure/fertilizer (i + ii)		653			
	Total Benefits		**7222**		**3302**	
	Total Benefits in USD		**111.11**		**50.80**	
CBA[d]*(Discount rate – 3%; life span of intervention – 10 years)*						
	Net Present Value (NPV)[e] (INR)		47983.37		12859.11	
	Net Present Value(USD)		738.21		197.83	
	Benefit-Cost Ratio[f]		3.30		1.69	

Source: Authors' analysis

Notes: Average household size is 6 members in the sample. All values are expressed in Indian rupees. One US$ equals 65 Indian Rupees (at the time of the survey).

[a]Inconvenience cost due to non-usage during flood events is valued at Rs. 60 per day for a 6 member family for 9 days in a year.

[b,c]A probability of 0.5 (i.e. 50% chance) of falling ill with diarrhoea in a given year has been assumed. Based on self-reporting by the households, this is the probability of occurrence of acute diarrhoea which lasts for more than 2 days and requires treatment. The other episodes are self-limiting and are not perceived to cause major disruptions in activities and nor is treatment sought. Hence, only 50% of the incidence is used for the calculations.

[c]The cost includes costs of transportation, doctor's fees, and expenses on home remedies. For computational purposes, the costs are considered to be distributed proportionately across the days of illness.

[d]This component of the convenience cost seeks to quantify the otherwise implicit or intangible value that villagers reported of having a toilet facility of their own. The averted cost component is incurred even by those with access to DPFtoilet during flood events.

[e,f]The Net Present Value (NPV) is the difference between the present value of the benefits and the present value of the costs. A benefit-cost ratio attempts to identify the relationship between the cost and benefits of this initiative.

[g]The calculations are done using the assumption that the benefits accrue from the year of construction as the construction time for toilets varies between 5–10 days and health and convenience benefits in both cases are considered to accrue from the time it becomes operational. While the fertilizer benefits from urine accrue as soon as the toilet is functional, benefits from manure from faeces and costs of emptying the ES toilet are realized from the 9 month onwards. In DPF toilets the implicit inconvenience cost is applicable from the time it becomes functional, while the cost of emptying the pit is incurred approximately a year from its becoming functional. Note also that the attribution assumes that the underlying hygiene practices are similar across households.

for the duration of each illness episode is 3.98 days. Data from the sample indicated that on average 50% of the household members report diarrhoeal illness which requires medical intervention in any given year. The reduction in the number of days of illness in a year due to this intervention is accordingly calculated and subsequently monetized by using the daily wage rate.

Linking diarrhoeal illness to sanitation under climate change: Available estimates for increase in the incidence of diarrhoeal illness attributable to climate change fall in the range of 5–10% for developing countries, including those which take note of the improvements brought about by economic growth (Hallegatte et al., 2016; Kolstad & Johansson, 2010; WHO, 2003; 2013). Based on these findings, a modest increase of 5% in annual incidence of illness is assumed for the RCP 4.5 scenario and a 10% increase under the RCP 8.5 scenario by 2030. There is relatively less agreement and evidence on the extent to which increase in incidence of illness during floods can be directly attributed to lack of sanitation facilities. Thus, on one hand evidence shows a direct and positive correlation between flooding and diarrhoeal illness such as in terms of the number of admissions during heavy rainfall events or floods, (Campbell-Lendrum, Pruss-Ustun, & Corvalan, 2004; Carlton et al., 2014; Checkley et al., 2000; Dasgupta, Ebi, & Sachdeva, 2016; Ebi, 2008; Singh et al., 2001). On the other hand, there is a lack of conclusive evidence on the additionality to diarrhoeal disease burden attributable *solely* to lack of sanitation during flood events (Campbell-Lendrum et al., 2004; WHO, 2011). So, a conservative approach is maintained, and the base case assumptions (36% for ES and 10% for DPF) are assumed to continue to hold for calculating averted health costs.

Convenience benefits during floods: Villagers in Kairi experience up to 3 flood events in a year. For monetising the convenience cost of having access to a toilet during these days, as compared to open defecation, the opportunity cost of making an alternative arrangement during a flood is used to impute values. DPF toilets also cease to be functional for 3 days at a stretch during each flood event, rendering these non-functional for 9 days in the year if there are 3 floods annually. Whereas, ES toilets continue to be functional as these are constructed at a height well above the average height to which flood waters rise in the area surrounding the house. The benefit from this could not be estimated directly. Therefore, the study drew upon the experience of women villagers from Charkhi village to estimate the value of this benefit.

Valuing access during floods: During floods, women in Charkhi village who did not have access to toilets and practise open defecation, hire a boat to get to a dry patch of elevated land to defecate once in two to three days. Women from better-off households usually pay the larger share of the boat fare. For the poorest, the expenditure for a day (for one trip) during a flood event is approximately INR 10 per day (self-reported). For a 6-member household which is the average size of a household in Kairi, the equivalent cost would be INR 60 per day. The value of the benefit accrued (in the form of avoided costs) during three flood events lasting a day each would be INR 180. Again, it must be noted that this is a minimum valuation. Women from better-off households pay upto triple the amount that members of poorer households pay.

Convenience benefits from daily use: However, regular access to a toilet facility even during non-flood events has substantially greater convenience value for the respondents than open defecation. Although it is difficult to do a direct attribution of the value of this benefit, an imputation of the value is done at a minimum of Re. 1 per day, which is the minimum charge for using a community latrine in an urban area in India. This implies a minimum net benefit of INR 365 (if used once a day) per household member. It is assumed that the convenience value of having access to a toilet is the same for DPF and ES. However, as 9 days of flood-related non-functionality occur in the case of DPF, this benefit accrues for 356 days in the case of DPF, and 365 days for ES.

Fertilizer benefits: Households use fertilizers from the waste generated in ES toilets. Again, households were unable to provide accurate data on the amount of individual nutrients in the compost generated from ES, though they were able to report the quantities of compost generated and the extent to which it was being used in their fields.[5] Based on secondary sources, the amounts of nitrogen, phosphorous and potassium generated from urine are assumed to be 4.01, 0.40 and 1 kg/person/year respectively, while on average, a household with six members generates 100 kg of compost each year (Chariar & Saktivel, 2011; Water Aid, 2008). The equivalent costs of nitrogen, phosphorous and potassium have been estimated based on their content in urea, DAP and potassium along with their market prices while compost generated through the ES is also valued at the local market price at which it sells. Other assumptions are based on standardized norms wherever local data is unavailable. Thus, the life of the interventions is assumed to be 10 years based on secondary sources.

Discount rate: The costs and benefits that accrue over time are discounted using a constant discount rate of 3%. There is no consensus in the literature on the rate of discount that should be chosen for climate change contexts (Goulder & Williams, 2012; Nordhaus, 2007; Weitzman, 2001). In the present study, a major part of the benefits are health benefits and convenience benefits which contribute to well-being. The underlying assumption here is that the social welfare function approach to discounting with its focus on ethical considerations is appropriate in the current context. The related literature offers a range of options from not discounting at all to using relatively high discount rates for the future. A zero-discount rate would imply that the present and future are valued equally. A low, non-zero discount rate tends to be used more widely for health benefits, and in the context of climate change policies more specifically, results from discount rates between 3% and 6% are often presented (Clasen & Haller, 2008; Remais et al., 2014). Findings from costs and benefits discounted at 3% are presented below. A sensitivity analysis is also done using a 0% discount rate for all benefits, and an alternative with 0% discount rate for health benefits, 6% discount rate for costs and 6% for non-health benefits.

4. Results

The results from the cost–benefit analysis indicate that including the specific costs (or avoided damages) attributable to floods in the form of convenience costs, in particular, increases the BC ratio and the NPV in favour of the ES design more markedly than compared to an exercise where these are not included. Factoring in climate change in the form of enhanced precipitation events leading to higher frequency of flooding, makes the ES significantly more cost-effective than the DPF design.

4.1. Cost–benefit analysis of sanitation interventions

Table 3 presents the summary of the results from the cost–benefit analysis. The health benefits that accrue from the ES are substantially higher than for DPF on account of both averted treatment costs and averted wage losses. The benefit is 2.6 times higher for an ES intervention. While the convenience benefits are also higher for ES than DPF, the difference is much smaller. Note that this is partly because the monetized value of the alternative which is used during floods is low – with poor households sharing a lower proportion of the costs of hiring a boat than the better-off households. An important point to also keep in mind is that the negative externalities of open defecation cannot be captured adequately through any such valuation exercise. The benefits from manure and fertilizer also add to the benefits accruing from ES. In ES, the benefit-cost ratio (B/C) using a discount rate of 3% is almost double that of DPF. Although the B/C ratio is greater than 1 for both interventions, suggesting that both are economically viable by this criterion, the B/C ratio is almost double in ES. The Net Present Value (NPV) is 2.73 times higher for ES than DPF, implying that this intervention is likely to be far more beneficial. It is useful to compare the results in terms of the associated cost curves (Figure 2). It is also noted that in both instances of using alternative discount rates, the BCR and the NPV exhibit the expected pattern, with the NPV for the ES option being higher than that with the DPF option under both presents as well as future scenarios with RCP4.5 and RCP 8.5. The avoided health losses are 2.6 times higher in case of ES as compared to DPF. The cumulative value of benefits from averted convenience costs and health costs is substantial under current conditions.

4.2. Projected flood events and cost curves under RCP 4.5 and RCP 8.5

Figure 3 presents the projections for precipitation events. Precipitation events of interest to the study recur on average 1.5 times per year during the reference period (1981–2010). The analysis clearly shows an increase in these precipitation events, up to an approximate doubling towards the end of the century, depending on the scenario. These projections are used subsequently to calculate the averted losses from convenience and health benefits and simulate the cost curves for the two sanitation response options, under the projected flood risk for the future. Figure 4 plots the cost curves for the future for the years 2031–2040, factoring in the increase in flood events as per the projections under the two RCPs. It becomes obvious that even small changes in flood events can have large implications for the savings that can result through avoidance of losses (costs) by adopting the appropriate sanitation intervention.

5. Conclusion: ES as a cost-effective adaptation option in flood zones

The study provides an illustration of the use of cost–benefit analysis in judging the effectiveness of options for simultaneously addressing a developmental goal and climate adaptation. It provides estimates for future losses that can be averted by encouraging investment at the household and community level in appropriate infrastructure. While one option may appear to be the least cost option in terms of the initial investments required, as in the case of DPF, a full accounting of the benefits and costs shows that another option namely, the ES is more beneficial in a particular context.

The sampled households which did not have toilets were actively contemplating whether to build a toilet, and if so, of what design. Given the reimbursement of INR 12,000 under the SBM, most of these households were more favourably inclined towards the DPF at the time of the start of the field exercise. Costs and being used to open defecation (behavioural reason) were the two most prominent reasons stated for not

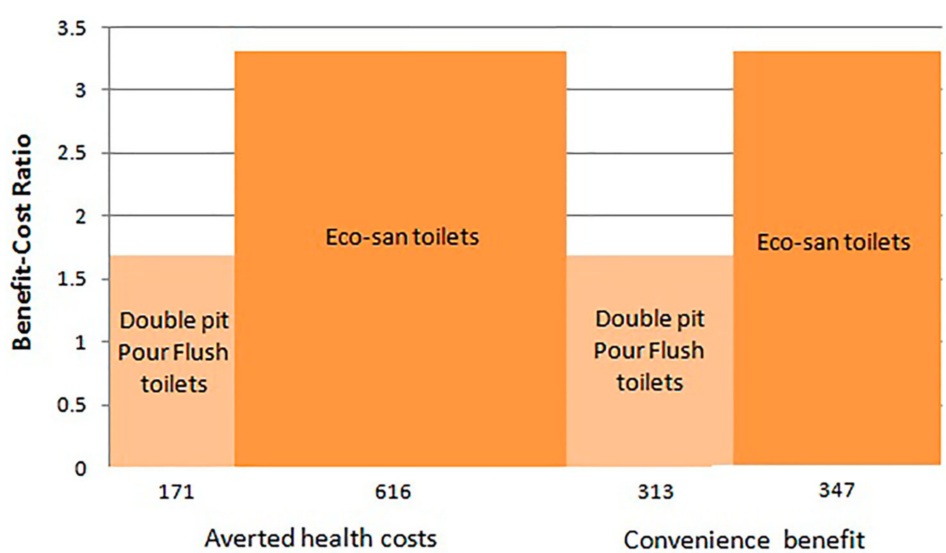

Figure 2. Cumulative avoided health costs and convenience benefits (in US$).

Source: Authors' analysis.

Note: On the X-axis, the width of the first two bars represent the cumulative averted health costs or health benefits and the next two bars represent the cumulative convenience benefits per household attributable over the total life span of 10 years for the two technology options. All costs and benefits are in US$. The Y-axis plots the corresponding B/C ratio, measured by the height of the bars.

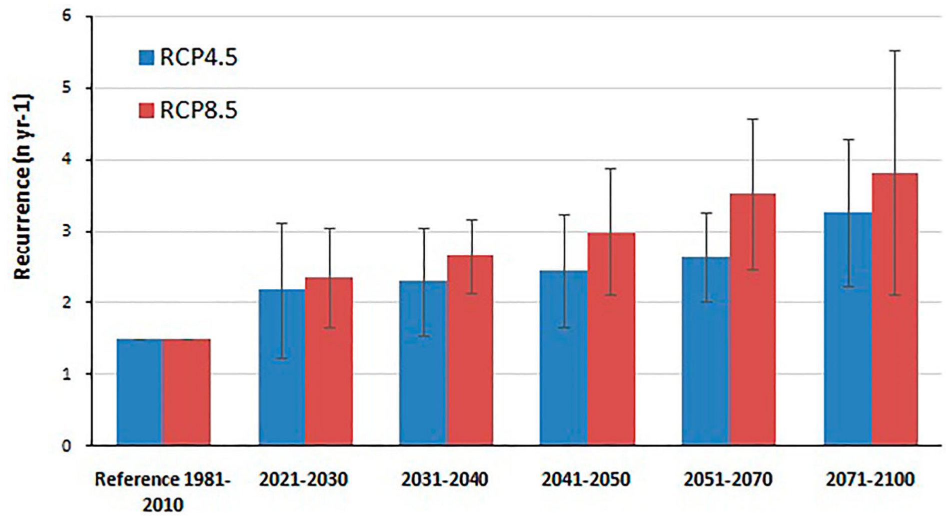

Figure 3. Recurrence of precipitation events under RCP 4.5 and 8.5.

Source: Authors' Analysis

Note: Bars indicate the ensemble mean of 4 downscaled General Circulation Models. Error bars indicate the full range of the ensemble.

having toilets. Given that the DPF design is being actively promoted under the current sanitation programme of the government and can be constructed well within the amount being reimbursed, poor households tend to adopt this design rather than the more costly ES. For the poor, coming up with resources to meet the initial cost can also become a constraint under a reimbursement scheme.

The fieldwork conducted in the area provides some insights on the social reasonings that explain the community's behaviour and perception. The area has been affected by floods which had not been experienced earlier in terms of either intensity or frequency, with the occurrence of the flood events having increased as compared to previous 3 decades. People have been largely caught unawares. Combined with a lack of response from the government, the first option is in general not to invest in new technologies (in any sector) but to look for exit options, migrating to areas which offer better income earning opportunities (Dandekhya et al., 2017). Typically, it is the women who stay back in the family in the study area, given the gendered dimension to migration (Udas, Prakash, & Goodrich, 2018). Remittances are small and mostly invested in meeting essential household expenses (Maharjan et al., 2018). As the FGDs and personal interviews confirm, the capacity of households to adapt to the negative effects of environmental changes and shocks is limited.

Most adaptation studies stop at identifying or proposing adaptation options, and there is a huge gap in conducting adaptation costing studies for the region. This study is an attempt to

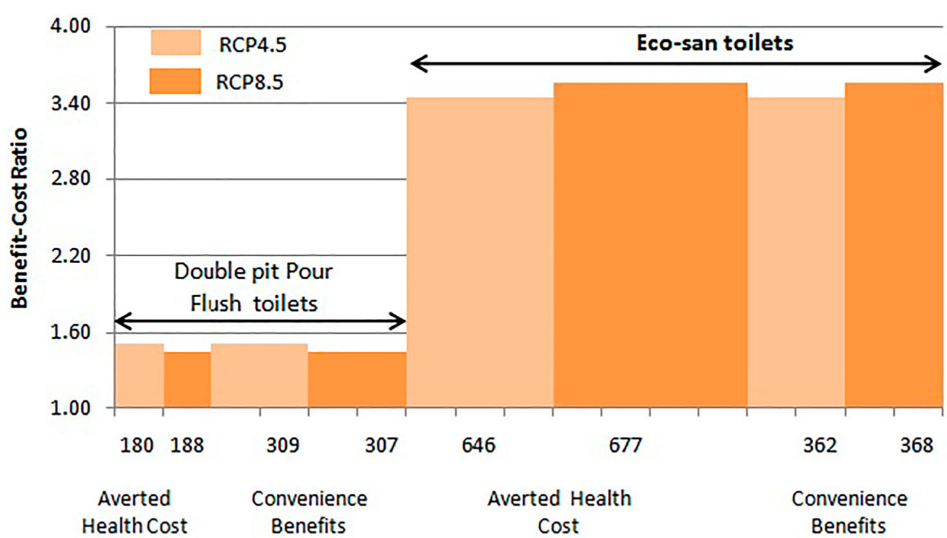

Figure 4. Future avoided losses from health costs and convenience benefits per household for ES and DPF under RCP 4.5 and RCP8.5 (2031–2040) (in US$).

Source: Authors' analysis

Note: On the X-axis, the first four bars are for the DPF option and the next four bars are for the ES option. The width of the first two bars for each option represent the cumulative averted health costs (or health benefits) per household over a span of 10 years, under conditions of increased flood events for the RCP 4.5 and RCP 8.5 scenarios respectively. Similarly, the subsequent two bars under each option, represent the cumulative convenience benefits that accrue over a period of 10years, under conditions of increased flooding for the RCP4.5 and RCP8.5 scenarios respectively. All costs and benefits are in US$. The Y-axis plots the corresponding B/C ratio, measured by the height of the bars.

illustrate how such gaps can be filled by innovatively applying the tools of cost–benefit analysis. The few available studies often apply only engineering or construction cost-based norms to capture differences across options, and these can thereby under-estimate the benefits of adaptation. This also does a serious injustice to the non-marketed benefits which are particularly important for provision of clean water or sanitation which have known positive externalities.[6] In the present study, explicit consideration of averted health costs and convenience benefits during and in the aftermath of flood events makes it clear that the differences across options in the sanitation sector are substantial. The way forward to ensure sustainability and positive impacts on multiple SDGs, is to address vulnerabilities by incorporating the current and future climate risks.

The cost curves associated with the choice of a sanitation intervention illustrate how a particular option can score over another when climate-related risks are explicitly factored into the calculations. This would add to the information at the hands of decision makers in encouraging and incentivising investments in the right choices, both for private and public spending. It is worth reiterating that the avoided costs from adopting flood-resistant designs (ES) in reality are likely to be much higher than those reported here, given the conservative assumptions on incidence of illness and valuation of convenience benefits.[7] It is possible to address multiple objectives with due consideration of both immediate and future risks. There is a need for policy to intervene and subsidize climate-resilient technologies, so that affordability issues do not compel the community, especially the poorest, towards more vulnerable solutions. There is need to build upon such research, advocating the adoption of designs that are most suited for particular climatic and geographical conditions, both in the present and the future.

Drawing upon inputs from this study, an initiative to pilot ES toilets has been taken up in a flood-prone village in the study district. None of the 100 households in this settlement, which is surrounded and submerged by water during floods, has a toilet. Based on the experience with the pilots, the implementation challenges are found to be two-fold. The first is a behavioural one, where people have become used to open defecation over centuries. Effective communication to bring about behavioural change was found to be a key implementational concern in the initial days. Additionally, in the case of ES toilets, there were taboos and hesitations about touching night soil, turning it into manure and using it for cultivation. The possibility of using human urine as bio-pesticide was initially mocked at by villagers. Persistent communication and awareness activities finally led to some courageous families to come forward to adopt it. Gradually when people saw the benefits, interest in it picked up. It is still a challenge for many but with strong communication things seem to be improving. The second challenge is in convincing the local government officials in charge of the sanitation programme, which is target driven in terms of number of toilets built and does not place emphasis on either behavioural change or actual usage of toilets. There is also a perception that the government would have greater control and hence better implementation would be assured in a targeted top-down driven sanitation programme than one which is community driven. The materials used in ES are largely locally sourced while in the pour-flush latrines built under the government programme, the materials are brought from outside. There are multiple levels of control and scope for rent seeking which impinge upon the choice of technology. The desired social acceptability can come from a community-driven process, stronger communication and information sharing, and incentivisation that is commensurate with the appropriate technological options.

Findings of this paper clearly indicate that factoring in the interaction effects between the physical design of technology and the increased climate risk leads to substantial improvements in the cost-effectiveness of one option over the other. Availability and access to technological options, differential reimbursements in line with the flexibility to meet costs under the SBM, along with community engagement is required to bring about the desired change.

Notes

1. The authors are using the term 'backwards' as per the official terminology of the Government of India.
2. See for instance, methodology as discussed in Freeman, 2003; Freeman, Herriges, & Kling, 2014; Dasgupta, 2009; UNDP, 2013; Kunreuther et al., 2014.
3. A lower radiative forcing (RCP2.6) scenario is unlikely given its implications for stringent and immediate mitigation action, alongside the relatively high emissions projected for the region (Lutz, Immerzeel, Kraaijenbrink, Shrestha, & Bierkens, 2016b).
4. Informal interactions took place in several other villages, which were not finally included in the sample as they did not meet the necessary criteria such as having more than one functional DPF or ES toilet.
5. Apart from the benefits enumerated here, there may be other positive externalities such as long term improvements in soil and water conditions, improved social well-being and secondary benefits from improved health status due to reduced diarrhoeal illness that are associated with having access to toilets but these cannot be captured here.
6. There are for instance, several studies on adaptation in agriculture which evaluate the effectiveness of the adaptation measure on the basis of direct impacts on outcome parameters such as income or yield or food security. Very few estimate the cost of adaptation measures as an input into evaluating effectiveness or conducting cost-benefit studies (e.g. see Di Falco, Veronesi, & Yesuf, 2011; Mendelsohn & Dinar, 2003; Kurukulasuriya & Mendelsohn, 2008; Dasgupta, Bhattacharjee, & Kumari, 2013; Siderius et al., 2016).
7. Moreover, as is well known, cost of illness estimates do not include the benefits of avoided suffering from an illness, or the value of reduced risk of mortality or cumulative effects on productivity (Whittington et al., 2009).

Acknowledgements

This paper is a substantially revised version of a working paper published by ICIMOD of the Himalayan Adaptation, Water and Resilience (HI-AWARE) consortium under the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA) with financial support from the UK Government's Department for International Development (DFID), London, UK, and the International Development Research Centre (IDRC), Ottawa, Canada. This work was also partially supported by core funds of ICIMOD contributed by the governments of Afghanistan, Australia, Austria, Bangladesh, Bhutan, China, India, Myanmar, Nepal, Norway, Pakistan, Sweden and Switzerland. The views expressed are those of the authors and do not represent those of the UK Government's Department for International Development, the International Development Research Centre, Canada or ICIMOD. We gratefully acknowledge the support of these funding agencies. We thank the anonymous reviewers of the journal, Christian Siderius, Golam Rasul, Philippus Wester and Arun Bhakta Shrestha for their valuable suggestions. We are grateful for the excellent field support received from Eklavya Prasad (Megh Pyne Abhiyan), Vinay Kumar (Water Action) and the officials, key informants and households who spared their valuable time for the research team.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by HI-AWARE, CARIAA.

Notes on contributors

Dr *Purnamita Dasgupta* is Chair Professor & Head, Environmental & Resource Economics Unit, at Institute of Economic Growth, Delhi. Her teaching and research focus is on the relationship between environment and economic development. She has been Visiting Professor at University of Cambridge, UK and Johns Hopkins University, USA. Her recent research includes modelling future socio-economic scenarios for India's National Communications and GHG emissions for India's Nationally Determined Contributions (NDC), choice experiments for enhancing transitions to clean energy use among rural households in India (LPG, LED programs), and cost-benefit evaluations of ecosystem services, climate change impacts and adaptation. She has been Co-ordinating Lead Author of the Intergovernmental Panel on Climate Change (IPCC) and the International Panel on Social Progress (IPSP); Advisor for the IPCC's Scientific Steering Group on Economics, Costing and Ethics, Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA) and the Association of Commonwealth Universities, UK. In India, she has served on various committees including member of the committee drafting legislation on Electronic Waste, the Supreme Court committee on NPV for Forests, and the Expert committee to evolve environmental standards in India, among others. She has published widely in books and journals and participates actively in discussions on the environment in various fora.

Dr *Samraj Sahay* is an Independent Researcher based in New Delhi, India and works in the field of Environment and Economic policy research. He is a PhD in Environmental Economics with specialization in Economics of Climate Change Adaptation and its health effect from University of Delhi, India. He has worked on several research projects at University of Delhi, mainly related to economics of adaptation, mitigation, socio-economic modelling (shared socio-economic pathways - SSPs) for climate scenarios, adaptation to floods and waste management. His work mainly involves empirical research and application of econometric models. His research interest includes climate change adaptation, health effects, mitigation, socio-economic modelling for future climate scenarios; renewable energy; greenhouse gases; waste management and econometric modelling.

Dr *Anjal Prakash* is an Associate Professor and Associate Dean at TERI-SAS Hyderabad Campus. He is also associated with Department of Regional Water Studies at TERI- SAS, New Delhi. Before joining TERI-SAS in December 2018, Dr. Prakash worked as the Programme Coordinator of Himalayan Adaptation, Water and Resilience (HI-AWARE) Research on Glacier and Snowpack Dependent River Basins at International Center for Integrated Mountain Development (ICIMOD) based in Kathmandu, Nepal. HI-AWARE was a special initiative that focused on adaptation issues in three river basins of South Asia namely the Indus, the Ganges and the Brahmaputra. Dr Prakash is a coordinating lead author for the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC). He is a Lead Author in the chapter on cities, settlements and key infrastructure in the IPCC's 6th Assessment Report. Recently he was nominated as member of the Gender Task Group of IPCC to develop a framework of goals and actions to improve gender balance and address gender-related issues within the IPCC. Before joining ICIMOD in 2014, Dr Prakash led the South Asia Consortium for Interdisciplinary Water Resources Studies (SaciWATERs) as Executive Director. SaciWATERs is a south Asian thinktank that works in six countries of South Asia. His earlier associations were with WaterAid, New Delhi and VIKSAT, Ahmedabad, India.

Dr *Arthur Lutz* is a physical geographer with a solid background in hydrology, hydrological modelling, GIS, remote sensing and cryospheric sciences. His expertises include hydrological modelling at scales ranging from large river basins to small catchments, and climate change impacts for future water resources. He obtained his PhD degree at Utrecht University in 2016 for his thesis titled 'Impact of climate change on the hydrology of High Mountain Asia' He has nine years of experience in research and consultancy related to water resources and climate change, with focus on South and Central Asia. At present he is researcher at Utrecht University and hydrologist and climate change expert at FutureWater Wageningen, The Netherlands.

ORCID

Purnamita Dasgupta http://orcid.org/0000-0001-5148-4402

References

Ahern, M., Kovats, R. S., Wilkinson, P., Few, R., & Matthies, F. (2005). Global health impacts of floods: Epidemiologic evidence. *Epidemiologic Reviews*, *27*, 36–46.

Atkinson, G., Bateman, I., & Mourato, S. (2012). Recent advances in the valuation of ecosystem services and biodiversity. *Oxford Review of Economic Policy*, *28*, 22–47. doi:10.1093/oxrep/grs007

Bern, C. (2004). Diarrhoeal diseases. In J. L. Christopher, A. D. Murray, & C. D. Lopez (Eds.), *Global epidemiology of infectious diseases* (pp. 1–27). Geneva: WHO.

Cairncross, S., Valdmanis, V. (2006). Chapter 41: Water supply, sanitation, and hygiene promotion. In D. T. Jamison, J. G. Breman, & A. R. Measham et al. (Eds.), *Disease control priorities in developing countries* (pp. 771–792). New York, NY: World Bank and Oxford University Press.

Campbell-Lendrum, D. H., Pruss-Ustun, A., & Corvalan, C. (2004). *How much disease could climate change cause. Climate change and human health: Risks and responses* (pp. 133–158). Geneva: WHO. Retrieved from http://www.who.int/globalchange/publications/climatechangechap7.pdf

Carlton, E. J., Eisenberg, J. N. S., Goldstick, J., Cevallos, W., Trostle, J., & Levy, K. (2014). Heavy rainfall events and diarrhea incidence: The role of social and environmental factors. *American Journal of Epidemiology*, *179*(3), 344–352.

Chambwera, M., Heal, G., Dubeux, C., Hallegatte, S., Leclerc, L., Markandya, A., … Neumann, J. E. (2014). Economics of adaptation. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White (Eds.), *Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change* (pp. 945–977). Cambridge: Cambridge University Press.

Chariar, V. M., & Saktivel, S. R. (2011). *Ecological sanitation, practitioner's guidebook*. Delhi: UNICEF, GoI and Indian Institute of Technology. Retrieved from http://web.iitd.ac.in/~chariarv/files/EcologicalSanitationHandbook.pdf

Checkley, W., Epstein, L. D., Gilman, R. H., Figueroa, D., Cama, R., Patz, J. A., & Black, R. E. (2000). Effects of El Nino and ambient temperature on hospital admissions for diarrhoeal diseases in Peruvian children. *The Lancet*, *355*(9202), 442–450.

Clasen, F., & Haller, L. (2008). *Water quality interventions to prevent diarrhoea: Cost and cost-effectiveness*. Geneva: Public Health and the Environment, World Health Organization.

Cochrane, L., Cundill, G., Ludi, E., New, M., Nicholls, R. J., Wester, P., … Landry, M.-E. (2017). A reflection on collaborative adaptation research in Africa and Asia. *Regional Environmental Change*, *17*, 1553–1561. doi:10.1007/s10113-017-1140-6

Dandekhya, S., England, M., Ghate, R., Goodrich, C. G., Nepal, S., Prakash, A., … Udas, P. B. (2017). The Gandaki basin. Retrieved from http://lib.icimod.org/record/32707/files/hiaware529_WP_9_Gandaki%20Basin.pdf

Dasgupta, P. (2009). Valuation of ecosystem services: Methodologies, illustrations and use. In K. Chopra & V. Dayal (Eds.), *Handbook of environmental economics in India* (pp. 137–150). New Delhi: Oxford University Press.

Dasgupta, P. (2016). *Climate sensitive adaption in health: Imperatives for India in a developing economy context*. New Delhi: Springer.

Dasgupta, P., Bhattacharjee, D., & Kumari, A. (2013). Socio-economic analysis of climate change impacts on food grain production in Indian states. *Environmental Development*, *8*, 5–21.

Dasgupta, P., Ebi, K., & Sachdeva, I. (2016). Health sector preparedness for adaptation planning in India. *Climatic Change*, *138*, 551–566. doi:10.1007/s10584-016-1745-7

Di Falco, S., Veronesi, M., & Yesuf, M. (2011). Does adaptation to climate change provide food security? A microperspective from Amer'. *American Journal of Agricultural Economics*, *93*, 829–846.

Ebi, K. L. (2008). Adaptation costs for climate change-related cases of diarrhoeal disease, malnutrition, and malaria in 2030. *Globalization and Health*, *4*, 9. doi:10.1186/1744-8603-4-9

Ebi, K. L., Woodruff, R., von Hildebrand, A., & Corvalan, C. (2007). Climate change-related health impacts in the Hindu Kush–Himalayas. *EcoHealth*, *4*(3), 264–270.

Elalem, S., & Pal, I. (2015). Mapping the vulnerability hotspots over Hindu-Kush Himalaya region to flooding disasters. *Weather and Climate Extremes*, *8*, 46–58.

Eriksson, M., Fang, J., & Dekens, J. (2008). How does climate change affect human health in The Hindu Kush-Himalaya region. *Regional Health Forum*, *12*(1), 11–15.

Fewtrell, L., Kaufmann, R. B., Kay, D., Enanoria, W., Haller, L., & Colford, J. M. J. (2005). Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: A systematic review and meta-analysis. *The Lancet Infectious Diseases*, *5*, 42–52.

Freeman, A. M. (2003). *The measurement of environmental and resource values: Theory and methods*. New York, NY: Resources for the Future.

Freeman, A. M., Herriges, J. A., & Kling, C. L. (2014). *The measurement of environmental and resource values: Theory and methods* (3rd ed.). New York, NY: *Resources for the Future*.

Girard, C., Pulido-Velazquez, M., Rinaudo, J.-D., Pagé, C., & Caballero, Y. (2015). Integrating top–down and bottom–up approaches to design global change adaptation at the river basin scale. *Global Environmental Change*, *34*(34), 132–146.

GOI. (2014). *Handbook on gram panchayat and sanitation*. New Delhi: Ministry of Panchayati Raj.

GOI. (2015). *Ministry of Social Justice and Empowerment*. Retrieved from http://socialjustice.nic.in/UserView/index?mid=76750

GOI. (2016a). *Sector overview at a glance*. Ministry of Social Justice and Empowerment, Government of India. Retrieved from http://socialjustice.nic.in/UserView/index?mid=76661

GOI. (2016b). *National Commission on Schedule Tribes*. Retrieved from http://ncst.nic.in/content/frequently-asked-questions

GOI. (2018). Guidelines for Swachh Bharat Mission (Gramin). Ministry of Drinking Water and Sanitation. Retrieved from https://mdws.gov.in/sites/default/files/SBM(G)_Guidelines.pdf

Goulder, L. H., & Williams, R. C. I. I. I. (2012). The choice of discount rate for climate change policy evaluation. *Climate Change Economics*, *03*(4), 1250024–1251-18.

Hallegatte, S., Bangalore, M., Bonzanigo, L., Fay, M., Kane, T., Narloch, U., … Vogt-Schilb, A. (2016). *Shock waves: Managing the impacts of climate change on poverty*. Climate Change and Development Series. Washington, DC: World Bank. doi:10.1596/978-1-4648-0673-5.

Hara, K., Wasito, E. B., Hosea, D., Katsumata, T., Soeparto, P., Kohno, S., & Ranuh, I. G. (1998). Cryptosporidiosis in Indonesia: A hospital-based study and a community-based survey. *The American Journal of Tropical Medicine and Hygiene*, *59*, 628–632.

Hashimoto, M., Suetsugi, T., Ichikawa, Y., Sunada, K., Nishida, K., Kondo, N., & Ishidaira, H. (2014). Assessing the relationship between inundation and diarrhoeal cases by flood simulations in low-income communities of Dhaka city, Bangladesh. *Hydrological Research Letters*, *8*(3), 96–102.

Hunzai, K., Gerlitz, J. Y., & Hoermann, B. (2011). *Understanding mountain poverty in the Hindu Kush-Himalayas: Regional report for Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan*. Kathmandu: ICIMOD, Kathamndu.

Khadka, D., Babel, M. S., Shrestha, S., & Tripathi, N. K. (2014). Climate change impact on glacier and snow melt and runoff in Tamakoshi basin in the Hindu Kush Himalayan (HKH) region. *Journal of Hydrology*, *511*, 49–60.

Kolstad, C., Urama, K., Broome, J., Bruvoll, A., Cariño Olvera, M., Fullerton, D., … Mundaca, L. (2014). Social, economic and ethical concepts and methods. In O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel, & J. C. Minx (Eds.), *Climate change 2014: Mitigation of climate change. Contribution of working group III to the fifth assessment report of the intergovernmental panel on climate change* (pp. 173–248). Cambridge: Cambridge University Press.

Kolstad, E. W., & Johansson, K. A. (2010). Uncertainties associated with quantifying climate change impacts on human health: A case study for diarrhea. *Environmental Health Perspectives*, *119*, 299–305.

Kraaijenbrink, P. D. A., Bierkens, M. F. P., Lutz, A. F., & Immerzeel, W. W. (2017). Impact of a global temperature rise of 1.5 degrees Celsius on Asia's glaciers. *Nature*, *549*, 257–260.

Kunreuther, H., Gupta, S., Bosetti, V., Cooke, R., Dutt, V., Ha-Duong, M., … Weber, E. (2014). Integrated risk and uncertainty assessment of climate change response policies'. In O. Edenhofer, R. Pichs-Madruga, & Y. Sokona et al. (Eds.), *Climate change 2014: Mitigation of climate change. Contribution of working group III to the fifth assessment report of the intergovernmental panel on climate change* (pp. 151–206). Cambridge: Cambridge University Press.

Kurukulasuriya, P., & Mendelsohn, R. (2008). Crop switching as a strategy for adapting to climate change. *AfJARE*, *2*(1), 105–125.

Lakshminarayanan, S., & Jayalakshmy, R. (2015). Diarrheal diseases among children in India: Current scenario and future Perspectives. *Journal of Natural Science, Biology and Medicine*, *6*(1), 24–28. doi:10.4103/0976-9668.149073

Lamberti, L. M., Walker, C. L. F., & Black, R. E. (2012). Systematic review of diarrhoea duration and severity in children and adults in low- and middle-income countries. *BMC Public Health*, *12*, 276. Retrieved from http://www.biomedcentral.com/1471-2458/12/276

Liu, Z. D., Li, J., Zhang, Y., Ding, G.-Y., Xu, X., Gao, L., … Jiang, B.-F. (2016). Distributed lag effects and vulnerable groups of floods on bacillary dysentery in Huaihua, China. *Scientific Reports*, *6*, 29456. doi:10.1038/srep29456

Lutz, A. F., Immerzeel, W. W., Kraaijenbrink, P. D. A., Shrestha, A. B., & Bierkens, M. F. P. (2016b). Climate change impacts on the upper Indus hydrology: Sources, shifts and extremes. *PLoS ONE*, *11*(11). doi:10.1371/journal.pone.0165630

Lutz, A. F., ter Maat, H. W., Biemans, H., Shrestha, A. B., Wester, P., & Immerzeel, W. W. (2016a). Selecting representative climate models for climate change impact studies: An advanced envelope-based selection approach. *International Journal of Climatology*, *36*, 3988–4005. doi:10.1002/joc.4608

Lutz, A. F., ter Maat, H. W., Wijngaard, R. R., Biemans, H., Syed, A., Shrestha, A. B., … Immerzeel, W. W. (2019). South Asian river basins in a 1.5 °C warmer world. *Regional Environmental Change*, *19*(3), 833–847. doi:10.1007/s10113-018-1433-4

Maharjan, A., Hussain, A., Bhadwal, S., Ishaq, S., Saeed, B. A., Sachdeva, I., … Ferdous, J. (2018). *Migration in the lives of environmentally vulnerable populations in four river basins of the Hindu Kush Himalayan Region*. HI-AWARE Working Paper 20. Kathmandu: HI-AWARE. Retrieved from http://hi-aware.org/wp-content/uploads/2018/10/working-paper-20.pdf

McKinsey. (2009a). *Charting our water future: Economic frameworks to inform decision-making*. New York, NY: McKinsey and Company for the 2030 Water Resources Group.

McKinsey. (2009b). *Shaping climate-resilient development: A framework for decision-making*. A report of the Economics of Climate Adaptation Working group.

Mendelsohn, R., & Dinar, A. (2003). Climate, water, and agriculture. *Land Economics*, *79*(3), 328–341.

Minh, H. V., & Hung, N. V. (2011). Economic aspects of sanitation in developing countries. *Environmental Health Insights*, *5*, 63–70.

Mukherji, A., Scott, C., Molden, D., & Maharjan, A. (2018). Megatrends in Hindu Kush Himalaya: Climate change, urbanisation and migration and their implications for water, energy and food. In *Assessing global water Megatrends* (pp. 125–146). Singapore: Springer.

Nibanupudi, H. K., Gupta, A. K., & Rawat, P. K. (2015). Mitigating climatic and human induced disaster risks through ecosystem resilience: Harmonizing built and natural environments in the HKH region. In *Mountain hazards and disaster risk reduction* (pp. 139–157). Tokyo: Springer.

Nordhaus, W. (2007). A review of the stern review on the economics of climate change. *Journal of Economic Literature*, *45*, 686–702.

Remais, J. V., Hess, J. J., Ebi, K. L., Markandya, A., Balbus, J. M., Wilkinson, P., … Chalabi, Z. (2014). Estimating the health effects of greenhouse gas mitigation strategies: Addressing parametric, model, and valuation challenges. *Environmental Health Perspectives*, *122*, 447–455. doi:10.1289/ehp.1306744

Schwartz, B. S., Harris, J. B., Khan, A. I., Larocque, R. C., Sack, D. A., Malek, M. A., … Ryan, E. T. (2006). Diarrheal epidemics in Dhaka, Bangladesh, during three consecutive floods: 1988, 1998, and 2004. *The American Journal of Tropical Medicine and Hygiene*, *74*, 1067–1073.

Shrestha, M. S., Grabs, W. E., & Khadgi, V. R. (2015). Establishment of a regional flood information system in the Hindu Kush Himalayas: Challenges and opportunities. *International Journal of Water Resources Development*, *31*(2), 238–252. doi:10.1080/07900627.2015.1023891

Siderius, C., Biemans, H., van Walsum, P. E. V., van Ierland, E. C., Kabat, P., & Hellegers, P. J. G. J. (2016). Flexible strategies for coping with rainfall variability: Seasonal adjustments in cropped area in the Ganges Basin. *PLoS ONE*, *11*(3), e0149397. doi:10.1371/journal.pone.0149397

Singh, R. B., Hales, S., de Wet, N., Raj, R., Hearnden, M., & Weinstein, P. (2001). The influence of climate variation and change on diarrhoeal disease in the Pacific Islands. *Environmental Health Perspectives*, *109*(2), 155–159.

Tilley, E., Luthi, C., Morel, A., Zurbrugg, C., & Schertlenberg, R. (2008). Compendium of sanitation systems and technologies. *Eawag*, WSSCC.

Udas, P. B., Prakash, A., & Goodrich, C. G. (2018). Gendered vulnerabilities in Diaras. *Economic & Political Weekly*, *53*(17), 46–54.

UN. (2018). *Health, water and sanitation. United Nations in India*. Retrieved from http://in.one.un.org/health-water-and-sanitation/

UNDP. (2013). *Water governance in the Arab region: Managing scarcity and securing the future*. New York, NY: United Nations Development Programme (UNDP) and Regional Bureau for Arab States (RBAS), United Nations Publications.

Uneze, E., Tajudeen, I., & Iweala, O. (2013). *Cost-effectiveness and benefits-cost analysis of some water interventions (the case of Bauchi state, Nigeria)*. Abuja: Centre for the Study of the Economies of Africa (CSEA), Global Development Network (GDN).

USAID. (2016). *Analyzing the economic costs and benefits of climate change adaptation options: A how-to example from the Pacific cost-benefit analysis initiative*. Adapt Asia-Pacific Project. Adaptation Finance Knowledge SeriesNo. 4, January 2016.

van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., … Rose, S. K. (2011). The representative concentration pathways: An overview. *Climatic Change*, *109*(1–2), 5–31. doi:10.1007/s10584-011-0148-z

Waddington, H., Snilstveit, B., White, H., & Fewtrell, L. (2009). *Water, sanitation and hygiene interventions to combat childhood diarrhoea in developing countries*. New Delhi: International Initiative for Impact Evaluation. Retrieved from http://www.3ieimpact.org/media/filer_public/2012/05/07/17.pdf

Water Aid. (2008). *Assessment of urine-diverting eco-san toilets in Nepal*. www.wateraid.org/~/media/Publications/ecological-sanitation-nepal.pdf

Weitzman, M. (2001). Gamma discounting. *American Economic Review*, *91*(1), 260–271.

Whittington, D., Hanemann, M. W., Sadoff, C., & Jeuland, M. (2009). The challenge of improving water and sanitation services in less developed countries. *Foundation and Trends in Microeconomics*, *4*, 469–609.

World Health Organization. (2011). Water, sanitation and hygiene interventions and the prevention of diarrhoea. *Biological, Behavioural and Contextual Rationale*, Retrieved from http://www.who.int/elena/titles/bbc/wsh_diarrhoea/en/

World Health Organization (WHO). (2003). *Summary booklet: Climate change and human health – Risks and responses*. Geneva: World Health Organization.

World Health Organization (WHO). (2013). *Diarrhoeal disease: Fact sheet*. Geneva: World Health Organization.