Solid Waste and Water Quality Management Models for Sagarmatha National Park and Buffer Zone, Nepal

Authors: Manfredi, Emanuela Chiara, Flury, Bastian, Viviano, Gaetano, Thakuri, Sudeep, Khanal, Sanjay Nath, et al.

Source: Mountain Research and Development, 30(2) : 127-142

Published By: International Mountain Society

URL: https://doi.org/10.1659/MRD-JOURNAL-D-10-00028.1

Mountain Research and Development (MRD)
An international, peer-reviewed open access journal
published by the International Mountain Society (IMS)
www.mrd-journal.org

MountainResearch
Systems knowledge

Solid Waste and Water Quality Management Models for Sagarmatha National Park and Buffer Zone, Nepal

Implementation of a Participatory Modeling Framework

Emanuela Chiara Manfredi[1,2], Bastian Flury[1], Gaetano Viviano[1,2], Sudeep Thakuri[1], Sanjay Nath Khanal[3], Pramod Kumar Jha[4], Ramesh Kumar Maskey[3], Rijan Bhakta Kayastha[3], Kumud Raj Kafle[3], Silu Bhochhibhoya[3], Narayan Prasad Ghimire[4], Bharat Babu Shrestha[4], Gyanendra Chaudhary[3], Francesco Giannino[5], Fabrizio Carteni[5], Stefano Mazzoleni[5], and Franco Salerno[1,2]*

* Corresponding author: manfredi@irsa.cnr.it
[1] Ev-K2-CNR Committee, Via San Bernardino 145, 24126 Bergamo, Italy
[2] Water Research Institute–National Research Council (IRSA–CNR), Via del Mulino 19, 20047 Brugherio (MB), Italy
[3] Kathmandu University, Dhulikhel, PO Box 6250, Kathmandu, Nepal
[4] Tribhuvan University, Kirtipur, PO Box 6132, Kathmandu, Nepal
[5] University Federico II, Department of Agricultural Engineering and Agronomy, Via Università 100, 80055 Portici (Napoli), Italy

The problem of supporting decision- and policy-makers in managing issues related to solid waste and water quality was addressed within the context of a participatory modeling framework in the Sagarmatha National Park and Buffer Zone in Nepal. We present the main findings of management-oriented research projects conducted within this framework, thus providing an overview of the current situation in the park regarding solid waste and water quality issues. We found that most of the solid waste generated in the park is composed of organic matter, paper, and minor reused waste that is mainly reused for cattle feeding and manure, while disposal of other nondegradable categories of collected waste (glass, metal, and plastic) is not properly managed. Particularly, burning or disposal in open dumps poses a great hazard to environmental, human, and animal health, as most dump sites situated close to water courses are prone to regular flooding during the rainy season, thereby directly contaminating river water. Pollutants and microbiological contamination in water bodies were found and anthropogenic activities and hazardous practices such as solid waste dump sites, open defecation, and poor conditions of existing septic tanks are suggested as possibly affecting water quality. Collection of these data on solid waste and water quality and compilation of management information on the targeted social-ecological system allowed us to develop consensus-building models to be used as management supporting tools. By implementing such models, we were able to simulate scenarios identifying and evaluating possible management solutions and interventions in the park. This work reveals insights into general dynamics that can support the quest for solutions to waste and water quality management problems in other protected areas and mountain landscapes where traditional livelihood and land use patterns are changing under the influence of a growing population, changing consumption patterns, and international tourism.

Keywords: *Participatory modeling; system dynamics; solid waste management; water quality; water pollution; Sagarmatha National Park and Buffer Zone; Nepal.*

Peer-reviewed: *March 2010* ***Accepted:*** *March 2010*

Introduction

Solid waste and water quality have become major environmental problems in recent years, especially in developing countries (Cointreau 1982; Pokhrel and Viraraghavan 2005; Markandya 2006). Concerns regarding solid waste in the Himalaya are growing, especially in densely populated areas, not only because of the increase of waste caused by rapid urbanization, a growing population, improved living standards, and changing consumption patterns, but chiefly because of the lack of an efficient waste management system (Alam et al 2008). If solid waste is not effectively and properly managed, it can result in adverse impacts on both environmental and human health causing air, soil, and water pollution and disease. Sustainable management of solid waste in mountain areas such as in the Himalaya is particularly important because of the vulnerability of natural resources such as surface waters and underground aquifers (Hinsby et al 2008), landscape, and biodiversity

(Hamilton 2002). Furthermore, the deterioration of natural resources may affect the economy of countries where tourism is the most important economic sector. In mountain areas with high concentrations of tourism activities, improper disposal can be a major despoiler of the natural environment. Solid waste and littering can degrade the physical appearance of water bodies and cause deterioration of water quality.

It is the world's poor regions that are also the most affected by inadequate supply of good water quality (Agarwal and Narain 1999; Karn and Harada 2001). For instance, although Nepal is rich in water resources, its people are not getting enough water to meet their needs nor is the available water potable. The State of Environment (SoE) Report of Nepal (2001) identified water pollution as the most serious public health issue in Nepal, with most of the pollution load from human activities, especially domestic sewage, as already reported by Devokta and Neupane (1994). Inadequate management of water resources may lead to an increase in their degradation. Therefore, improving management plans for reducing impacts on water resources while assuring their sustainable usage in developing countries is also essential for enhancing the quality of life and for further development in these regions as well as for safeguarding these important resources (Harmon and Worboys 2004; Xing et al 2008). In establishing protected area management plans and regulations, adequate waste and water management has indeed to be carefully considered and addressed, given its close relation to health and well-being, which are of paramount importance to local people as well as to park visitors, and hence the tourism industry itself.

In such a context, there is a need for integrated and participatory approaches, such as participatory modeling, for environmental management to support decisions concerning complex natural resource questions and social problems (Curt and Terrasson 1999; Pirot 2000; UNEP 2004; Jansky and Pachova 2006; Newig et al 2008), particularly in protected mountain areas. The strength of these approaches lies in the highly transparent and open-ended exploration of the issues, problems, and objectives that characterize the complex environment typical of many resource management situations.

Voinov and Gaddis (2008) define participatory modeling as the process of incorporating stakeholders and decision makers into an otherwise purely analytic modeling process to support decisions involving complex environmental questions. The participatory modeling process itself, regardless of its outcomes, leads to improved understanding of a system's interactions and behavior, thus providing a platform for integrating scientific knowledge with local knowledge (Voinov and Gaddis 2008). "Subjective" local knowledge not only can provide valuable information for the model building process (Geurts and Joldersma 2001), but also can serve to qualitatively evaluate the validity of model predictions (Arnold and Fernandez-Gimenez 2007). When executed well, participatory modeling supplies an objective, value-neutral locus that can contribute information concerning natural resource issues of interest for different groups of stakeholders (Cokerill et al 2006; Voinov and Gaddis 2008). The involvement of stakeholder groups can improve the quality and acceptance of plans and management strategies, and eventually the implementation of policies (Coenen et al 1998; Priscoli 1999; Welp 2000). Advantages reported in support of participatory modeling include providing stakeholders with system insight, scoping analyses, and education toward a common understanding of the issues (Palmer et al 1993; Rouwette et al 2002; van den Belt 2004).

To help address complex natural resource questions, an approach that couples soft and hard system methodologies in participatory modeling involving researchers, stakeholders, and decision-makers has been proposed by Salerno et al (2010), consisting of a 5-module framework that moves from modeling actors involvement and a modeling and consensus building phase to adaptive management. In this paper we present the experience of participatory modeling to support waste and water management in Sagarmatha National Park and Buffer Zone (SNPBZ), Nepal, applying this framework. The overall objective of this work was to improve knowledge of the social-ecological system (SES) with regard to waste and water management issues, build consensus on how solid waste and water should be managed, and identify possible management options for solving identified problems in an environmentally sustainable manner, by analyzing alternative management scenarios obtained through the modeling.

Overall methodology

We adopted the 5-module framework proposed in Salerno et al (2010), which couples hard and soft methodology for participatory modeling building that enables an overall modeling process and has its roots in adaptive management, computer-supported collaborative work, and SES theory. Once key actors were identified (stakeholders, decision-makers, researchers), a Scenario Planning (Daconto and Sherpha 2010) technique was used to *bound the system* (Module 1) identifying the SES drivers and defining what aspects of the SES needed to be analyzed, that is, what were the key management issues of concern for stakeholders and decision-makers. In what follows we start by describing the main waste- and water-related issues in our case study, SNPBZ; these were identified as major management constraints by concerned stakeholders. This is followed by a description of the methods used to collect the necessary data for implementing the management models on solid waste and water quality. These data were identified during the *qualitative phase* (Module 2) together with modelers and local researchers in order to address the identified key management issues concerning solid waste and water pollution. Identification of the research requirements for supplying data to the quantitative models was indeed possible only after having analyzed the selected dynamics of the system and after having made an effort to formalize this analysis. In particular, we point out that at this stage, after having completed the data gap analysis, we defined what data were available in the literature and what data had to be acquired in the field; thus, a suitable *management-oriented research* plan (Module 3) was drawn up. We continue with a brief presentation of the aims and conceptual design for each of the developed models combining the *qualitative and quantitative modeling* phases (Modules 2 and 4). Presentation of the data collected in the field according to the *management-oriented research* plan (Module 3) is combined with a discussion of the most significant *management scenarios* obtained by modeling simulations (Module 5). In closing, we elaborate recommendations and draw conclusions for a broader application of the adopted participatory modeling framework.

Social-ecological system (SES) bounding

SNPBZ is situated in the northeastern region of Nepal, and occupies the northernmost part of the Dudh Kosi River basin. The park and its BZ cover an area of about 1400 km^2 and have unique geographical features, being surrounded on all sides by the highest mountain ranges on Earth. The terrain is extremely irregular, with altitudes ranging from 2300 m (Surke village in the BZ) to 8848 m (Mount Everest or Sagarmatha, in Nepali) (Figure 1). Byers (2005) and Salerno et al (2008) have described main geographical, climatic, and physical-chemical characteristics of SNPBZ, while an overview of its social-ecological features is given in Caroli (2008) and Daconto and Sherpha (2010).

In recent decades the local economy and social structure has been profoundly reshaped by the tourism industry (Jefferies 1982; Nepal 2000), although agriculture and animal husbandry remain of great relevance for local people's livelihoods. Environmental degradation in SNPBZ is omnipresent and can be traced back mainly to increasing pressure on natural resources caused by a largely uncontrolled sprawl of the tourism industry, which started in the 1970s. In 2008, SNPBZ was home to slightly more than 6000 people, the majority of whom are mostly ethnic Sherpa; in comparison, SNPBZ had to cope with an influx of more than 28,000 visitors during the same period (Caroli 2008). The growing tourism industry has been responsible for the increasing import of packaged modern consumer goods, especially foodstuffs that, once consumed, accumulate in the area as nonrenewable solid waste and human excrement.

The accelerated and largely uncontrolled development of tourism in SNPBZ has resulted in a discrepancy between the accumulation of solid and human waste and disposal and waste water treatment infrastructure, facilities, and capacity for their management. It is widely recognized that these factors are important causes not only of environmental degradation but also of hazardous hygienic conditions, which can lead to outbreak of disease that substantially affect the well-being of both local inhabitants and visitors (Hamer 2003). Caravello et al (2007) reported that visitors' perception of SNPBZ indicated that a hygiene problem was about to develop, and it may already be a reality in some parts of the park and its Buffer Zone. Moreover, according to many locals and visitors to SNPBZ, the disposal of human waste is one of the most serious issues in the Park, as anticipated by Lachapelle (1995). Many foreign expeditions that go to the different Himalayan peaks each year are reported to leave a great deal of garbage—tins, cans, bottles, plastic bags, and papers—on trails and camp sites (Basnet 1993; Sharma 1995; Bishop and Naumann 1996; Kuniyal 2002; Kuniyal 2005). In addition, they dispose of human excreta that contribute to degradation of the quality of the environment at high altitude (Tabei 2001). Lodging and accommodation facilities are also responsible for a great share of solid and human waste production and accumulation.

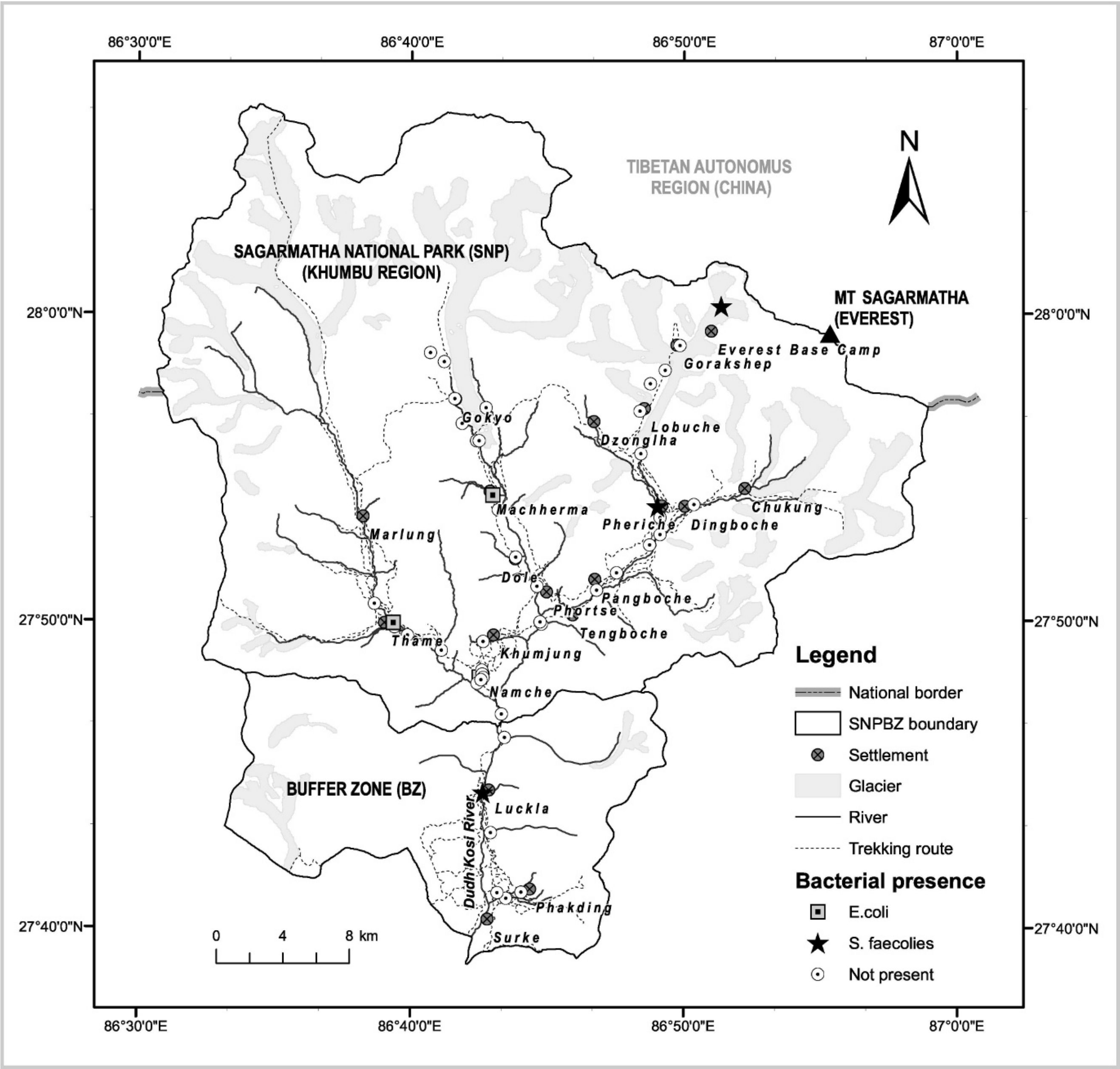
A 2-day workshop held in Namche in November 2008 as a capacity-building activity for local stakeholders provided an opportunity to take stock of existing waste collection and management systems for solid waste as well as related problems and gaps. Inside SNPBZ, waste collection mechanisms have been put in place by the Sagarmatha Pollution Control Committee (SPCC), through door-to-door waste collection in Luckla and Namche only, waste bins along trails, and supervision and control of waste returns from expedition groups (SPCC 2006). SPCC is a national nonprofit organization founded in the early 1990s with a mandate to establish and operate a solid waste management scheme in SNPBZ, which has effectively introduced a waste collection and rudimentary disposal system in key settlements, albeit with limited resources and capacity (TRPAP-NEP/99/013 2003). In all settlements except Namche and Luckla, community initiatives collect waste independently and SPCC supports these initiatives. The waste collected by SPCC is classified as burnable (plastic, paper, cloth, wood, and other organic matter) and nonburnable (metal, glass, batteries) (SPCC 2006). The latter is commonly dumped in pits whereas burnable waste, often mixed, is burned to reduce volume and weight in separate pits.

The SNPBZ Management Plan (2006) pointed out the relation between solid waste and water quality, anticipating that:

> *[t]he pollution problem is now no longer confined to solid waste. Water resources along the major trails are being contaminated from improper affluent discharge, human*

 http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00028.1

FIGURE 1 Map of SNPBZ showing locations where microbiological contamination was detected.
(Map by Gaetano Viviano)



waste, and garbage dumping. Untreated sewage and toilet waste can be found piped into nearby streams and rivers.

Besides, the lack of public toilets along the trails forces travelers to leave their excreta in the open air in the surroundings of trails (Tabei 2001). In some places, private toilets are built too close to rivers and streams. Furthermore, most private and public toilets lack appropriate excreta and wastewater storage and treatment facilities. Most often temporary pits are dug as toilets used by trekkers. These are not necessarily constructed in a way that safeguards the environment or protects against health risk and disease transmission. In villages a lack of proper drains leads to uncontrolled drainage of a mixture of stormwater, greywater, and even excreta-contaminated wastewater flowing on streets and into nearby streams, thus contributing significantly to degradation of water quality.

http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00028.1

Caravello et al (2007) reported that the water quality of rivers in the Khumbu Valley has deteriorated microbiologically as well as chemically, contradicting et al (1998) who found that surface waters of the Khumbu Valley were free of chemical contamination of human origin. According to Caravello et al (2007), observed alterations of water quality were likely caused by fecal pollution (organic human waste) in correspondence with increased tourism-related anthropic pressures.

Another source of surface water and groundwater contamination with respect to nutrient flows, which are of paramount importance to the condition and development of the ecosystem and organic pollution, derives from livestock rearing and the use of animal organic wastes as agricultural fertilizer. According to Byers and Sainju (1994), animal dung is indeed essential as fertilizer to sustain agricultural productivity on thin, fragile mountain soils. Although the use of chemical fertilizers is currently still uncommon in SNPBZ, the excrement of around 2000 domestic animals, mainly sheep and yaks living inside the park, is used by local people as organic fertilizer (Watanabe 2005) and fuel (Ives 1987; Byers 2005).

Data collection methods

Solid waste

Two field visits were conducted in September–October 2007 and in May–June 2008 for quantitative characterization of accumulated solid waste, its spatial distribution, sources, and an assessment of components of the existing waste management scheme and disposal technologies. To cover the area of SNPBZ, a total of 35 major settlements situated along main trekking routes (Caroli 2008) were investigated. The households were categorized into residential (private houses), commercial (hotels and lodges), and institutional (schools, hospitals, local offices and monasteries). A random structure sampling technique (Sutherland 1996) to cover all household types was applied and a sample of 15% of the households overall ($n = 154$) were sampled for waste generation quantification using a standardized questionnaire developed through consultation with the local stakeholders based on identified data gaps (Salerno et al 2010).

Rapid appraisal was also done whenever it was not possible to use standard questionnaires. In each selected household and for each household type, the number of members (inhabitants, customers, visitors) was recorded as well as the amount of both overall and per person solid waste generated per day for 14 different types of waste. These were subsequently grouped into 4 main waste categories: plastic, metal, glass, and "other" (including kitchen waste, paper, dust, etc). The quantification of solid waste produced was estimated during 7 consecutive days. Different disposal methods (ie burning, burying, incinerating, transporting outside, reusing, recycling) were identified and quantified per each type of solid waste produced. In addition, for some settlements a survey of existing waste dumping sites was conducted, collecting information about their location, volume, lifetime, and burning efficiency. Following the methods of Gupta (2000), environmental impacts of waste dumping sites on water, soil, and air quality were also assessed: samples were collected at different locations from drinking water sources (in 11 sampling sites along rivers), soil (in 22 sampling locations), and air (in Luckla and Namche) close to existing waste dumping sites, and analyzed by atomic absorption spectrometry (AAS) to assess possible heavy metal (ie Cu, Ni, Cd, Zn) contamination in water and soil and contents of inhalable suspended particles less than 10 μm diameter (PM_{10}) in the air.

Water quality

A comprehensive water quality survey to evaluate the current situation in SNPBZ was carried out by collecting 104 surface water samples—mostly from streams and rivers, but also from Gokyo, Imja, and Pyramid Inferior Lakes—taken along the major trekking routes during three field visits in October 2007, May 2008, and October 2008. Water samples were analyzed to determine hydro-chemical and physical variables (temperature, pH, conductivity, total dissolved solids, nutrients such as nitrogen [N] and phosphorus [P], macro-constituents, alkalinity) following Trivedy and Goel (1986) and Camusso and Galassi (1998), and microbiological parameters (total and fecal coliforms, bacterial composition), following APHA, AWWA, WPCF (2005) methods. Phytological analyses (aquatic algae presence, chlorophyll content) were done on water samples collected from the Gokyo Lakes series and Imja Lake. River and lake water samples from 11 different locations (including 3 Gokyo Lakes) were additionally tested for heavy metals (Fe, Pb, Ni, Zn) by means of an atomic absorption spectrophotometer (AAS) and volumetric methods. To determine the nutrient influx, N, P, and potassium (K) content of organic fertilizer, litter, and fresh as well as burnt waste from dump sites was also analyzed (altogether 100 waste samples) by Kjeldhal, Stannus Chloride, and flame photometer methods (Jackson 1967), respectively.

In addition, a field survey to identify potential and actual sources of water pollution and to analyze water quality was carried out by means of a structured standard questionnaire (Converse and Presser 1986) developed through consultation with the local stakeholders based on identified data gaps. Households were selected in major settlements along main trekking routes (Caroli 2008). The households were categorized into different functional categories (large lodge, small lodge, tea shop, residential house), and a random sampling technique was applied to

http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00028.1

each group (Sutherland 1996) to cover all these household types, resulting in a coverage of around 20% of all households in SNPBZ. The questionnaire survey collected information about production of organic human waste, construction details, operation and management of sanitation facilities and services, use of organic and chemical fertilizers, and location of garbage pits.

Designing the models

With the aim of facing the issues related to solid waste management and environmental and human health problems caused by water pollution, qualitative models on solid waste and water quality (Figure 2) were initially developed—by means of the free-accessible CmapTools® software (Institute for Human and Machine Cognition [ICHM], Pensacola, FL, USA)—together with local stakeholders and researchers during the participatory modeling framework applied in SNPBZ, as described by Salerno et al (2010). In view of developing possible management scenarios, such qualitative models were then translated by the core team (modelers) into quantitative System Dynamics models by using Simile® software (Simulistics Ltd, University of Edinburgh, Edinburgh, UK). A detailed users' manual was prepared (ICIMOD 2009) that included examples of models runs that could be modified to create scenarios that reflect the hypothetical or proposed changes in a SES and to view, analyze, and compare the output from 2 or more scenarios. A description of the models' structure from a quantitative perspective, as well as of the models' input data, intermediate variables, and performance indicators, is also provided in the quantitative documentation of each model (downloadable at http://hkkhpartnership.org). All the models were developed using a generalizing design that allows for user-friendly adaptation to other contexts and are downloadable free of charge at www.hkkhpartnership.org. The models are illustrated and described below to make their functioning more understandable to the reader from a qualitative perspective.

The solid waste management model

The solid waste management model describes the process of waste production, collection, and treatment, providing, for each time step (monthly), the amount of solid waste—divided into the 4 identified categories: glass, plastic, metal and "other"—produced, treated, and disposed on the soil. The model structure was repeated for 18 selected park settlements, for which a complete set of the necessary data collected on the field and from the literature was available.

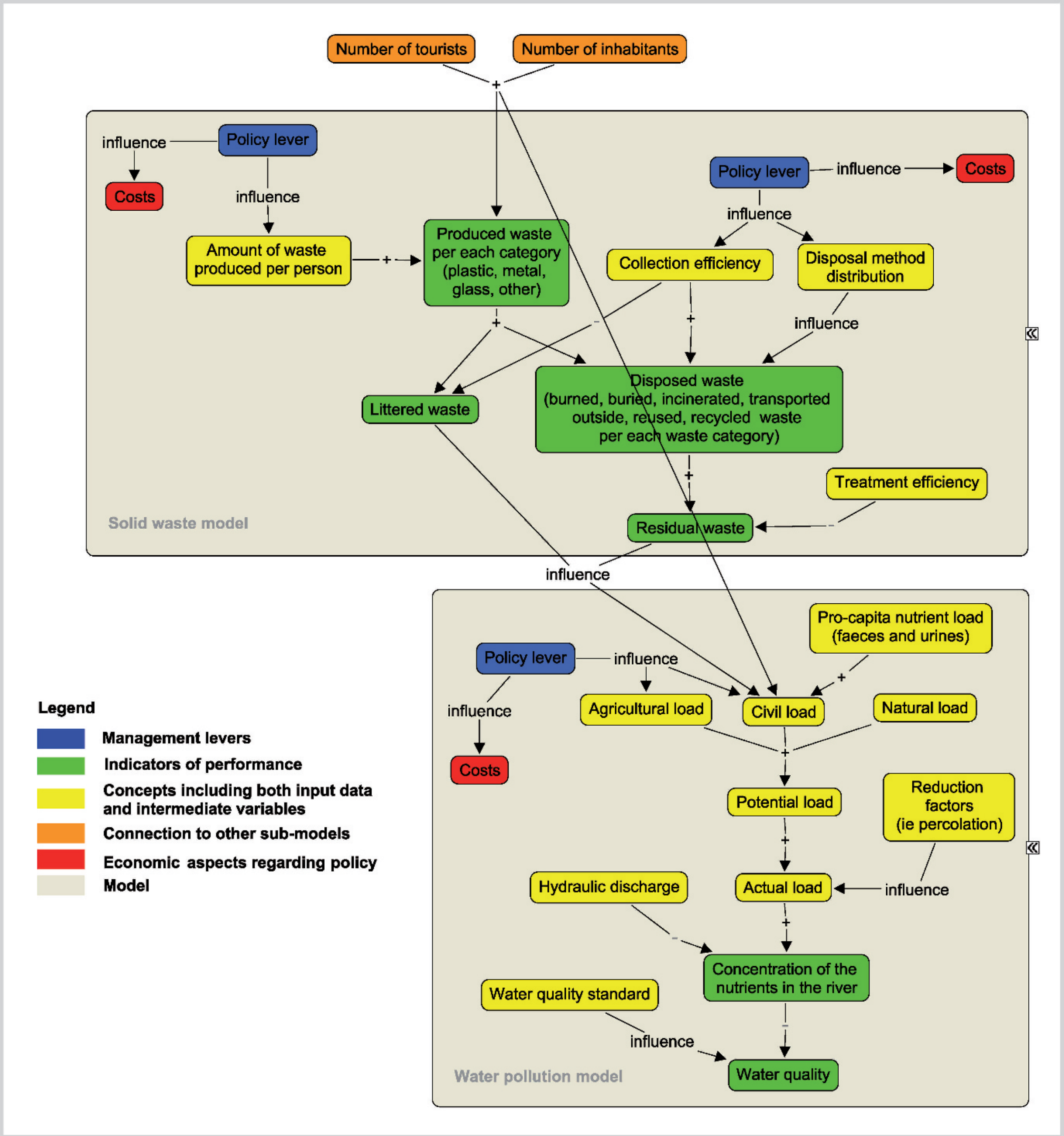
Starting from the *number of tourists* and *inhabitants* in each settlement (calculated in the Tourism and Population dynamics model, see ICIMOD 2009) and considering the amount of solid waste produced pro capita (obtained from the field survey on waste generation), the model calculates the amount of *waste produced* for each category (Figure 2). The waste produced and collected (*disposed waste*) is then assigned to six different treatment options (reusing, burying, burning, incinerating, recycling, and transporting outside) according to specific coefficients of repartition (*disposal method distribution*). The waste not collected is represented in the model by *littered waste*, while *residual waste* indicates all collected and treated waste left after the treatment (*treatment efficiency*), particularly burying, burning (ie waste burned on the soil in open dumping pits), and incinerating (ie waste burned in incinerators). We assumed in the model that buried waste and the remains of burned and incinerated waste (*residual waste*) as well as uncollected waste (*littered waste*) are accumulated in the soil compartment.

To reduce the amount of solid waste that ends on the ground (both littered and residual waste), the model offers the possibility of implementing 2 different management policies (*policy levers*). Particularly, in the case of SNPBZ, the following were implemented: one leading to reduction of waste production, and the other entailing a change of treatment typology per each waste category by choosing the more suitable disposal method (eg recycling for plastic, transporting outside for metal and glass, reusing, and/or incinerating for "other") while enhancing collection efficiency. The model provided information on the tourism-related impact of solid waste management while also assessing the economic consequences caused by the application of the above-mentioned possible management levers.

The water pollution model

The water pollution model was developed with the aim, first, of evaluating nutrient (ie N and P) concentration in streams and then assigning an index (*excellent*, *good*, *sufficient*, *poor*, *very bad*) representing the water quality. As shown in Figure 2 (bottom part), the model is able to estimate the nutrient concentration in each river's section by considering the *civil load* of nutrients, deriving from civil point sources like organic human waste (feces and urine), and residual (burned, buried, and incinerated) and littered solid waste. The *civil load* is indeed influenced by both the *littered waste* and *disposed waste*, which are outputs of the solid waste management model, as well as by the *number of inhabitants* and *number of tourists* that, considering the *pro-capita nutrient load*, contribute to the nutrient load through human excreta. The aggregation of nutrients from *civil load*, *natural load* (nutrients from forests, rocks, precipitations) and *agricultural load* (nutrients from chemical and organic fertilizers) defines the *potential load* of nutrients in the park. Then, considering natural *reduction factors* such as percolation, the actual nutrient load is appraised. At this stage, the model estimates the *nutrient concentration in the river* section dividing the actual nutrient load by the experimental *hydraulic discharge*.

FIGURE 2 Qualitative models of SNPBZ for the management of solid waste and water quality. Colors represent modeling meanings; link arrows are labeled. The symbols +, −, and +/− are used as linking phrases to indicate causal relationships between the connected concepts, describing either positive or negative (inverse) relationships or relationships that can be either positive or negative depending on conditions. (Modeling by Gaetano Viviano, Francesco Giannino, and Franco Salerno)



http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00028.1

Location of sampling points was chosen with the aim of calibrating on the one hand the nutrient sources (agricultural, civil and natural loads) calculated by the model, and on the other hand their impacts on water quality in different sections of the main course, as represented in the map of SNPBZ with indication of the sampling sites (see Figure 1). To achieve the first aim, some samples were taken (during field research) in the closure point of small watersheds considered representative of each type of pressure. For instance, watersheds completely dominated by natural land cover classes, watersheds with a predominance of agricultural fields, or watersheds characterized by densely populated settlements were considered. Comparisons between the nutrient concentrations calculated by the model and those measured on the field allowed us to calibrate the model so that it could simulate the experimental concentrations. By comparing the simulated concentration of nutrients in the river section with national or international standard parameters, the river ecological status (ie *water quality*) can be assessed. As described later on, this model made it possible to estimate the *water quality* of the main river sections in SNPBZ, considering recent environmental regulations in the European Water Framework Directive, WFD 2000/60/CEE (international regulations such as the WHO guidelines regards just quality of drinking water). By acting on the management levers that allow for change of agricultural and civil nutrient loads, different sustainable or unsustainable water pollution scenarios were obtained and evaluated, which are presented below. Furthermore, the model allows calculation of the cost implied by the specific management policy lever.

Results and management scenarios

Below, we provide an overview of the major results from field surveys and experimental analyses conducted within the management-oriented research (see Module 3 in Salerno et al 2010), while introducing the most significant solid waste and water quality management scenarios that were developed through the relevant models and discussed in consultation with local stakeholders.

Field data were used to calibrate the models or rather to set the different parameters. The models were calibrated using field data, and their parameterization made it possible to obtain a scenario, called here the "business as usual" scenario, which depicts the current situation in the park regarding the collection, segregation, and disposal of solid waste (solid waste management model), and the rivers status (water quality management model). In this basic scenario, any specific policy lever was indeed implemented in the models. Through such models it was then possible to develop and analyze possible future management scenarios to simulate the effects of specific management options (or policy levers) applied in each model and on which the model user may act directly (detailed explanations are provided in the models' users manual, see ICIMOD 2009).

Improving solid waste management

The household questionnaire survey revealed that more than any other environmental problem, solid waste was perceived by interviewed local people as the key challenge for SNPBZ (for more than 65% of respondents). As reported in Table 1, daily total waste generated in SNPBZ was empirically assessed to amounts of around 4.6 t day^{-1} during the tourist seasons (October–November and April–May), when the waste quantification survey was conducted. We found that local people and tourists on average produce around 0.109 kg day^{-1} and 0.123 kg day^{-1} of solid waste per capita. Thus, compared with visitors, waste generated by local people living in the park and its buffer zones is 15%–20% less. However, because visitors spend on an average of 10 days in the park per year, the actual yearly average generated waste is only 3–4 g day^{-1}.

Considering the rather small difference with regard to the amount of waste produced per visitor and local resident, at an annual scale the tourism industry is responsible for only around 10% of the accumulated waste, but the accumulation pattern is extremely unequally distributed over the year. Considering the distinct seasonal pattern of tourism-related activities, the overall waste production could be as low as 2 t day^{-1} in the low season and is at a maximum during the 2 peaks in the tourist seasons (October–November and April–May).

Kitchen waste ("other"), largely composed of organic matter and preferably used for cattle feeding, amounts to around 88% of the waste generated, leaving the share of nondegradable waste categories at 7% for plastic, 3% for glass, and 1% for metals. Though the amount of plastic, metal, and glass generated is low if compared with largely biodegradable waste, these nonbiodegradable waste types create a great visual pollution problem on the landscape. They can cause environmental pollution and public health problems (eg ground and surface water pollution, air pollution caused by toxic gas emissions from burning, harmful effects on aquatic and terrestrial animals; see El-Fadel et al 1997; Hamer 2003; Pokhrel and Viraraghavan 2005). Particularly, plastic, and synthetic materials when burned easily generate charred residue solid ashes and toxic gas emissions that pollute the atmosphere (Kuniyal 2002; Valavanidis et al 2008).

With regard to the spatial distribution of the waste generation pattern, it is clear that since Luckla, Phakding, and Namche—the major settlements in SNPBZ located along the main route to Everest Base camp, Gokyo, and Thame—host a high number of hotels and service enterprises, daily waste generation for all types of households in these settlements is high, particularly in the tourism node of Namche. Glass and metal are accumulated predominantly in the BZ and Namche (first

7 settlements in Table 1). The ban on import of glass bottles (mainly beer) into the park initiated by the BZ Management Committee was successful in reducing the problem of glass accumulation in SNPBZ.

The only running incinerator in SNPBZ is located in Luckla. Its incineration capacity is theoretically around 30 kg^{-1}, producing 2.3 kg of ash from 30 kg of wastes. Leakages have been observed in the device, and maintenance of the incinerator is urgently required. Furthermore, most of the supporting technical components are not operating properly, so that the current use of the system resembles a "closed burning" practice. Because of a lack of alternatives, current waste disposal practices in the park, besides exporting, are limited to permanent storage of waste in open dumping pits (a total of 49 were found in the park), which are occasionally set on fire to reduce the volume of waste, and burning in the closed burning installations in Namche and Kumjung. Because degradable waste is commonly used by households as fodder or for composting, the waste in the open pits consists predominantly of nonsegregated nondegradable waste.

Although attempts have been made to manage glass and metal, plastic is currently the most problematic waste type in SNPBZ. It is accumulated in large quantities and is spatially widely distributed across the park. Furthermore, current disposal of plastic (open dumping or burning) is a great hazard for environmental and human health (Gatrell and Lovett 1992; Thompson et al 2009). Although around half of the plastic accumulated in SNPBZ is openly burnt, 40% is dumped in pits or scattered around. A small share is reused by local residents. Figure 3 shows percentages of disposed solid waste for each waste category according to both the current treatment practices (Figure 3A) (ie burning, burying, incinerating, transporting outside, reusing, recycling) as well as the best options identified (Figure 3B).

The heavy metal analysis of the river water samples taken from 11 locations near waste dump sites showed elevated concentrations of lead (Pb) in all samples (0.09–0.34 mg l^{-1}) and elevated iron (Fe) in 60% of the samples (5.07–14.43 m l^{-1}), whereas nickel (Ni) and zinc (Zn) at all sites never exceeded the Nepali guidelines for drinking water (Gov. of Nepal, 2005: National Drinking Water Quality Standard (NDWQS) limits: Pb = 0.01 mg l^{-1}, Ni = 0.02 mg l^{-1}, Fe = 0.3 mg l^{-1}, Zn = 3.00 mg l^{-1}). Analysis of soil quality at different locations near dumping sites also showed a contamination by heavy metals. Thus, copper (Cu) was above WHO standards (Cu=0.1–2.5 ppm) only in the soil collected near Namche burning pit (5.44 ppm), while Zn exceeded WHO guidelines (Zn=1.2–2.0ppm) in most of the sampling points, with the highest values found near Luckla's incinerator (262.70 ppm) and Namche's closed burning installation (153.78 ppm), but cadmium (Cd) and Ni never exceeded the WHO standards (20 ppm and 3–1000 ppm, respectively). As a reference condition (control), we referred to the paleolimnological study of Lami et al (1998) who reported that trace metal concentrations, particularly Cu, Zn, and Ni, found in sediment cores from 2 lakes situated in the Upper Khumbu Valley, were generally close to the world average for rocks. Given that these lakes are situated in a remote area where the human impact is very limited and receive primarily water from glaciers and snowfield, no evidence was found indicating an anthropogenic contribution to the observed metal loads, which most likely are of geological origin. On the contrary, high concentrations of Cu and Zn observed in this study in the sample form Luckla and Namche may be associated with the presence, respectively, of the nearby small-size incinerator and open burning installation (Yoo 2002). However, as these results are preliminary, further specific investigations would be needed to support this hypothesis. Similarly, PM_{10} concentration in air samples collected close to the burning pits at Luckla and Namche were found to be from 2 to 4 times higher than the standard threshold in ambient air (120 μg m^3). Natural reference conditions for PM_{10} concentration were provided by the study of Decesari et al (2009), who reported on chemical composition data for PM_{10} from the Nepal Climate Observatory-Pyramid (NCO-P) located at 5079 m at the foothill of Mt Everest, where air pollution is mainly caused by transport of anthropogenic aerosols and the average PM_{10} mass measured was of the order of 6 μg m^3.

Microbiological contamination (fecal coliform) was also found in water samples obtained near the waste dump site in Namche.

With the aim of investigating alternative solutions for reducing waste scattered after treatment on the soil (littered and disposed) and consequent impacts on the environment, the solid waste model was developed and implemented. Before presenting and discussing the modeling scenarios, we must state beforehand that, to individuate the management options to be implemented in the model, different suggestions for improvement of management of solid waste in SNPBZ that emerged during the November 2008 workshop in Namche (SES bounding section) with local stakeholders (including local policy- and decision-makers, park managers, SPCC staff, school teachers, and local lodge owners from some settlements) were evaluated. Those included the following: promotion of indigenous knowledge and practices for waste management through related training and capacity building activities; introduction of appropriate incineration technology in suitable locations (repairing and functioning maintained of the Luckla incinerator or installation of a new incinerator of greater capacity (100 kg $hour^{-1}$) in Namche or other nearby places to incinerate waste produced from Luckla and other settlements in lower Khumbu); promotion of better segregation and disposal of waste at different levels (SPCC's staff and households); introduction/installation of

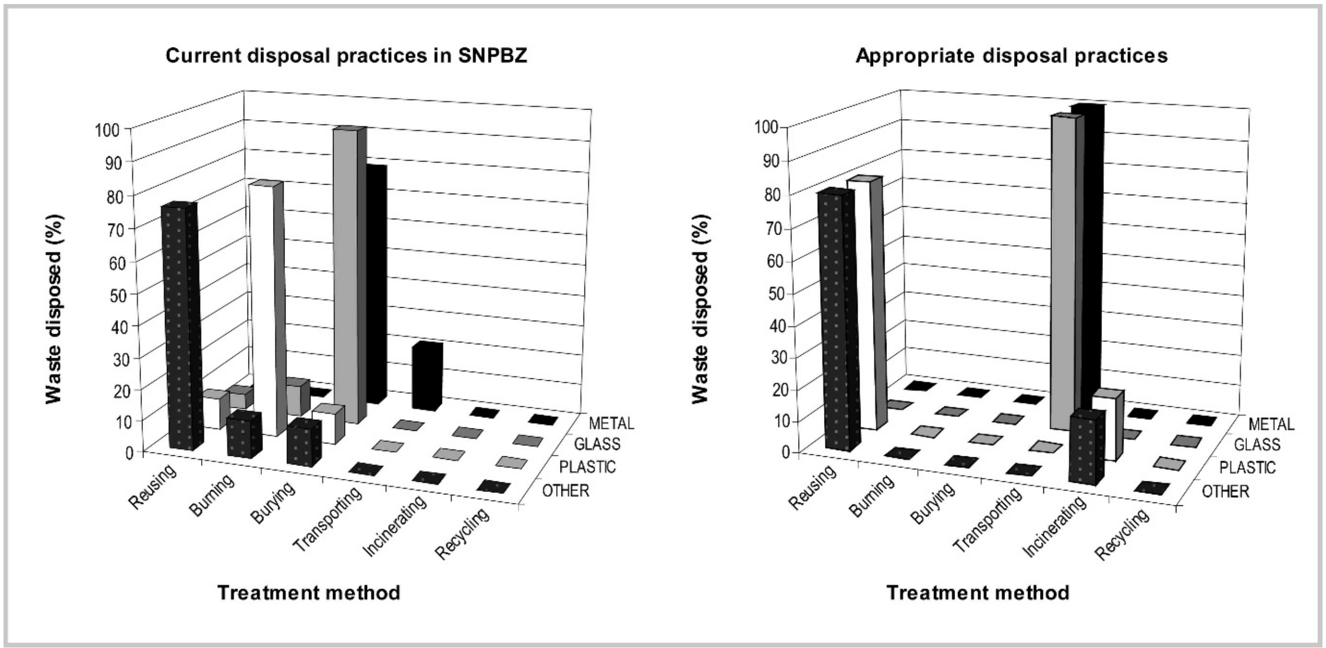
http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00028.1

TABLE 1 Waste generation in different locations in SNPBZ, per different waste categories. For every investigated settlement, the total daily amount of solid waste generated is reported as well as the amount per capita.

Settlement	Waste composition (%)				Total households per settlement	Total daily waste generation (kg day^{-1})	Total daily waste generation per capita (kg day^{-1})
	Plastic	Glass	Metal	Others (kitchen waste, paper, dust, etc)			
Buffer zone							
Luckla	4	36	2	57	153	501	0.16
Phakding	2	4	3	91	84	351	0.42
Ghat	3	11	1	85	16	25	0.13
Tok tok	1	7	2	90	29	52	0.13
Chaumo	2	3	0	95	29	65	0.32
Monjo	5	2	2	91	18	47	0.26
Sagarmatha National Park							
Namche	5	5	5	86	141	**835**	0.16
Tyangboche	11	0	2	87	11	60	0.09
Pangboche	7	0	1	92	44	151	0.49
Upper Pangboche	13	0	0	87	50	126	0.25
Pheriche	10	10	1	79	22	105	0.30
Dingboche	7	0	0	93	52	426	0.33
Thukla	7	0	0	93	1	10	0.32
Lobuche	8	0	0	91	7	32	0.24
Gorakhshep	7	0	1	92	6	26	0.17
Syangboche	4	0	0	96	5	30	0.40
Khunde	7	0	0	93	73	102	0.28
Khumjung	8	0	1	91	230	469	0.41
Phortse	3	0	0	97	84	304	0.30
Phortsethanga	7	0	0	92	6	28	0.42
Dole	4	0	0	96	10	61	0.28
Mochhermo	8	0	0	92	12	89	0.39
Gokyo	8	3	13	76	9	72	0.15
Kyangjuma	9	0	1	90	5	28	0.43
Sanasa	4	0	0	96	10	60	0.67
Lausasa	8	0	0	92	17	85	0.50
Phungithenga	20	0	0	80	4	6	0.50
Thamo	17	0	1	82	55	144	0.44
Thame	4	4	1	91	45	265	0.65
Thametenga	13	13	0	73	42	63	0.50
	Average	**Average**	**Average**	**Average**	**Total**	**Total**	**Average**
	7	**3**	**1**	**88**	**1270**	**4618**	**0.34**

http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00028.1

FIGURE 3A and 3B (A) Current waste disposal practices in SNPBZ; (B) best options for each category of waste.



waste recycling equipment (eg recycling plants for plastic); improving export of nondegradable waste; and encouraging use of low waste generating materials.

At first, the model was run applying the current management policy adopted by SPCC in the park to have a reference condition, the so-called "business as usual" scenario, useful to understand the model's performance and assess how the system changed when an alterative waste management lever was implemented. The simulated "business as usual" scenario depicted the current situation in the park, providing results similar to those found in the field, as expected, because the model was calibrated at the actual time step under local conditions in the study area, based on data collected from field surveys.

An alternative scenario was then simulated by implementing the model with a management policy, foreseeing at the same time a 100% collection efficiency total and a waste disposal practice in accordance with the most appropriate treatment methods proposed per each waste category in contrast with the current practice. According to this proposed policy lever, all plastic waste would be preferably recycled (alternatively incinerated), glass and metal exported, while remaining solid waste (category "other") would be mostly reused (80%) and partly incinerated (20%) (Figure 3A). As a result, both the *littered waste* on the soil and the *residual waste* after treatment would be zero: this may help to significantly reduce the civil nutrient loads—influenced also by burned, buried, and incinerated solid waste as well as uncollected waste littered on the soil—that goes into streams.

A broader management analysis required that the projected costs of operations (ie collection and exportation) and the infrastructure needed (ie small incinerator with 100 kg hour^{-1}) to properly dispose each waste category were considered. A preliminary cost assessment was initiated with regard to the different disposal treatment methods considered in the above-mentioned management scenario. For instance, at park level, the cost estimated for a 100% collection of all solid waste produced amounted to US$ 3000, while costs for exporting plastic, glass, and metal were found to be around US$ 2900, 3300, and 3000, respectively, including discounted air cargo charge and porter charge from Namche to Luckla. Costs for incineration of solid waste depend mainly on the capacity of the incinerator. Considering an incinerator with a medium capacity of 100 kg hour^{-1}, the cost to incinerate solid waste generated in the park has been calculated to be around US$ 126, which is relatively low but does not include the high costs of building and maintaining the incinerator (which, however, can be amortized over time).

Improving water quality management

The water quality analysis revealed that the nitrate content of all water samples was within the threshold for drinking water, according to WHO and Nepali guidelines (Gov. of Nepal, 2005), ranging between 0.14 and

http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00028.1

1.94 mg l^{-1}. We found that P content in collected river water samples ranged between 0.02 and 0.66 mg l^{-1} whereas USEPA (2000) criteria for streams and river water is 0.1 mg l^{-1}, and for streams entering lakes is 0.05 mg l^{-1}. P concentration measured in water samples collected from lakes (four Gokyo Lakes, and Imja and Pyramid Inferior Lakes) ranged from 0.01 to 0.42 mg l^{-1}, thus exceeding USEPA (2000)'s standard, which set a range between 0.01 and 0.03 mg l^{-1} for lake reservoirs, and indicating high probability of algae blooming (Stevenson et al 2009). Particularly, the elevated P concentrations found in the first and second lake of Gokyo (0.24 and 0.27 mg l^{-1}) are most likely caused by anthropic pressure caused by the nearby presence of touristic lodges: They discharge a mixture of greywater and even excreta-contaminated wastewater into the water body, thus contributing significantly to degradation of its water quality. Altogether 62 species of aquatic algae were recorded from lake waters in the study area; 10 were new records for Nepal. Chlorophyll content in algae ranged between 0.17 and 0.72 mg g^{-1}.

Reynolds et al (1998) analyzed sodium content at 1.61 mg l^{-1}, whereas this study found lower contents with an average of 0.2–6.4 mg l^{-1}. However, the highest values found for magnesium was 1.2 and 8.7 mg l^{-1}, showing higher values than those found by Reynolds et al (0.11 and 0.52 mg l^{-1}). However, as the dominant sources of Na and Mg are geochemical (moraine deposits), differences in their concentration are more likely associated with the different geological settings (described in Bortolami, 1998) of the investigated areas rather than the presence of waste dumping sites. Moreover, Mg concentration found in this study can be explained by means of geochemical origins as a result of the scour of the rocks and the pedogenetic layer.

Total dissolved solids, pH, sodium, magnesium, lead, and manganese were found to be everywhere within the limits for safe drinking water. Regarding the data collected on conductivity, the water quality in the Khumbu Region was still *excellent*. Analysis of heavy metals found that Fe and Cu content in water samples from 6 and 8 sampling sites, respectively, was above the WHO and Nepali standards for drinking water, which sets thresholds for Fe at 0.3 mg l^{-1} and for Cu at 1.0 mg l^{-1}.

Regarding the use of fertilizer, total annual production of organic fertilizers was estimated to be about 2000 tons in SNPBZ. A farming household produces on average 1.7 t $year^{-1}$, used at a rate of 82 kg m^{-2} on farmland. Different types of organic fertilizers are used: decomposed litter or litter mixed with animal or human waste from a single pit—one of the most widely used sanitation technologies: excreta, along with anal cleansing materials (water or solids) are deposited into a pit (Tilley et al 2008).

To meet the high demand for vegetables from the tourism industry (especially potatoes), farmers are tempted to use excessive amounts of organic fertilizers. Considering the N and P content of analyzed samples, the average ratio of organic fertilizer to area was 80 t ha^{-1}, which is higher than the recommended dose. At this rate, N, P, and K are brought out on the field at around 97, 54, and 137 kg ha^{-1} respectively, whereas the recommended dose of organic fertilizer in potato crop is 70 kg ha^{-1} for N, 50 kg ha^{-1} for P, and 40 kg ha^{-1} for K (Salerno et al 2009). Only 2 interviewed households in Namche were found to use chemical fertilizer, which is not sold on the markets of SNPBZ.

Elevated levels of microbiological contamination by fecal coliform bacteria (*Escherichia coli* and *Streptococcus faecalis*) were found in the water at 6 sampling points (see Figure 1). For business reasons, tourism services and facilities are preferably provided and situated directly along the trekking trails, which in turn often follow the river sections draining the valleys along the valley bottom. Consequently, rivers and streams are contaminated by human excrement, which leaches into the groundwater or is discharged and piped directly into the rivers and streams from open toilets and lodging facilities.

Three types of septic tanks were observed in SNPBZ: with cemented walls, stone walls (noncemented), and single pits (including litter toilet) (Figure 4). Only 5% of the inspected toilets had a septic tank with cement walls, while 47% consisted of a single pit and 48% had stone walls. Twenty percent of the houses in SNPBZ did not have a septic tank and were generally situated along the trekking routes.

The impermeability of septic tanks depends on the depth of the tank, soil texture (high if soil texture is fine) and material used for the tank wall (cement or stones). In addition, the distance of the tank from the water source influences the time for the fecal matter to reach the water body by leaching. Stone-walled septic tanks have a permeability of 40%–50%. Although tanks with cement walls have an average permeability of less than 10%, the cost for construction material is relatively high because of the high cost of transportation and the cold climate, hindering the cementing process. For this reason, only a few lodges have such a tank. Septic tanks built out of stone are the most viable option for tourism enterprises in SNBPZ. This kind of septic tank has the advantage of low construction costs, also for tanks with a high volumetric capacity, as required for such enterprises.

Findings from field surveys gave a picture of the current situation in SNPBZ, which was also reflected in the "business as usual" scenario simulation by running the model without implementing any policy lever. As previously explained, the "business as usual" scenario represented the current condition in the study area (data collected on the field were used to calibrate the model at actual time) and provided a reference condition to understand the performance of the model. By evaluating such scenarios depicting the current situation in the park

http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00028.1

FIGURE 4 Types of toilets in SNPBZ. From left to right: (A) and (B) 2 toilets using litter, the most common type of toilet in the lower part of the park; (C) a temporary toilet at Everest Base Camp; (D) the toilet of a hotel showing waste flowing out on the surface from a septic tank. (Photos by Pramod Kumar Jha, Bharat Babu Shrestha, and Narayan Prasad Ghimire)

(where no policy levers are implemented) and considering the classes for water quality set in the European WFD, the water quality in the section of Dudh Kosi River below Surke village (BZ) was found *sufficient* on a yearly average. However simulation modeling showed that it became *very bad* during dry months.

The application of different policy levers allowed us to estimate the possible benefits of each policy on the river water quality. The model was run by implementing a policy lever to foresee the upgrading of already existing stone-wall septic tanks to cemented-wall ones with greater permeability or construction of a new cement wall, as possible management actions to reduce the leaking of fecal matter (human organic waste) into surface water bodies and groundwater that is a major source of water contamination, as previously stated. We obtained a simulation scenario showing that the river water quality in the same section became *good* in general on a yearly time scale, although it was *sufficient* during the driest months (April–May) when the pressures on water quality are greatest given that river flow is at a minimum and the weather is most favorable for tourist trekking.

As an overall result of the application of the above-mentioned management lever in SNPBZ, the water quality in the river section considered in general would improve, even if differently, during dry season—from *very bad* (Class V) to *sufficient* (Class III)— as well as the rest of the year—from *sufficient* (Class III) to *good* (Class II). The average estimated cost to realize this scenario in all selected settlements in SNPBZ was around US$ 1.4 million (NRs 110 million) and included both the costs of construction materials for cement wall septic tanks with a tank capacity of 1000 cubic feet (below 4000 m, US$ 2000 = NRs 150,000; above 4000 m, US$ 1100 = NRs 80,000) as well as the transportation costs (higher at higher altitudes). Because of the high transportation costs of construction material for cemented-wall septic tanks, they do not seem economically viable for small lodges and tea shops, especially at high altitudes (here stone-wall septic tanks could be the best option), but they can be constructed for bigger lodges and hotels.

Another alternative management option is related to the fact that local people living inside the park commonly use domestic animal excrement as organic fertilizer. According to Hatfield and Cambardella (2001), whether N source is animal manure, as in the case of SNPBZ, or commercial fertilizer, over-application of either source can provide too much plant-available N and increase the potential for NO_3 leaching and leakage into water resources, which can contribute to surface water and groundwater degradation. Among management strategies for reducing nonpoint NO_3 loss from cultivated fields through drainage, the establishment of riparian buffer zones, wetlands, or biofilters can contribute to nitrate removal and minimizing nitrate contamination of water resources (Dinners et al 2002). Given this background, we explored the possibility of introducing streamside forested buffers on one side of a cultivated field to reduce nitrate leaching and drainage caused by runoff from field applications of animal manure. Streamside forested buffers may indeed attenuate N inputs to aquatic ecosystems through plant uptake, microbiological denitrification, soil storage, and dilution (Haycock and Pinay 1993; Balestrini et al 2006; Dosskey 2001). By implementing this management lever, although the water quality in the considered river section would remain *poor* in the dry season, it would be *good* during most of the year. The model also estimated that the necessary surface of

http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00028.1

trees to be planted at park level would be at least 40 ha, for a total cost of US$ 19,000 (NRs 1.5 million).

Conclusion

This paper has shown the process and findings of an application of the methodology and framework described in Salerno et al (2010) to support participatory modeling of natural resource management in SNPBZ. Efforts focused on incorporating researchers', stakeholders', and decision-makers' visions to help address emerging management questions related to solid waste and water quality in SNPBZ. After describing the SES studied and the main management issues that emerged, these were shared by modeling actors, and a conceptualization phase created the right platform for planning management-oriented research plans aimed at collecting data necessary for implementing the developed models.

The study revealed that although most of the solid waste generated in the park is composed of organic matter, paper, and minor waste that are mainly reused, disposal of other categories of collected waste (glass, metal, and plastic) is not properly managed. Particularly burning or disposal in open dumps poses a great hazard to environmental, human, and animal health, as most dump sites situated close to watercourses are prone to be flooded regularly during the rainy season, thereby directly contaminating river water. Moreover, we found pollutants and microbiological contamination in water bodies. Pollution and current water quality of water bodies analyzed can be associated with anthropogenic activities and current improper disposal of solid waste and human excreta such as solid waste dump sites, open defecation, and the poor condition of existing septic tanks. Direct discharge of toilet waste into water courses or on exposed surfaces may significantly intensify the problem.

Unlike for solid waste management, for which a policy has been established and has now started to be implemented, there is no organization or agency in SNPBZ assigned to address the problems related to the disposal of human feces and protection of water bodies from contamination—a drawback that should be addressed. Accelerated and largely uncontrolled development of tourism in SNPBZ has resulted in a discrepancy between the accumulation of solid and human waste, and disposal and waste water treatment infrastructure, facilities, and capacity for their management. We calculated that equipping toilets in lodges and guesthouses, especially public toilets located along the major trekking routes, with cement-wall septic tanks would effectively mitigate water contamination through human waste. However, the high cost of transportation and construction material for cement-wall septic tanks (that are higher at high altitudes) are to be considered; these are higher if compared with stone-wall septic tanks that have a lower permeability, however. In addition to preliminary cost assessments provided regarding the alternative management policy implemented within the models, a thorough and in-depth assessment of all related economic aspects is needed in the near future to individuate the most appropriate and realistic management interventions to be applied in the park.

Quantitative models for supporting management of solid waste and water quality were developed with an interactive modeling process, using a generalizing design that allows for user-friendly adaptation to other contexts (free-download at http://hkkhpartnership.org). The participatory modeling process was concluded with an adaptive management phase by simulating possible management scenarios with the participation of all modeling actors. The aim was to build consensus on the understanding of the system as well as to improve decision-makers' capacity to adapt not only by responding to changes, but also by anticipating them.

ACKNOWLEDGMENTS

This publication was produced within the framework of the project "Institutional Consolidation for the Coordinated and Integrated Monitoring of Natural Resources towards Sustainable Development and Environmental Conservation in the Hindu Kush–Karakoram–Himalaya Mountain Complex," financed by the Italian Ministry of Foreign Affairs–DGCS. The authors would like to thank the Department of National Parks and Wildlife Conservation, Nepal, the Sagarmatha National Park and Buffer Zone Management Committee, Nepal, the Sagarmatha Pollution Control Committee, Nepal, and the Khunde Hospital Laboratory in Namche. Simulistics Ltd, Edinburgh, is also thanked for contributing to modeling within the project.

REFERENCES

Agarwal A, Narain S. 1999. *Community and Household Water Management: The Key to Environmental Regeneration and Poverty Alleviation*. Mimeo. New Delhi, India: Centre for Science and Environment. Presented at UNDP-EC [United Nation Development Programme – European Commission] Experts Workshop on Poverty and Environment, Brussels, Belgium, 20–21 January 1999.
Alam R, Chowdhury MAI, Hasan GMJ, Karanjit B, Shrestha LR. 2008. Generation, storage, collection and transportation of municipal solid waste: A case study in the city of Kathmandu, capital of Nepal. *Waste Management* 28(6):1088–1097.
APHA [American Public Health Association], AWWA [American Waters Work Association], WPCF [Water Pollution Control Facilities]. 2005. *Standard Methods for the Examination of Water and Wastewater*. Washington, DC: American Public Health Association.
Arnold JS, Fernandez-Gimenez ME. 2007. Building social capital through participatory research: an analysis of collaboration on Tohono O'odham tribal rangelands in Arizona. *Society and Natural Resources* 20(6):481–495.
Balestrini R, Arese C, Delconte C. 2006. Nitrogen removal in a freshwater riparian wetland: An example from an Italian lowland spring. *Proceedings of the International Association of Theoretical and Applied Limnology* 29:2217–2220.

Basnet K. 1993. Solid waste pollution versus sustainable development in high mountain environment. A case study of Sagarmatha National Park of Khumbu Region. Nepal. *Contributions to Nepalese Studies* 20(1):131–139.
Byers A. 2005. Contemporary human impacts on alpine ecosystems in the Sagarmatha (Mt. Everest) National Park, Khumbu, Nepal. *Annals of the Association of American Geographers* 95(1):112–140.
Byers E, Sainju M. 1994. Mountain ecosystems and women: Opportunities for sustainable development and conservation. *Mountain Research and Development* 14(3):213–228.
Bishop BC, Naumann C. 1996. Mount Everest: Reclamation of the world's highest junk yard. *Mountain Research and Development* 16(3):323–327. In Memoriam: Bishop BC, 1932–1994.
Bortolami G. 1998. Geology of the Khumbu Region, Mt. Everest, Nepal. *In:* Lami A, Giussani G, editors. *Limnology of High Altitude Lakes in the Mt. Everest Region (Nepal)*. Memorie dell'Istituto Italiano di Idrobiologia 57:41–49.
Camusso M, Galassi S. 1998. Inorganic and organic micropollutants in high altitude and remote area. *In:* Baudo R, Tartari G, Munawar M, editors. *Top of the World Environmental Research: Mount Everest-Himalayan-Ecosystem*. Ecovision World Monograph Series. Leiden, The Netherlands: Backhuys Publisher, pp 143–166.
Caravello GU, Boselli AM, Bertollo P, Baroni A. 2007. Assessing ecosystem health: An analysis of tourism related change and impact in Khumbu Valley, Nepal. Ecoprint, *International Journal of Ecology* 14:45–64.
Caroli P. 2008. *Visitor Survey – Sagarmatha National Park, HKKH Partnership Project Working Paper,* Kathmandu, Nepal. http://hkkhpartnership.org; accessed on 31 December 2008.
Coenen FHJM, Huitema D, OToole LJ Jr, editors. 1998. *Participation and the Quality of Environmental Policy Making. Environment and Policy*. Dordrecht, The Netherlands: Kluwer Academic Publisher.
Cointreau SJ. 1982. *Environmental Management of Urban Solid Wastes in Developing Countries: A Project Guide*. Urban Development Technical Paper Number 5. Washington, DC: The World Bank.
Cokerill K, Passell H, Tidwell V. 2006. Cooperative modeling: Building bridges between science and the public. *Journal of American Water Resources Association (JAWRA)* 42(2):457–471.
Converse JM, Presser S. 1986. *Survey Questions: Handcrafting the Standardized Questionnaire (Quantitative Applications in the Social Sciences)*. Newbury Park, CA: Sage Publications.
Curt T, Terrasson D, editors. 1999. *Boisements naturels des espaces agricoles en déprise*. Numéro special *Ingénieries*. CEMAGREF-ECOFOR.
Daconto G, Sherpha LN. 2010. Applying scenario planning to park and tourism management in Sagarmatha National Park, Khumbu, Nepal. *Mountain Research and Development* 30(2):103–112.
Decesari S, Facchini MC, Carbone C, Giulianelli L, Rinaldi M, Finessi E, Fuzzi S, Marinoni A, Cristofanelli P, Duchi R, Bonasoni P, Vuillermoz E, Cozic J, Jaffrezo JL, Laj P. 2009. Chemical composition of PM_{10} and PM_1 at the high-altitude Himalayan station Nepal Climate Observatory-Pyramid (NCO-P) (5079 m a.s.l.). *Atmospheric Chemistry and Physiology Discussion* 9:25487–25522. http://atmosph-chem-physdiscuss.net/9/25487/2009/acdp-9-25487-2009.pdf; accessed on 26 November 2009.
Delli Priscoli J. 1999. What is public participation in water resources and why it is important? Participatory processes in water management. *Satellite Conference to the World Conference on Science*. Budapest, Hungary: UNESCO International Hydrobiological Programme. Technical document in *Hydrology* 3:1–12.
Devokta SR, Neupane CP. 1994. Industrial pollution inventory in the Kathmandu Valley and Nepal (a working paper). *Kathmandu Industrial Pollution Management Project*, Ministry of industry, Nepal.
Dinners DL, Karlen DL, Jaynes DB, Kaspar TC, Hatfield JL, Colvin TS, Cambardella CA. 2002. Nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils. *Agronomy Journal* 94:153–171.
Dosskey MG. 2001. Toward quantifying water pollution abatement in response to installing buffers on crop land. *Environmental Management* 28(5):577–598.
El-Fadel M, Findikakis AN, Leckie JO. 1997. Environmental impact of solid waste landfilling. *Journal of Environmental Management* 50(1):1–25.
Gatrell AC, Loverr AA. 1992. Burning questions: Incineration of wastes and implication on human health. *In:* Clark M, Smith D, Blowers A, editors. *Waste Location: Spatial Aspects of Waste Management, Hazards and Disposal*. London, United Kingdom: Routledge, pp 143–157.
Geurts JLA, Joldersma C. 2001. Methodology for participatory policy analysis. *European Journal of Operational Research* 128:300–310.
Government of Nepal, Ministry of Land Reform Management. 2005. *National Drinking Water Quality Standards, 2062 and National Drinking Water Quality Standard Implementation Guideline, 2062. Year: 2063 (BS)*. Singhadurbar, Kathmandu, Nepal: Government of Nepal, Ministry of Land Reform and Management [in Nepali].
Gupta PK. 2000. *Methods in Environmental Analysis: Water, Soil and Air*. Jodhpur, India: Agrobios Publishing, pp 240–241.
Hamer G. 2003. Solid waste treatment and disposal: Effects on public health and environmental safety. *Biotechnology Advances* 22:71–79.
Hamilton LS. 2002. Conserving mountain biodiversity in protected areas. *In:* Körner C, Spehn EM, editors. *Mountain Biodiversity, A Global Assessment*. Parthenon, London: 295–306.
Harmon D, Worboys GL, editors. 2004. *Managing Mountain Protected Areas: Challenges and Responses for the 21st Century*. Colledara, Italy: Andromeda Editrice Srl.
Hatfield JL, Cambardella CA. 2001. Nutrient management in cropping systems. *In:* McFarland J, Sanderson M, editors. *Integrated Management of Land Application of Animal Waste*. St. Joseph, MI: American Society of Agricultural Engineering.
Haycock NE, Pinay G. 1993. Groundwater nitrate dynamics in grass and poplar vegetated riparian buffer strips during the winter. *Journal Environmental Quality* 22:278–278.
Hinsby K, Purtschert R, Edmunds WM. 2008. Groundwater age and quality. *In:* Quevauvallier P, editor. *Groundwater Science and Policy: Aan International Overview*. Cambridge, United Kingdom: RSC Publishing, pp 217–239.
ICIMOD [International Centre for Integrated Mountain Development]. 2009. *Decision Support Toolbox User Manual*. HKKH Partnership Project Working Papers. http://www.hkkhpartnership.org; accessed 2 February 2010.
Ives JD. 1987. The theory of Himalayan environmental degradation: Its validity and application challenged by recent research. *Mountain Research and Development* 7(3):189–199.
Jackson ML. 1967. *Soil Chemical Analysis*. New Delhi, India: Prentice Hall of India Pvt. Ltd.
Jansky L, Pachova NI. 2006. Towards sustainable land management in mountain areas in Central Asia. *Journal of Global Environmental Research* 10(1):99–115.
Jefferies B. 1982. Sagarmatha National Park: The impact of tourism in the Himalayas. *Ambio* 11:274–281.
Karn SK, Harada H. 2001. Surface water pollution in three urban territories of Nepal, India and Bangladesh. *Environmental Management* 28(4):483–496.
Kuniyal JC. 2002. Mountain expeditions: Minimizing the impact. *Environmental Impact Assessment Review* 22(6):561–581.
Kuniyal JC. 2005. Solid waste management techniques for the waste generated and brought from campsites in the hill spots, trails and expedition tops. *Waste Management and Research* 23(3):182–198.
Lachapelle P. 1995. *A Report on Human Waste Management in Sagarmatha National Park. Environmental Programme*. University of Vermont, Burlington, VT, and School for International Training Kathmandu, Nepal. http://www.uvm.edu/~rlachape/rep-snp.htm; accessed in May 1995.
Lami A, Guilizzoni P, Marchetto A, Bettinetti R, Smith DJ. 1998. Paleoclimatical evidence of environmental changes in some high altitude Himalayan lakes (Nepal). *In:* Lami A, Giussani G, editors. *Limnology of High Altitude Lakes in the Mt. Everest Region (Nepal)*. Memorie dell'Istituto Italiano di Idrobiologia 57:107–130.
Markandya A. 2006. Water quality issues in developing countries. *In:* Lopez R, Toman MA, editors. *Economic Development and Environmental Sustainability. New Policy Options*. New York, NY: Oxford University Press, pp 307–344.
Nepal SK. 2000. Tourism in protected areas: The Nepalese Himalaya. *Annals of Tourism Research* 27(39):661–681.
Newig J, Haberl H, Pahl-Wostl C, Rothman DS. 2008. Formalized and non-formalized methods in resource management—Knowledge and social learning in participatory processes: An introduction. *Systemic Practice and Action Research* 21:381–387.
Palmer RN, Keyes AM, Fisher S. 1993. Water management in the 90's: A time for innovation. *In:* Hon K, editor. *Proceedings of the 20th Anniversary Conference*. Reston, Virginia: American Society for Civil Engineering, pp 451–454.
Pirot JY, Meynell PJ, Elder D, editors. 2000. *Ecosystem Management: Lessons From Around the World. A Guide for Development and Conservation Practitioners*. Gland, Switzerland and Cambridge, UK: IUCN [International Union for Conservation of Nature].
Pokhrel D, Viraraghavan T. 2005. Municipal solid waste management in Nepal: Practices and challenges. *Waste Management* 25(5):555–562.
Reynolds B, Jenkins A, Chapman PJ, Wilkinson J. 1998. Stream hydrochemistry of the Khumbu, Annapurna and Lantang regions of Nepal. *In:* Baudo R, Tartari G, Munawar M, editors. *Top of the World Environmental Research, Mount Everest-Himalayan ecosystem.* Ecovision World Monograph Series. Leinden, The Netherlands: Backhuys Publishers, pp 123–141.
Rouwette EA, Vennix JAM, van Mullekom T. 2002. Group model building effectiveness: A review of assessment studies. *System Dynamics Review* 18(1):5–45.

http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00028.1

Salerno F, Buraschi E, Bruccoleri G, Tartari G, Smiraglia C. 2008. Glacier surface-area changes in Sagarmatha national park, Nepal, in the second half of the 20th century, by comparison of historical maps. *Journal of Glaciology* 54(187):738–752.
Salerno F, Cuccillato E, Caroli P, Bajracharya B, Manfredi EC, Viviano G, Thakuri S, Flury B, Basani M, Giannino F, Panzeri D. 2010. Experience with a hard and soft participatory modeling framework for social-ecological system management in Mount Everest (Nepal) and K2 (Pakistan) protected areas. *Mountain Research and Development* 30(2):80–93.
Salerno F, Flury B, Thakuri S, Basani M, Maskey R, Khanal S, Sapkota A, Bhuju D, Jha P, Bhochhibhoya S. 2009. Management-oriented environmental research in Sagarmatha National Park and Buffer Zone. HKKH Partnership Project Working Paper. Ev-K2-CNR. http://hkkhpartnership.org; accessed on 31 August 2009.
SoE [State of the Environment] Nepal. 2001. *United Nations Environment Programme (UNEP) and International Centre for Integrated Mountain Development (ICIMOD), Kathmandu*. Edwards P, Rana G, Shrestha ABM, editors. Pathumthani, Thailand: UNEP Publisher. http://www.rrcap.unep.org/pub/soe/nepalsoe.cfm.
Sutherland WJ. 1996. *Ecological Census Techniques. A Handbook*. Cambridge, MA: Cambridge University Press.
SPCC [Sagarmatha Pollution Control Committee]. 2006. *Annual Progress Report 2004/05–2005/06*.
Stevenson RJ, Hill BH, Herlihy AT, Yuan LL, Norton SB. 2008. Algae–P relationships, thresholds, and frequency distributions guide nutrient criterion development. *Journal of the North American Benthological Society* 27(3):783–799.
Tabei J. 2001. Climbers' impact on the natural environment in mountain areas and environmental conservation: present situation of wastes left by climbers in the Mount Everest region. *In:* Watanabe T, Sircroff S, Khanal NR, Gautam MP, editors. *Proceedings of the International Symposium on the Himalayan Environments: Mountain Sciences and Ecotourism/Biodiversity*. 24–26 November 2000. Kathmandu, Nepal: Tribhuvan University and Hokkaido University, pp 6–13.
Thompson RC, Moore CJ, vom Saal FS, Swan SH. 2009. Plastics, the environment and human health: Current consensus and future trends. *Philosophical Transactions of the Royal Society B* 364(1526):2153–2166.
Tilley E, Lüthi C, Morel A, Zurbrügg C, Schertenleib R. 2008. *Compendium of Sanitation Systems and Technologies*. Dübendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology (Eawag). http://www.eawag.ch/organisation/abteilungen/sandec/publikationen/compendium_e/index_EN; accessed on 12 March 2010.
TRPAP [Tourism for Rural Poverty Alleviation Programme] - NEP/99/013. 2003. Training Need Assessment in Sagarmatha National Park and Buffer Zone. *UNDP [United Nations Development Programme]*. Kathmandu, Nepal: Government of Nepal, Ministry of Culture, Tourism and Civil Aviation. http://www.undp.org.np/uploads/publication/2007091114455599.pdf.
Trivedy RK, Goel PK. 1986. *Chemical and Biological Methods for Water Pollution Studies*. Karad, India: Environment Publication.
UNEP [United Nations Environment Programme]. 2004. *UNEP's Strategy on Land Use Management and Soil Conservation: A Strengthened Functional Approach, Policy Series*. Nairobi, Kenya: UNEP Division of Policy Development and Law.
USEPA [United States Environmental Protection Agency]. 2000. *Nutrient Criteria Technical Guidance Manual: Rivers and Streams*. Washington, DC: Office of Water, USEPA.
Valavanidis A, Iliopoulus N, Gotsis G, Foitakis K. 2008. Persistent free radicals, heavy metals and PAHs generated in particulate soot emissions ash from controlled combustion of common types of plastic. *Journal of Hazardous Materials* 158(1–3):277–284.
van den Belt M. 2004. *Mediated Modeling: A System Dynamics Approach to Environmental Consensus Building*. Washington, DC: Island Press.
Voinov A, Brown Gaddis EJ. 2008. Lessons for successful participatory watershed modeling: A perspective from modeling practitioners. *Ecological Modeling* 216(2,24):197–207.
Watanabe K. 2005. Trading process of livestock products: The case of mobile sheep herders in eastern Nepal. *In:* Ikeya K, Fratkin E, editors. *Pastoralists and Their Neighbors in Asia and Africa*. Senri Ethnological Studies 69:153–169.
Welp M. 2000. *Planning Practice on Three Island Biosphere Reserves in Estonia, Finland and Germany: A Comparative Study*. Paris, France: INSULA [International Scientific Council for Island Development] c/o UNESCO-Man on the Biosphere Programme.
WHO [World Health Organization]. 2008. *Guidelines for Drinking-water Quality: Incorporating 1st and 2nd addenda.* Vol 1, 3rd edition. Geneva, Switzerland: World Health Organization.
Xing M, Jianchu X, Jie Q. 2008. Water resource management in a Middle Mountain Watershed. A case study in Xizhuang, Yunnan, China. *Mountain Research and Development* 28(3/4):286–291.
Yoo JI, Kim KH, Jand HN, Seo YC, Seok KA, Hong HJ, Jang M. 2002. Emission characteristics of particulate matter and heavy metals from small incinerators and boilers. *Atmospheric Environment* 36(32):5057–5066.

http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00028.1