Water Air Soil Pollut (2012) 223:3207–3218
DOI 10.1007/s11270-012-1102-z

Environmental System Analysis for River Pollution Control

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Received: 14 August 2011 / Accepted: 31 January 2012 / Published online: 18 February 2012

Abstract This paper presents a new tool, developed with the aim of assessing the environmental impact from industrial effluents and sewage systems in Hanumante River and to recommend the finest procedures to control water pollution so as to improve the water quality of Hanumante River using environmental system analysis. Hanumante River is heavily polluted due to inefficient management resulting in water-associated problems. The time horizon for this study is from 2000 to 2030, yearly, and the spatial boundary is considered to be Hanumante River, Bhaktapur, Nepal. The stakeholder, function, and scenario analyses are employed as three tools for study. The participation of main stakeholders aids in resolving their various conflicting interests in Hanumante River, thus creating a common understanding about the crisis under study. A complete functional analysis illustrates various functions fulfilled by the river and their associated services. Based on the interests of the stakeholders and their priorities, two alternatives resulting in four scenarios are identified and ranked against four selected criteria. A combination of improved industrial technology and efficient municipal waste management gives the best solution to the pollution problem in Hanumante River. Different alternative themes have corresponding effects on the selected criteria. The choice is in the hands of the decision makers of Bhaktapur City. The outcome of this paper will ultimately help decision and policy makers to analyze the environmental impact of river systems and find efficient and better-quality decision making for water resource management incorporating the knowledge and experiences of various stakeholders.

Keywords Environmental system analysis · River pollution control · Hanumante River · Nepal

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1 Introduction

Natural resources have been bestowed to support life on planet earth. With increasing human population density, stress on environmental resources has been increased simultaneously with unparalleled growth in technology capacity, energy consumption, international trade, and social complexity (Huang and Chang 2003; Pykh et al. 2000). The potential conflict between protection of water quality and economic development by different uses of land within river basins is a common problem in regional planning (Thakur et al. 2011b; Trevors 2010). Thus, due to these conflicts, it has been crucial to manage the environment and to scrutinize multifarious interactions. In the ecological research for natural resource and environment management, systems analysis and simulation have been used (Grant et al. 1997; Patten 1971). Authorities at higher position need information and data for the decision-making process in the control of water pollution (Jabeur and McCarthy 2011). Environmental system analysis (ESA) may provide an effective and efficient tool to promote understanding and aid the decision-making process for the environmental discussion. ESA is a system-based approach which provides various tools for addressing the human-induced impacts, their interactions with natural systems, to whet the related processes for the evaluation of resulting impacts in order to generate alternatives (risk-informed, consensus-oriented, and cost-effective solution) to provide insightful planning and formulate environmental policy effective in decision making (Lung and Sobeck 1999; Somlyody et al. 1998). This system analysis is also crucial in the context of sustainable development to maintain a balance between development and environment. Li et al. (2009) used ecological network analysis to study water use systems. Adeka et al. (2008) used the ESA of Lake Elementaita, Kenya, and applied the Generalized Watershed Loading Function model to stimulate nutrient transport processed in the watershed. Holm (2008) also developed a tool, VeVa River Basin, to assess the environmental impact from sewage systems in a river basin including sensitivity analysis, nutrient recycling, energy analysis, and discharge of nitrogen, biochemical oxygen demand, and cadmium resulting in reduction of phosphorous discharge to Sävjaån River from existing on-site wastewater systems. Bonzini et al. (2008) used the structure of macrobenthos communities as a tool for the assessment of the effect of pesticide exposure on aquatic ecosystems in surface water, while Matthies et al. (2006) did comprehensive system analysis of the Elbe River basis to develop decision support system for integrated river basin management.

This paper aims to use ESA to prescribe the best measures including different views, values, and interests of the stakeholders to control water pollution in Hanumante River with the time horizon from 2000 to 2030 yearly. In particular, it demonstrates how different types of uncertainty in a water pollution control system can be quantified and combined using interval numbers and membership functions.

2 Study Area and Data Used

Hanumante River is an important tributary of the Bagmati River with a catchment area of 143 km^2. The river originating from Mahadev Pokhari at Nagarkot covers 3.92% of the area of the Bhaktapur and Madhyapur Thimi municipalities (DWIDP 2003; Pant and Dongol 2009). The river is the lifeline of the people of Bhaktapur because it is an important source of freshwater and a major drainage waterway, and the river has special cultural and religious significance among the people (Sada 2010; Shrestha 2007). The population growth rate of Bhaktapur district from 2001 to 2011 is 2.96%, which is just above twice the national population growth rate (Table 1). The population density of Bhaktapur is 14 times greater than that of the nation.

The rapid migration and rise in the population in all three districts: Kathmandu, Bhaktapur, and Lalitpur has led to continued expansion of the city core, thereby converting the agricultural lands and areas under vegetation covers into settlements; the public lands along the rivers have been more vulnerable to the continued encroachment by the people. This has led to the emergence of numerous slums and squatter settlements (MOF/GON 2010).

Upstream water extraction in the Hanumante River is through 148 community drinking water schemes, 127 community-managed irrigation systems, and 42 brick kilns, which abstract large quantities of water, leaving very little water to flow downstream reaches as the river enters into the city core (Sada 2010). A similar effect was seen in the study of Ning et al. (2001) that the water transfer in the upstream area further increases negative impacts on the water quality in the wet season. The knowledge of low flows has lately been engaged one step further to create decision support tools for water managers that assess the impacts of artificial influences on river flows to support licensing of abstractions from and discharges to rivers (Holmes et al. 2002).

Effluents from industries are either discharged directly into the Hanumante River or through the municipal sewerage system without any standard treatment process. Analysis of water quality at seven different locations along the Hanumante River course —Sudal, Hanumanghat, Sallghari, Srijananagar, Dadhikot, Kaushaltar, and Lokanthali, revealed progressive degradation in the river water quality as the river

Table 1 Comparison of population demography of Bhaktapur in 2001 and 2011

Area	Population, 2001			Population, 2011			Annual growth rate (%)	Number of households	Average household size	Population density (persons/km^2)
	Total	Male	Female	Total	Male	Female				
Nepal	23,151,423	11,563,921	11,587,502	26,620,809	12,927,431	13,693,378	1.40	5,659,984	4.70	181
Bhaktapur	225,461	114,798	110,663	303,027	154,006	149,021	2.96	73,084	4.15	2,546

Source: CBS (2001, 2011)

passes through the city core, due to increasing pollution load resulting from untreated effluent discharge (Sada 2010). In a study of IUCN, Nepal (2007), high levels of potassium, nitrate, ammonia, and orthophosphate were found in river water samples collected from small agricultural catchments. In this study, the pollutant loads of potassium (8,140 tons/day), nitrate (1,850 tons/day), ammonia (460 tons/day), and orthophosphate (370 tons/day) were estimated as being discharged from about 220 km^2 of agricultural land in Kathmandu valley (including Kathmandu, Bhaktapur, and Lalitpur) into the river system (Stanley et al. 1994). Water pollution due to pesticide residue from the agricultural land was already predicted by HMG/MHPP (1994) based on an increasing trend of insecticide use in the country. The amount of chemicals unconfined into surface water bodies is tremendously huge; their dynamics are multifaceted, and furthermore, their impact over the globe is still very complicated to assess (Munafò et al. 2005). The farmers practicing wastewater irrigation are essentially those who have been traditionally using river water for irrigating vegetable crops. A survey of Sada (2010) among 55 farmer households who were practicing wastewater irrigation revealed that 64% of the farmers were using wastewater from Hanumante River for the whole year, whereas 34% of them were using the river water only during the monsoon. The most common health problem resulting from exposure to wastewater irrigation, noted among the farmers, has been skin diseases, followed by headache, cough and cold, fever, diarrhea, and eye infection (DoHS 2000–2010). Moreover, this polluted river and its sources under infiltration and percolation processes also contaminate the ground water such as well, tube well, stone spout, and other drinking water sources such as municipal water distribution system under leakage (Brunke and Gonser 1997; Santos et al. 2002). The people of Bhaktapur depend heavily on groundwater mainly for drinking and household use purposes. A study of Diwakar et al. (2008) on drinking water quality from different sources such as stone spout, well, tube well, and tap water in Bhaktapur municipality revealed water samples contaminated with chloride (0.87%) and ammonia (5.17%); furthermore 82.76% of water samples were found to be contaminated with total coliform bacteria.

The number of cases related to water-borne diseases such as typhoid and intestinal worm fluctuated and has increasing trend. However, those suffering from diarrhea and jaundice rocketed up until 2006. After, patients suffering from these diseases slowly decreased in later years; nevertheless, their number again rose in 2010 indicating water-borne disease problems are still prevalent in the study area (Table 2).

The management of the river is administratively fragmented in such a way that various authorities including the Bhaktapur Municipality, District Development Committee (DDC), and other related government organizations are involved in the maintenance of the river. The stakeholders involved in the use of the river have different conflicting agenda and interests. For instance, various NGOs are interested in solving the water pollution problems and in the protection of biodiversity. The managers of existing industries, the farmers' representatives, and the denizens of the Hanumante residential area are interested in better quality of water and esthetic values. The recreational associations are mainly interested in generating revenue from ecotourism. There might be appalling consequences on addressing one's interest over the others.

3 Methods

The environmental system was analyzed using system components and tools to prescribe the best measures to control water pollution in Hanumante River including different views, values, and interests of the stakeholders with the time horizon from the years 2000 to 2030.

3.1 System Components

Based on the driving forces–pressures–state–impacts–responses (DPSIR) model, the system components constituting driving forces, pressures, state, impact, and responses were analyzed. There was a chain of causal links starting with "driving forces" (economic sectors, human activities) through "pressures" (emissions, waste) to "states" (physical, chemical, and biological) and 'impacts' on ecosystems, human health, and functions, eventually leading to political "responses" (prioritization, target setting, indicators) (Kristensen 2004) (Fig. 1). A study of the community structure may provide a potent tool for the assessment of the ecosystem as many factors can influence the communities. Therefore, it is crucial to learn and identify the nature of stressors (Bonzini et al. 2008).

3.2 Tools for the Analysis

In order to analyze the entire system, three tools were used in this study namely stakeholder analysis, scenario analysis, and function analysis.

(a) Stakeholder analysis

In stakeholder analysis, stakeholders who can affect or are affected by the policy and decision-making process were included as their participation is becoming widespread where a range of interested parties play an influencing role (Hage and Leroy 2008; Petts and Leach 2000). The use of the stakeholder analysis tool in our study was motivated by both the nature of our problem and the objective of the analysis, which was to propose alternatives of solutions towards the environmental problem of water pollution in Hanumante River. Such objective implied the consideration of the problem in the decision-making perspective. In fact, various parties with different interests contribute to the problem by their activities. These included the municipality where the river is located, various industries present in the city, and the population in and around Bhaktapur City. Therefore, they must take part in the whole process of identifying, designing, and screening alternatives.

Table 2 People of Bhaktapur suffering from water-borne diseases from 2000 to 2010

Diseases/year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Typhoid	345	228	394	843	1,187	1,103	2,263	848	1,221	2,172	2,711
Diarrhea	2,923	2,219	2,265	2,930	5,864	6,255	7,541	7,434	1,953	3,650	4,177
Intestinal worm	2,240	1,635	1,787	1,746	2,865	2,515	2,870	2,325	2,765	4,312	3,453
Jaundice	65	40	79	186	294	392	709	705	342	323	338

Sources: DoHS (2000-2010)

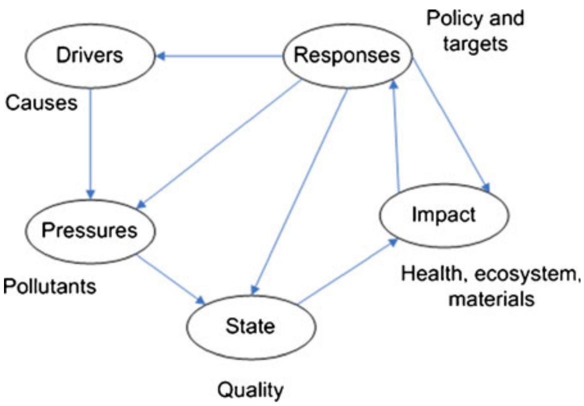


Fig. 1 The DPSIR assessment framework (Kristensen 2004)

(b) Scenario analysis

In order to have a prolific participation, the right stakeholders must be involved. Since we expected from our stakeholders to provide their knowledge and experience, and the support for the identified best ways of tackling the water pollution problem in Hanumante River, those with relevant experience, knowledge, and relative social influence were selected. These included Bhaktapur Municipality, DDC, various governmental organizations, various non-governmental organizations (NGOs), managers of existing industries in the city, farmers' representatives, and any other individuals involved directly in the management of river, local denizens.

In order to make stakeholder participation effective, methods like brainstorming, interactive workshops, and scenario analysis workshops were used. Co-production and consultation were at the core center of the whole participation process. These methods and approaches enabled us to create conditions for innovative thinking and ensured the ownership of the results by all the stakeholders.

(c) Ecosystem function analysis

Because of anthropogenic activities, Hanumante River is degraded, impacting its ecosystem. Along with the relevant stakeholders, the major priority is to figure out the function of the ecosystem of the river in terms of information, habitat, production, and regulation to the inhabitants of Bhaktapur who are directly and indirectly interlinked with the river. The following ecosystem functions were analyzed: (a) information function: the religious and cultural significant places along the Hanumante River and its importance in education and the research sector were analyzed; (b) habitat function: the species diversity along the Hanumante River and the importance of habitat function to stakeholders were also analyzed; (c) production function: the kinds of benefits that the Hanumante River provides to the inhabitants of Bhaktapur City were discussed under this section; (d) regulatory function: in this section, the function regulated by the Hanumante River in the context of anthropogenic acitvities and their health along with the serious consequences related to their activities were analyzed.

4 Results

4.1 System Components

The components of the environmental system in controlling river pollution in Hanumante River are demonstrated in the causal diagram (Fig. 2). Water resources management is done to protect human health at the same time to maintain sustainable aquatic and associated terrestrial ecosystems. Hence, it is imperative to quantify and appraise the current state of, and impacts on, water milieu and temporal changes (Kristensen 2004).

4.2 Interpretation of the Causal Diagram

The causal diagram (Fig. 2) was developed using the DPSIR scheme. The drivers (causes) include increased population density, industries/factories, municipal waste, and different types of runoff (agricultural, urban, street/road, etc.). An increase in each of these factors constitutes a pressure to the Hanumante River. Pressures include the amount of waste discharged into river, heavy metals, pathogenic organisms, and acids and bases. Increased nutrient load, toxicity of the water, acidity, salinity, depletion of water quality, flooding, and change in river morphology are different states resulting from pressures. The impact (effect) of all these is water pollution associated with various adverse consequences including diseases, low productivity, loss in soil characteristics, economic loss, unemployment, deteriorating culture and heritage, loss in tourism and esthetic, decrease in water discharge, and loss in terrestrial and aquatic biodiversity. The responses (solutions) to these problems include integrated agricultural policies, improved industrial technology, efficient waste management system,

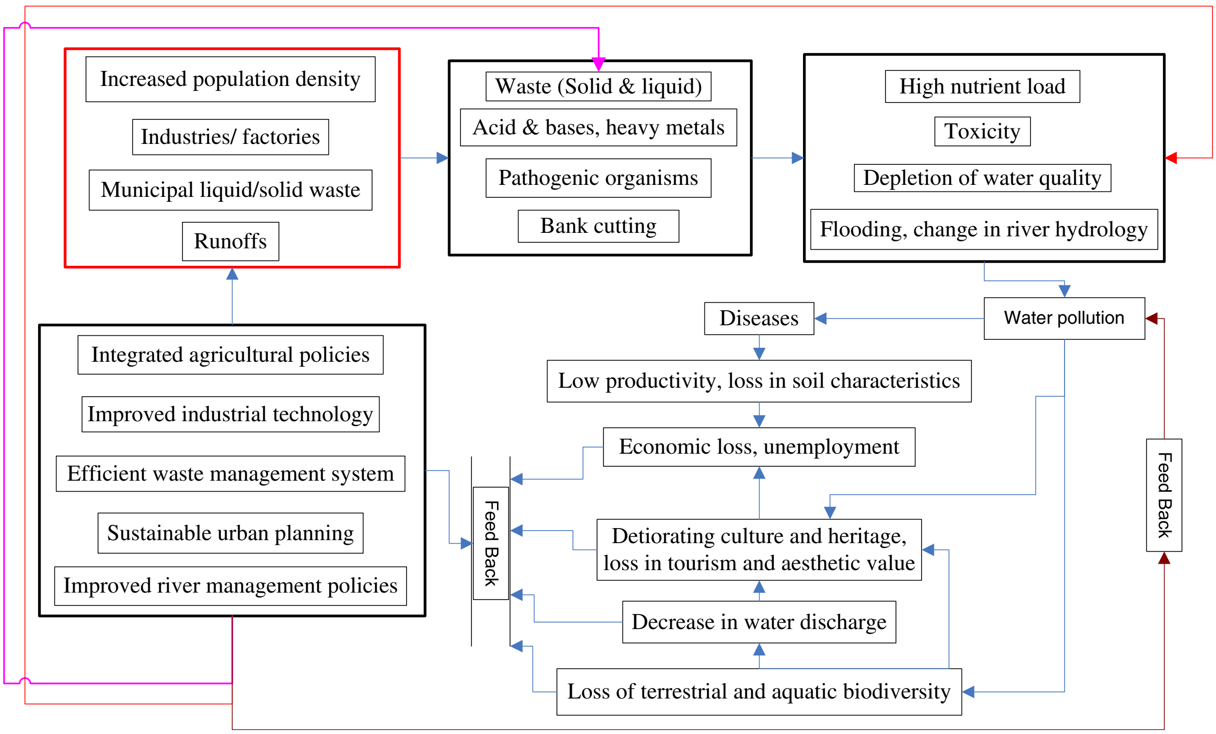


Fig. 2 Causal diagram illustrating various components in controlling river pollution in Hanumante River, Bhaktapur, Nepal, based on the DPSIR model

sustainable urban planning, and improved river management policies. When implemented, these alternatives can have effects on every component of the system. This is demonstrated by the different possible feedbacks.

4.3 Tools for the Analysis

(a) Stakeholder analysis

Since water resources around the globe are under mounting pressure, the allocation of water between abstractors and the environment necessitates to be based progressively more on sound knowledge (Acreman 2005). From the beginning, it is important to involve potential users in the system analysis for their input and feedback for water management and to take appropriate measures and scenarios (Matthies et al. 2006). By involving stakeholders, they can get to know each other's fields dependence and increase the understanding of their respective contribution in the problem, can also be helpful in the general understanding about water pollution problem, and share experiences, knowledge, and creative capacity of various stakeholders. These aid to find out efficient and comprehensive remedies to the existing water-related problem and to win support and acceptance for solutions identified and presented to the municipal authority as alternatives.

In the one hand, referring to Hisschemöller and Hopppe's classification of policy problems (Fig. 3), the water pollution problem in Hanumante River is a moderately structured political–ethical problem. The scientific knowledge about it is well established, but there is little or no consensus on norms and values about it. Therefore, the participation of stakeholders, which includes the municipality, various industries, and the local denizens, is needed in order to confront their opinions and hence achieve a common understanding on this issue. On the other hand, since any effective identification, designing, and screening of alternative solutions imply the consideration of different views, values, and interests of both the decision maker and the stakeholders, participation was used at this level of analysis too. More specifically, stakeholders participated in the identification of all the possible

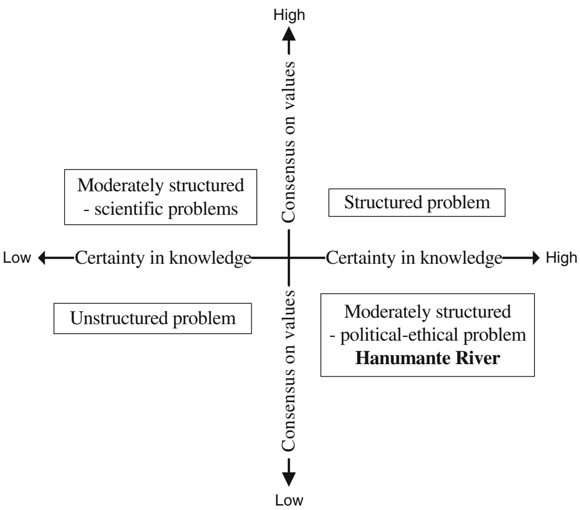


Fig. 3 Types of policy problems (Hisschemöller and Hoppe 1995)

solutions and the analysis of the consequences associated with each of them for a better comparison and ranking.

The discussion of different alternatives with stakeholders resulted in a certain ranking. Industrial technology and municipal waste (solid and liquid) had a very high score of 80% and 75%, respectively. The rest of the alternatives, population growth, drainage runoff, and agricultural runoff, had 65%, 58%, and 45%, respectively. This ranking of alternatives by stakeholders formed the basis for the selection of our themes and the development of associated scenarios.

Above all, these participants could bring many benefits which include the presence of more and more varied knowledge and the inclusion of different perspectives: the use of the creative problem-solving capacities of a group, the fact that influential actors get to know about the end product and that it ties in with their way of thinking during the decision-making process (Hage and Leroy 2008; Petts and Leach 2000). For all these reasons, a product produced through the participation of stakeholders directly and indirectly related to Hanumante River might contribute to better-quality decision making.

(b) Scenario analysis

Dunbar et al. (2000) modeled the impact on the salmonid fish habitat of five groundwater abstraction options in the River Wylye. Brown and King (2000) produced various scenarios of environmental flows from dams within the Lesotho Highlands Development Project for resolving the economic benefits of selling impounded water to South Africa and the impacts on dependent communities of the resulting degraded river ecosystems. Many alternatives can be applied to control Hanumante River pollution, but their acceptance and applications will depend on the interest, objective, and criteria of the decision maker and other stakeholders. Each alternative also comes with its merits and demerits. The scenarios developed in this study depict different future states of the Hanumante River associated with the assumed implemented courses of action. The baseline scenario (S_0) concerns the situation of the river as it is in the year 2000 (assuming that no intervention is made), and the end year is 2030. It is assumed that pollution loads increase with population growth, poor industrial technology, inefficient waste management, and runoffs if corrective measures are not taken.

For future scenarios, we assume that population growth can either increase exponentially, decline considerably, or even remain constant in the future; industrial technology can either improve or remain unimproved; waste management can be either efficient or inefficient; and runoffs can increase, reduce, or remain unchanged. Considering these assumptions, it is possible to deduce about ten scenarios, which can potentially result in over 40 themes. However, the stakeholder analysis revealed the two most important causes (forces) to be considered in this study. The order of importance of the various driving forces is depicted in Fig. 4 (Amoasah et al. 2008).

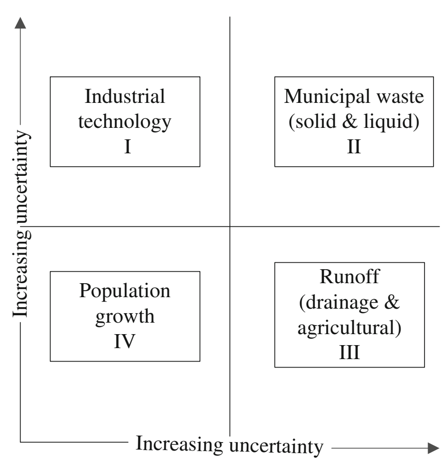


Fig. 4 Ranking of driving forces for importance and uncertainty in the scenario construction in Hanumante River pollution

Industrial technology and municipal waste are given high priority whereas runoff contributes insignificantly. Though population contributes significantly to the problem, its control is beyond Bhaktapur Municipality's scope and consequently out of our priorities.

4.3.1 Selection of Themes and Development of Scenarios

The combination of the selected factors (industrial technology and municipal waste) generates four themes from which we derive four different scenarios as demonstrated in Table 3. These themes are weighted against four identified criteria compromising economic prospects, biodiversity, eutrophication, and health and diseases (Table 4). It is generally expected that a combination of improved industrial technology and efficient municipal waste management gives an ideal situation, is best for the river, and satisfies all the selected criteria. On the other hand, a situation of unimproved industrial technology and inefficient municipal waste management results in a much polluted river and does not meet any of the selected criteria. Improvement in one alternative but failure in the other give a mixed situation, unsuitable for some criteria but suitable for others (Fig. 4).

The relationships existing between the various alternatives and their consequences can be explained with the diagrams below:

Improved industrial technology will decrease the heavy metals, nutrients, and harmful effluents (Fig. 5). Eutrophication is avoided to have a conducive environment for fish and other biodiversity to survive. Toxicity in edible aquatic flora and fauna is avoided, and human health is consequently improved. Relocation or closure of local industries is avoided because of improved technology, and this saves jobs for better socio-economic conditions of the denizens.

Table 3 Selected themes generated from selected factors like industrial technology and municipal waste

	Efficient municipal waste management measures (EMWM)	Inefficient municipal waste management (IMWM)
Improved industrial technology (IIT)	Optimum view: Ideal Theme 1	Mixed situations: Moderate ideal Theme 2
Unimproved industrial technology (UIT)	Mixed situations: Poor state Theme 3	Very poor state Theme 4

Efficient municipal waste management will decrease waste loads and eutrophication (Fig. 6). Fish survive, sanitary condition is improved, and ecotourism flourishes. Human health is improved because of a decrease in water-borne vectors and diseases. Humans become highly productive and contribute to the national economic development.

Decision-making processes are influenced by many circumstances, and decisions are not characterized in minute-detail structures by any rules. This requires understanding to edifice a problem and makes decision. The priority scales are derived objectively after subjective decisions are made in the decision-making process. In general, assessment with respect to the dominance of one object over another with respect to a certain attribute or criterion takes three forms: importance or significance that includes all kinds of influence—physical measurements, engineering and economics, making decisions, and likelihood as in probabilities. Abundant knowledge enables one to compare anything with anything else that shares a common attribute or criterion. Therefore, comparisons go beyond ordinary measurement to include intangibles for which there are no scales of measurement (Saaty 2008).

(c) Ecosystem function analysis

The significance of biodiversity for ecosystem function is reflected by the development in the analysis of the role of diversity in species-rich and complex communities (Bengtsson et al. 2000; Thakur et al. 2011a). With the increasing pollution level and encroachment of anthropogens in Kathmandu valley rivers, there is a risk of continued loss of species and genetic diversity locally at an alarming rate, seeking our attention to address the potential serious consequences such as changes in food webs, loss of specialist functions, and loss of ecosystem engineers, keystone species, and other species or functional groups while deciding priorities for conservation. Therefore, we tried to establish whether current losses in biodiversity of Hanumante River are likely to seriously impair life-supporting processes that humans need, i.e., ecosystem functions such as primary productivity, water retention, and provision of clean water, and reduce benefits to humans (Grime 1997).

Table 4 Scenarios analysis of Hanumante River pollution

Criteria	Theme 1 (ideal)	Theme 2 (moderate ideal)	Theme 3 (poor state)	Theme 4 (Very poor state)
Economic prospects	High	Low	Lower	Lowest
Biodiversity	High	Low	Lower	Lowest
Nutrient load	Low	Higher	High	Highest
Health and diseases	Good	Bad	Worse	Worst

Hanumante River as a lotic water ecological system executes various ecosystem functions such as regulatory, habitat, production, and information functions which are allied with different goods and services relished by citizens both inside and outside Bhaktapur City. They are labeled as provisioning and regulating services and cultural and supportive services. Thus, the analysis of ecosystem functions and services of Hanumante River is substantial for its future management. For this, different stakeholders along with decision makers entail the realization of its importance in all aspects for effectual management of such an ecosystem. Stakeholders giving prioritization to economic benefits over the function and services of an ecosystem are the main reason for inefficient decision-making process. This analysis provides stakeholders and the decision maker with a comprehensive view of the importance of Hanumante River.

1. Information functions

Hanumanghat, Maheshworighat, Chupinghat, and Mangal Tirtha are the cultural and religious significant places located along the course of the Hanumante River (Gutschow and Michaels 2005). Besides, several religious and archaeological imperative temples such as Brahmayani, Maheswori, Kaumari, Bhadrakali and Barahi are built along the banks of Hanumante River. Among the Hindus, rivers are intricately linked to rites and rituals such as holy dip in the rivers before performing many religious rites, the last rites after death, and bathing on specific days such as Dashain and Sankranti (every first day of a new month locally) (Pradhan and Manandhar 2007). Hanumante River provides many opportunities for education and research. Many research organizations and individuals working in the water domain find Hanumante River to be a good place to carry out their scientific research due to its relatively easy access and good location. Therefore, research institutes and students can use it to test their hypotheses.

2. Habitat functions

The Hanumante River ecosystem provides refuge and reproduction habitat to aquatic flora like *Salix babilonica*, *Sambucus canadensis*, *Artemisia* sp., and *Phragmites karka* (Dhamala et al. 2007). Therefore, for the continuation of the biological and genetic diversity of the river, its maintenance is very essential. Besides this, environmentalists and conservationists regard this kind of natural ecosystem as a storehouse for genetic information. For either subsistence or commercial purposes, under regular maintenance, the river could provide nursery areas to species, which as adults might be harvested elsewhere. These habitat functions

Fig. 5 Causal diagram of improved industrial technology (based on DPSIR)

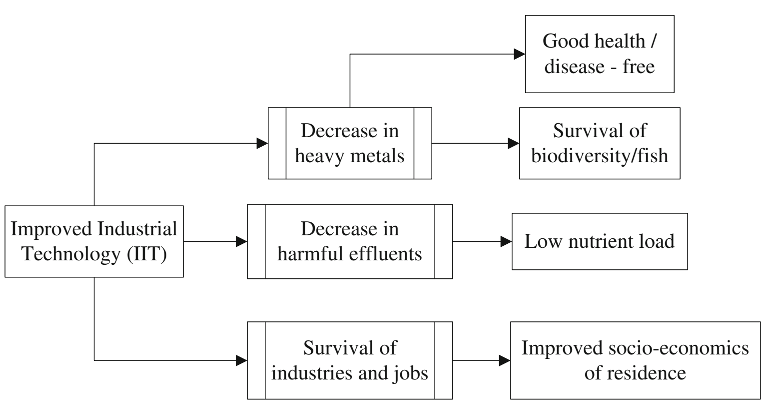
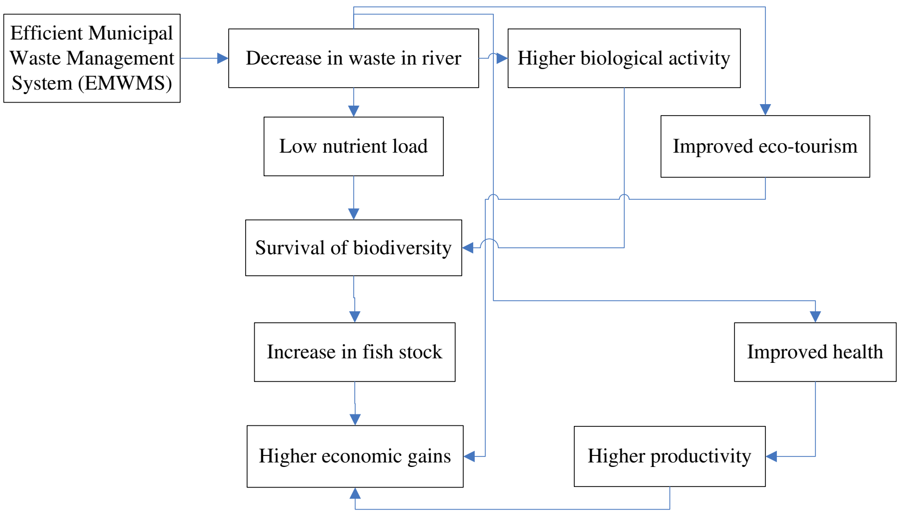


Fig. 6 Causal diagram of efficient municipal waste management system based on DPSIR



are often ignored by stakeholders who instead attached more importance to direct benefits.

3. Productive functions

Hanumante River provides water for many industries, farmers, and local residents. The water is used for agricultural irrigation and for industrial activities. Residents also use this river to fulfill their primary and secondary water needs. This exchange of water in the municipality resulted in different types of flows to evaluate the water use in a sustainable way (Bodini and Bondavalli 2002). In order to quantify the water requirement of the stream compartments, the water needs of stream for hydropower, navigation, fisheries, waste treatment, recreation, and the maintenance of biodiversity should be involved (Scatena 2004).

4. Regulatory functions

Hanumante River reduces anthropogenic activities by carrying away harmful and toxic compounds, untreated sewage, and agricultural runoff. Aquatic fauna such as micro and macro invertebrates and fish are seriously affected by conditions within the river. The regulatory functions of the river can influence its productive functions and provisional services. This is because favorable conditions directly relate to increment in fish stock that consequently results in a huge production. In addition, the river regulates the local health and water-borne disease of the residents. This can subsequently result in the regulation of municipal spending on health. Agricultural activities within the Hanumante area depend on the river for irrigation, and they can be said to be regulated.

5 Conclusion

There is evidently a need of cooperation among various stakeholders for the control of Hanumante River pollution. The ESA tool has been used to enable the analysis of the environmental impact from wastewater scenarios in Hanumante River, which is useful for the Bhaktapur Municipality authorities when establishing river basin management plans. The study concludes that the combination of improved industrial technology and efficient municipal waste management gives the best solution to the pollution problem in Hanumante River. A combination of unimproved industrial technology and inefficient municipal waste management aggravates the problem. Different alternative themes have corresponding effects on economic prospects, biodiversity, nutrient load, and health. The choice is in the hands of the decision makers. Thus, these tools can be used for the ESA of polluted rivers at other developing economies. The results are expected to be analogous to our studies for aiding decision makers with their choices on curtailing the river pollution level in order to restore the ecological balance. Further studies should be done using different analysis tools on Hanumante River pollution. The notion of "whole life support" which engrosses a cycle of research, manufacture of applied products for end users, user support, recognition of development needs, and further research can be favorable to all parties. However, it is almost certainly accurate to articulate that we will certainly not have a complete logical understanding of our surroundings, and consequently, judgment of water managers and expert scientists will at all times be a key component in decision making.

Acknowledgments We are thankful to Prof. Dr. H.B.J. (Rik) Leemans, Wageningen University, Wageningen, the Netherlands, for his kind supervision, as well as to Silas Mvulirwenande, George Amoasah, and Mohammad Nazrul Islam for their kind cooperation during the study.

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