Water quality in the Central Himalaya

Subodh Sharma[1,*], Roshan M. Bajracharya[1], Bishal K. Sitaula[2] and Juerg Merz[3]

[1]Aquatic Ecology Centre, Department of Biological Sciences and Environmental Science, Kathmandu University, P.O. Box 6250, Kathmandu, Nepal
[2]Centre for International Environment and Development Studies, Agricultural University of Norway, P. O. Box 5003, Norway
[3]People and Resource Dynamics Project, International Centre for Integrated Mountain Development, Lalitpur, PO Box 3226, Kathmandu, Nepal

This article reviews the water quality studies in the Central Himalayan Kingdom of Nepal at different sources and from different river systems as well as lakes and ponds. Sources considered for review are surface-water, groundwater and rainwater. All the major river systems are included and the water quality status of both upland and lowland streams and rivers are described separately. Studies on lakes and ponds are considered under different headings. Water quality studies of public distribution systems such as from taps, wells and other source types are cited separately. Water quality criteria and standards for different uses are discussed briefly and recommendations for water quality management are put forward.

Keywords: Himalaya, Nepal, water quality.

THE health and well-being of the human race is closely tied up with the quality of water used. Today, countries with vast water resources are also threatened with deteriorating water quality. In Nepal alone, some 44,000 children under the age of five die every year from water-borne diseases, according to Susan Murcott, MIT, USA. Nearly 67% of children in Nepal are stunted on account of water-borne diseases. Among the world's total of 2.7% freshwater, Nepal rates second only to Brazil in water availability. Still there are big gaps between demand and supply for water. Most of the people in the Himalaya use surface-water for drinking, which is most vulnerable to pollution due to surface run-off. It has been estimated that only 34% of the population in Nepal has access to safe drinking water[1]. The pressure on drinking water supply is heavy. Almost all major rivers have been tapped at source for drinking-water supplies; but there is no monitoring of water quantity or quality on regular basis. Demand for water is rapidly increasing for domestic needs, agriculture and industry. On the other hand, run-off from agricultural fields laden with pesticides and herbicides, discharge of untreated sewage into rivers and lakes, and dumping of industrial wastes are also increasing.

The major sources of water in Nepal are rainfall, glaciers, rivers and groundwater. Mean annual rainfall is about 1700 mm, 75% of which occurs during the monsoon season from June through September[2]. High rainfall generally gives rise to abundant water supplies, at least seasonally, and surface water and groundwater are both important sources for domestic, industrial and agricultural use. Rivers in Nepal flow through the high mountains in the country and thus have turbulent and rapid flow and considerable self-purifying capacity through mechanical and oxidation processes. All large rivers are fed by snowmelt from the Himalayas, and hence they are perennial. Rivers are the main natural resources of Nepal which can be utilized for power generation, irrigation and drinking-water[3]. Groundwater is abundant in the aquifers of the 'Terai' (lowland) and the Kathmandu Valley. In the populated hill regions its availability is limited due to the lower permeability and a major part of rainfall being wasted as surface run-off. The country's groundwater is being used for domestic, industrial and irrigation purposes. It is estimated that the Terai region has a potential of about 12 billion m^3 of groundwater, with an estimated annual recharge of 5.8 to 9.6 billion m^3 (the maximum that may be extracted annually without any adverse effects)[4]. The aquifers in this region, which consist of sediments of alluvial origin, are favourable for water accumulation beneath the surface area. The 'Bhabar' zone, which is an area contiguous with the Terai, as well as having better forest coverage, is the main recharge area for the latter. Groundwater is the best alternative source of water supply in the Terai region. Therefore, the forest in the Bhabar zone needs to be conserved, at least in its present condition, to ensure the present level of groundwater.

Groundwater in Nepal is at risk from contamination from mostly pathogenic bacteria, pesticides, nitrate and industrial effluents. The main source of pathogenic bacteria is sewage. Pesticides and nitrate contamination are mostly due to the use of inorganic fertilizers and pesticide spray in agricultural sector. Shallow groundwaters are also at risk due to pathogenic bacteria, pesticides, nitrate and industrial effluents. Shallow groundwaters in the Kathmandu Valley are reported to have industrial and domestic pollutants[5]. Deep groundwaters in Kathmandu and Terai are largely anaerobic and hence vulnerable to increased concentrations of iron, manganese, ammonium and possibly arsenic. While water quantity has always been a major concern in the hills and plains of Nepal[6,7], it has come up as a new challenge and concern in wide areas. Concern about the degradation of water quality is now widespread among the public. In recent years it became clear that the condition of some rivers in the country was getting out of hand, and this has necessitated close investigation and monitoring.

*For correspondence. (e-mail: sharmaku@yahoo.com)

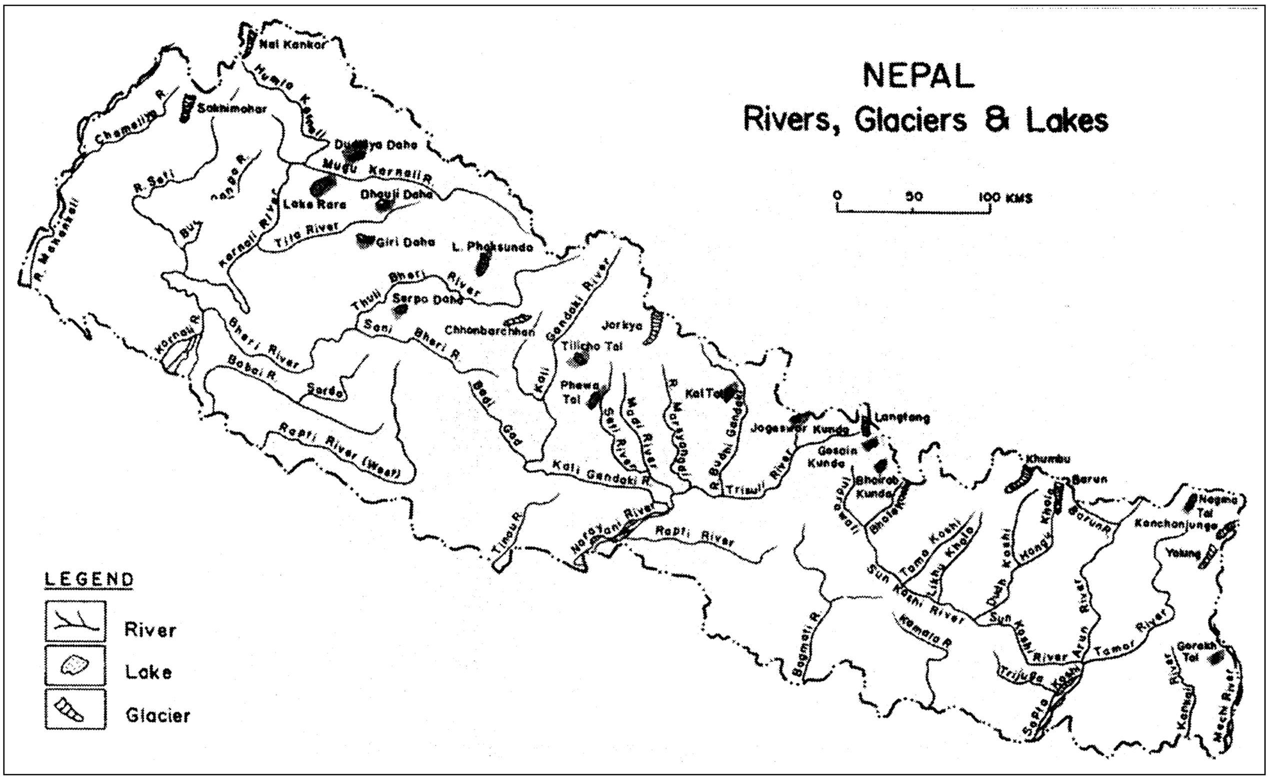

Figure 1. Major river systems in Central Himalaya.

Surface water quality

The Central Himalayan region has eight major river systems; Saptakosi, Saptagandaki, Karnali and Mahakali are the major ones followed by Bagmati, Tinau, West Rapti and Babai (Figure 1). Saptakosi, Saptagandaki and Karnali river systems originate from glaciers and snow-fed lakes. Rivers like the Mahakali, Bagmati, Tinau, West Rapti and Babai have their origin in the Mahabharat mountain range. Bagmati, which also rises at the Mahabharat mountain range, is the principal river of the Kathmandu Valley – the capital city of Nepal. Water quality monitoring of Nepal's surface-waters was done on project basis and depended on the interest of certain agencies and institutions or individuals involved in water quality research. There is no water quality monitoring network in Nepal and hence nowhere is monitoring done on a systematic basis.

A water quality data management system does not exist and data are not easily available. When available, there is no uniformity in the parameters considered and the methods used in analysis. Analysis methods range from the use of different field test kits such as American-made HACH test kits[8], Hydrolab MiniSonde[9], German-made WTW test kits[10], Indian-made Jal Tara test kits[11], British-made Delagua test kits[12] to Standard methods for the examination of water and wastewater[13] to calorimetric methods, use of UV-visible spectrophotometer, including atomic absorption spectrophotometric analysis[14].

Saptakosi river system: The Saptakosi river system consists of the Tamor, Arun, Dudhkoshi, Likhu, Tamakoshi, Sunkoshi and Indravati rivers. Flowing for almost 10 km through a narrow gorge before entering the plains, the 'Saptakosi' meaning 'Koshi' swollen with the waters of the seven rivers finally merges into the river Ganga in India. Heavy doses of fertilizer in agricultural land in the headwaters have been identified as causing water quality degradation in the Saptakosi river system[6,7]. Much of the applied fertilizer by farmers is washed into the river system of the watershed mainly during the monsoon. Figure 2 illustrates the water quality characteristics of selected rivers in the Saptakosi river system.

Saptagandaki river system: The Kaligandaki, one of the main tributaries of Saptagandaki, originates in the Trans-Himalayan region and converges with the Trishuli river at Deoghat, Chitwan, where it attains the name of Narayani and flows down to meet the Ganges at Patna in India. The headwaters of Kaligandaki river, which originate from the Trans-Himalayan zone in the Tibetan Plateau, are free from the impact of agricultural run-off. This makes the Kaligandaki river system relatively less polluted (Figure 3).

Surface-water quality of Kaligandaki river, in the section between Tsarang and Kagbeni (Figure 4) in the Trans-Himalayan zone, was evaluated by two kinds of indicators: microbiological analysis and biotic indices (EBI, BMWP and NEPBIOS)[17]. Evaluation using microbiological analysis

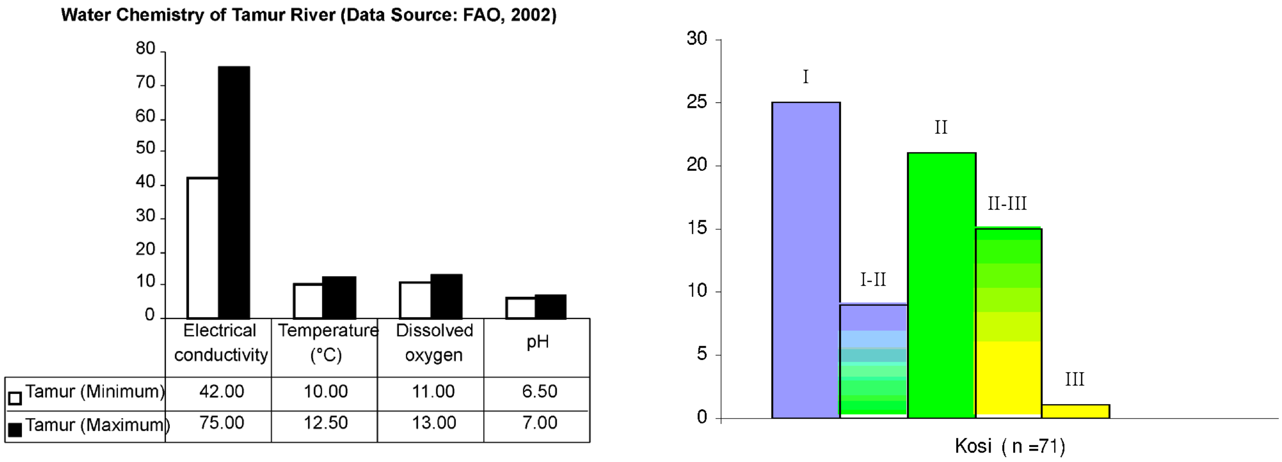

Figure 2. Chemical[15] and biological[16] water quality characteristics of selected rivers in Saptakosi river system. I, None to slightly polluted; I–II, Slightly polluted; II, Moderately polluted; II–III, Critically polluted; III, Heavily polluted.

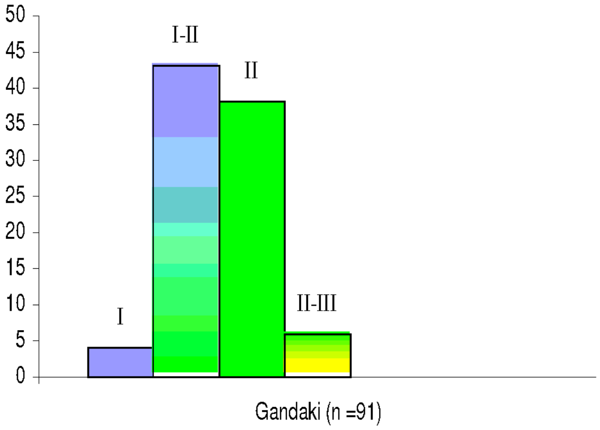

Figure 3. Biological water quality characteristics of selected rivers in the Saptagandaki river system[16]. I, None to slightly polluted; I–II, Slightly polluted; II, Moderately polluted; II–III, Heavily polluted.

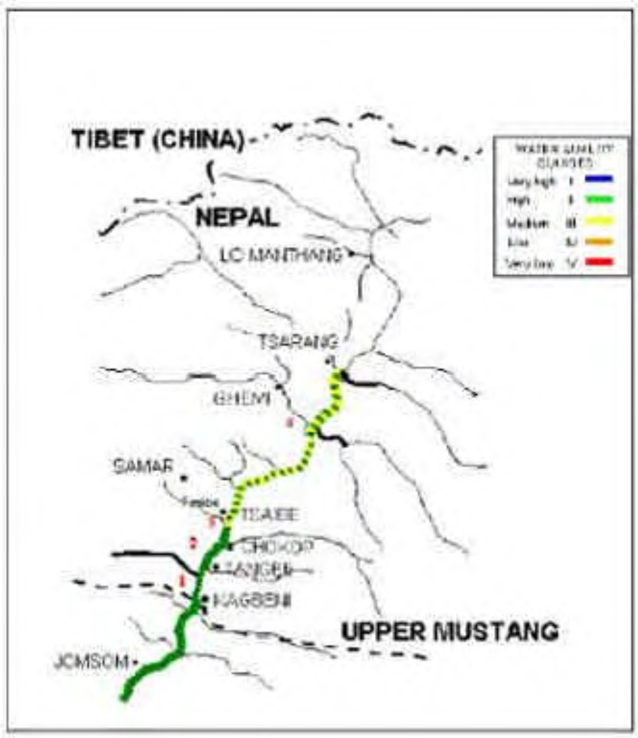

Figure 4. Water quality of Kaligandaki headwater assessed using NEPBIOS[17].

such as faecal pollution revealed deterioration of water quality in the section between Tangbe and Chele covering about 2 km. This is probably due to anthropogenic and animal wastes. The evaluation of surface-water quality using the Nepalese Biotic Score (NEPBIOS) indicates a similar situation, except for the section between Kagbeni and Chele, where the Nepalese results show better water quality (Classes II, III; Figure 4, Table 1).

The Government of Nepal[18] in cooperation with Japan Overseas Cooperation Volunteers to Nepal, surveyed the Marsyangdi River twice in May–June 1985 and March–April 1986 to collect preliminary information on fish and fisheries, to help assess the potential of fisheries development in the river. The physico-chemical studies of this river showed an exponential decrease in the water temperature with the decrease in elevation. Water was slightly alkaline, with pH values ranging from 7.4 to 8.0. Dissolved oxygen was almost over the saturation limit. About 17 species of fishes were collected during both the surveys.

The untreated discharge from the Bhrikuti Paper Mill into the Narayani and from the Everest Mill into Orahi rivers has been studied[19–21]. A national survey of the significant sources of industrial pollution in the rivers of Narayani and Koshi zones in addition to Bagmati river in Kathmandu was also carried out. Narayani river is considered as a suitable habitat of some endangered animals such as dolphin, gavial and crocodile. This river has also obtained international recognition as it flows through Chitwan National Park, which is listed as a World Heritage Site. The Bhrikuti Paper

Table 1. Summary of description of river water quality classes due to organic pollution[16]

Saprobic class/colour	I/Blue	I–II/Blue-green	II/Green
Saprobity level	Oligosaprobic	Oligo to β mesosaprobic	β-mesosaprobic
Degree of pollution	None/very slight pollution	Slight pollution	Moderate pollution
Cleanliness	Clean/with little organic matter and nutrient contents	Considerably clean	Not clean/with high organic matter and nutrients
Clarity	High (glacier-fed brooks are turbid)	High (glacier-fed brooks are turbid)	As before (lowland rivers are also turbid)
Oxygen content	Well oxygenated (100%)	Well oxygenated (100%)	As before (oversaturation and subsequent depletion possible)
Reduction	Nil	–	Few (in very fine sediments at lentic zones)
Faunal diversity and abundance	Very high/low	High/medium	High/high
Floral composition	Algae (mainly diatoms, specific blue-green algae and red algae) Moss (several species)	Algae (mainly diatoms, specific blue-green algae and red algae) Moss (several species)	Algae (all groups, high filamentous type possible) Moss (few species)
Faunal composition	Dominant insect larvae (Plecopterans highly abundant) Trichoptera (net spinning extremely scarce) Chironomidae (few subfam.–Diamesinae and Orthocladinae) Worms (mainly Planarians, Lumbriculidae (Stylodrilus) and Haplotaxidae)	Dominant insect larvae (Plec, Ephe, Tri, Coel present) Trichoptera (net spinning may also occur) Chironomidae (few subfam.–Diamesinae and Orthocladinae) Worms (mainly Planarians, Lumbriculidae (Stylodrilus) and Haplotaxidae	Many groups present (many insects, molluscs and crustaceans) Trichoptera (net spinning numerous) (e.g. Polycentropodidae) Chironomidae (abundant, diversed) Lot: Diamesinae Len: Orthocladinae Worms (diversed families; Oligochaeta–Lumbriculidae (Stylodrilus) and some Naididae).
Fish fauna	Salmonids (Dominant in Europe and North America)	?	?
River type	Spring Spring-fed brooks Cold water rivers (upper reach)	Spring Spring-fed brooks Cold water rivers (upper reach)	Brooks (Mod poll. up and lower reach and Unpoll. lower reach) Rivers (Mod poll. up & lower reach and Unpoll. lower reach)
Water uses	Multipurpose (drinking, fishing, bathing, etc.)	Restricted uses (drinking restricted for locals)	Restricted uses (drinking possible after treatment for locals)
Other remarks	Balanced trophic relations Productivity exceeds the sum of reductive processes.	Balanced trophic relations. Productivity prevails over the sum of reductive processes.	Balanced trophic relations. Productivity prevails over the sum of reductive processes.

Saprobic class/ colour	II–III /Green-yellow	III/Yellow	III–IV /Yellow-red	IV/Red
Saprobity level	β to α-mesosaprobic	α-mesosaprobic	α-meso to polysaprobic	Polysaprobic
Degree of pollution	Critical pollution	Heavy pollution	Very heavy pollution	Extreme pollution
Cleanliness	Polluted/with higher organic matter and nutrient contents	Heavily polluted	Very heavily polluted/with very high organic matter and nutrients contents	Extremely polluted with high organic matter and nutrient contents
Clarity	Occassionally turbid (lowland rivers are additionally turbid)	Turbid (local/occassional) (lowland rivers are additionally turbid) Human influenced act. impart diversed colour	Turbid (local/occasional (point sources drifting fil.bacteria). Effluents impart specific odour and colour	Mostly turbid (local/occassional) (point sources drifting fil.bacteria). Effluents impart specific odour and colour

(*contd...*)

Table 1. (*contd...*)

Saprobic class/ colour	II–III /Green-yellow	III/Yellow	III–IV /Yellow-red	IV/Red
Oxygen content	Fluctuating, causing injuries or kill to sensitive fish species	Oversaturation and heavy depletion, causing injuries and killing sensitive fishes	Oversaturation and very heavy depletion, excluding full-time fish residency	Extreme oversaturation and depletion, prohibiting the survival of any kind of water breathing aquatic fauna
Reduction	Remarkable Putrified: Fine sed., lentic Black spots: Stones	Remarkable Putrified: Fine sed., lentic Black patches: Stones	Septic Release of H_2S, large red spots in lotic and lentic zones	Sapropelic Release of H_2S after heavy degradation, large reduction patches beneath the stones (lotic) or on both sides (lentic)
Faunal diversity and abundance	Moderate/moderate (Insect fauna)	Low/high (Benthic fauna)	Very low/high (Benthic fauna)	Extremely low/very high (Air-breathing benthic fauna only)
Floral composition	Algae (highly abundant filamentous algae) Green algal diversity increases.	Algae (filamentous algae of *Stigeoclonium*) Tolerant blue green may occur	Algae	Algae (reduced quantitatively and qualitatively)
	Moss	Tolerant diatoms (e.g. *Nitzschia palea* may occur large in lentic zones	Moss	Moss
	Macrophytes (highly abundant covering large area of the river channel)	Tolerant macrophytes may grow in high abundance	Macrophytes unable to grow	Macrophytes
	Fungi (sewage fungi in cold waters obvious)	Sewage fungi (*Sphaerotilus*, *Fusarium*, *Leptomitus* may occur)	Huge sewage fungal growth	Fungi
Faunal composition	Dominant ciliates followed by leeches (Tolerant groups: orifera, Bryozoa, Molluscs, Crustacea, leeches, several insect orders with few tol. Plecop. And Heptag. spp.)	Porifera, leeches, Asellus occur in large nos. (Ciliates occur in the colonies of sessile species *Carchesium, Vorticella*)	Ciliates, flagellates, and bacterias dominating (Tol. groups of benthic fauna against oxygen deficiency occur in large nos.)	Free-living bacteriophagus ciliates, flagellatus and bacteria with colpidium–colpodae are typical. Filamentous sewage bacteria less abundant than in III–IV.
	Trichoptera (net spinning may be numerous)	Trichoptera	Trichoptera	Nearly no macroinverte-brates can colonize
	Chironomidae (highly abundant at specific sites) Tolerant species of Diamesinae and Orthocladinae in lotic zones and Prodiamesinae in sandy patches In muddy zones	Chironomidae (may be abundant at specific sites) Tolerant species of Orthocladinae occur	Chironomidae (mainly at lentic zones are highly abundant) Few species of *Chironomini* and genus *Chironomous* predominates	Chironomidae may occur sparsely Few species of *Chironomi Chironomous* predominate
	Tanytarsini (mainly *Microspectra*) and Chironomini (e.g. *Polypedilum*)	Tanytarsini (mainly *Microspectra*) and *Chironomini* are the dominant taxa		

(*contd...*)

Table 1. (*contd...*)

Saprobic class/ colour	II–III /Green-yellow	III/Yellow	III–IV /Yellow-red	IV/Red
	Worms Oligochaeta–Lumbriculidae (non Stylodrilus) Naididae may be numerous Tubificidae may occur In remarkable numbers	Worms Oligochaeta-Lumbriculus Naididae, Enchytraeidae and certain Tubificidae occur in remarkable numbers	Worms (Oligochaeta–Enchytraeidae (Lumbriculus) Tubificidae–Tubifex, and Limnodrilus occur in remarkable numbers Sulphur bacteria may occur in visible spots	Worms Oligochaeta–Enchytraeidae abundant Tubificidae–Tubifex, Limnodrilus occur in lesser numbers Sulphur bacteria are highly abundant.
Fish fauna		Reproduction not always possible, periodical fish injuries occur	Reproduction not always possible, periodical fish injuries occur	No fish fauna
River type	Polluted rivers	Highly polluted rivers	Very heavily polluted rivers	Extremely polluted rivers
Water uses	Restricted uses (drinking possible after treatment for locals)	Hazardous	Extremely hazardous. Unsuitable for any kind of human use.	Unsuitable for human use except as a receptacle for sewage
Other remarks	Increase of decomposers Excessive productivity	Production < reduction	Production < reduction	Assimilatory processes are always lower than the reductive processes

Mill is situated along the edge of Narayani river and is considered as main culprit discharging untreated effluents directly into the river. The condition of Orahi river was described as the worst, with a biochemical oxygen demand (BOD) of 1020 mg/l due to discharge from the Everest Paper Mill[20].

Environmental and socio-cultural aspects of Trisuli–Devighat hydropower upgrading project has been assessed[22]. Some physico-chemical and biological parameters and heavy metals such as arsenic, cadmium, copper, mercury, lead and zinc were analysed. Altogether water samples from nine locations were analysed. The pH, nitrogen, total phosphorus and BOD were within the permissible level, except BOD_5 in the fish farm. The water quality of Trisuli river has been reported as good in terms of its physico-chemical properties. However, information available revealed that the high content of faecal coliforms needs treatment before it is used for drinking purpose.

Karnali river system: The Karnali river system in western Nepal consists of the Humla Karnali, Mugu Karnali, Seti and Bheri rivers and is the longest river system in the country. The Humla Karnali, which rises in Tibet, is the main tributary. After entering India, this river assumes the name Ghaghra.

Studies on upland streams: The effects of altitude and landuse on macroinvertebrate communities of streams, which are considered as bio-indicators of impairment in the Dolpo region of Nepal have been studied[23]. Altogether forty-three streams were examined for water quality. Water chemistry and flow conditions were found to differ with altitude. Conductivity was not negatively correlated with altitude, as revealed in surveys conducted in central and northeastern Nepal[24].

Water quality status of selected rivers from Karnali basin has been studied[16] using macroinvertebrates as bio-indicators. Water chemistry from Simikot region in the Karnali basin has also been studied[25]. This region exhibited lowest chloride and sodium concentrations in Mugu and Humla Karnali, compared to other regions. On the contrary, markedly high calcium and phosphate concentrations were detected from this region. In Churto Khola from the Dunai region, high calcium concentration was detected. Sulphate concentrations appear to be closely related to calcium in this region.

Studies on lowland rivers: Lower section of Karnali river has been studied[26] under an environmental impact and mitigation plan of the Karnali (Chisapani) multipurpose project, by simulating a simplified aquatic ecosystem. This comprises seven nutrient and metabolic components (dissolved oxygen (DO), nitrites, nitrates, carbon dioxide, ammonia, phosphorus and carbonaceous BOD), two primary producers, five consumers and two material sinks.

Mahakali river system: Nepal has four major river systems with Mahakali as a westernmost border river with India. This river system has been poorly studied so far as its water quality is concerned. Only five sites were considered for water quality studies[16], which showed pollution levels from slight to moderate. Water chemistry of Mahakali river at Pancheshwar has also been studied[2] for pH, TDS, DO, and BOD_5 levels.

Bagmati river system: Water quality of Bagmati river has received the most consistent attention compared to other

Table 2. Classification of surface-water in Nepal[28]

Quality grade I: Unpolluted to very slightly polluted	Quality grade I–II: Slightly polluted	Quality grade II–III: Critically polluted
Clear water, low in nutrients	Low nutrient content	Considerable pollution load of organic substances
River bed usually stony, gravely or sandy	8 or more mg/l oxygen with frequent small detectable deficits	Turbid, eventually sludge
Amount of dissolved oxygen: > 8 mg l	BOD: Generally between 1 and 2 mg/l	Amount of oxygen 4 or even less mg/l
BOD: 0–1 mg/l	NH_4 is only present in concentrations averaging 0.1 mg/l	BOD between 5 and 10 mg/l
Absence of NH_4 (or traces only)	Quality grade II: Moderately polluted	NH_4 frequency below 1.3 mg/l
	Dense colonization of algae	Quality grade III: Heavily polluted
	High-yield fish water	Water turbid with sewage outfall
	Oxygen cotent always over 6 mg/l	Sludge, where the current is weak
	BOD frequently between 2 and 6 mg/l	Underside of stones blackened by iron sulphide
	NH_4 frequently below 0.3–0.4 mg/l	Periodic fish mortality
		Oxygen always present in amounts of 2–4 mg/l, but drops at times to <2 mg/l
		BOD frequently 7 to 13 mg/l
		NH_4 usually in excess of 0.6 mg/l and may reach up to several mg/l

Quality grade III–IV: Very heavily polluted	Quality grade IV: Excessively polluted
Water turbid with sewage outfall	Water highly turbid
Bed usually covered in sludge	Bed covered in sludge
Fish are only encountered locally and then not on a permanent basis	Often smells of hydrogen sulphide
Oxygen content sometimes less than 1 mg/l, as a rule not more than a few mg/l	No fish population
BOD frequently 10–20 mg/l	Often very low or no dissolved oxygen
NH_4 usually several mg/l	BOD over 15 mg/l
	NH_4 concentration usually several mg/l

river systems of the country[27]. The first report on the regular water quality programme of Bagmati river was published by the Department of Hydrology and Meteorology[28], that includes water analysis report of river water in Kathmandu Valley from 1992 to 1995. Water quality was classified into seven classes (Table 2) and an index map was also drawn for the river sections studied. The first systematic and detailed study[29] on the water quality status of the river Bagmati and its tributaries in Kathmandu Valley, introducing the use of saprobic system in monitoring surface water quality, was carried out in 1996. Different biotic indices and scores in use worldwide were applied in water quality monitoring of Nepalese rivers[30].

Effective management and regulatory actions based on sound technical and scientific information as design of water quality monitoring network for Kathmandu Valley rivers were suggested[31]. The final report on the Bagmati basin water management strategy and investment programme[32] stated that Bagmati river water within the Kathmandu Valley is not fit for drinking, recreation and irrigation purposes (Table 3). The daily BOD_5 generation in the Kathmandu Valley from industries and human interference is about 42 tons[33]. In the dry season, the Bagmati drains only 40% of the daily BOD_5 generation and the remaining is retained in the valley itself, which is becoming a major source of land and groundwater pollution.

Apart from the study conducted by the Department of Hydrology and Meteorology for a period of four years (1992–95), other studies do not provide time series data on the river quality for all seasons of the year[34–36].

Seventeen surface water samples were tested, most of which were from the Bagmati river[37]. Among these, only one had nitrates present at levels greater than 10 mg/l. However, 59% had nitrates present at levels between 1 and 10 mg/l. Ammonia was present at concentrations between 1 and 10 mg/l in two of the twelve surface-water samples tested. All other samples contained ammonia at levels below 1 mg/l.

All the studies carried out recently have reported that the water quality of the Bagmati river in the Kathmandu Valley is of poor quality, chemically and bacteriologically, and unsuitable for any freshwater fauna and flora for most of the dry season. However, in the rainy season (June–September), water quality improves considerably due to increase in assimilative capacity of the river. It has also been observed that the water quality in the Bagmati river in Kathmandu Valley is rapidly declining that the river is merely a sewer in the dry season.

Water quality characteristics of Bagmati river in Kathmandu Valley due to organic pollution[16,38] are illustrated in Figure 5.

Water quality in lakes and ponds

The first limnological study on lakes of Nepal was carried out in 24 lakes located at an altitude of 4500–5600 m above sea level in the Mount Everest region[39], providing the first data on morphometry, temperature, chemistry and biology. Rara, which is the biggest natural lake of Nepal, lies at an altitude of 2990 m above sea level. It covers an area[40] of

Table 3. Water quality criteria and standards proposed for Bagmati river and its tributaries

Parameter	Drinking	Aquatic life	Bathing	Agriculture
pH	6.5–9.2	6.5–8.5	6.5–9.0	6.5–9.0
TDS (mg/l)	1500	1000	1500	500–3000
SS (mg/l)	–	25	50	–
DO as O_2 (mg/l)	–	6	3	3
Cl as Cl (mg/l)	600	500	1000	100–1000
SO_4 as SO_4 (mg/l)	400	500	1000	1000
NO_3–N as N (mg/l)	–	20	20	25
NO_2–N as N (mg/l)	–	0.15	1.0	1.0
NH_3 –N as N (mg/l)	–	0.02	0.2	0.2
Total PO_4 as PO_4 (mg/l)	0.1	0.1	0.2	0.2
BOD as O_2 (mg/l)	4	4	6	10
F as F (mg/l)	3	1	1.5	1.5
Total Hg	–	0.0001	0.001	0.001
Total Cd	–	0.005	0.005	0.01
Total Pb	0.05	0.05	0.05	0.1
Cr	–	0.05	0.05	0.1
Phenol	0.002	0.005	0.1	0.2
Total cyanide	–	0.005	0.2	0.2
Total coliform (MPN/100 ml)	–	-	1000	1000

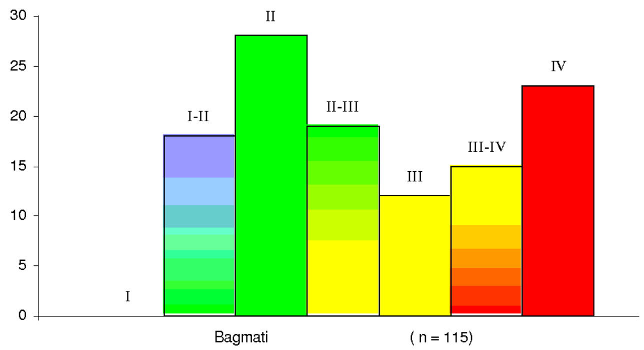

Figure 5. Water quality characteristics of Bagmati river system[16,38]. I, None to slightly polluted; I–II, Slightly polluted; II, Moderately polluted; II–III, Critically polluted; III, Heavily polluted; III–IV, Very heavily polluted; IV, Extremely polluted.

9.8 km^2 and has only one outlet that joins the river Karnali (river Ghaghra in India), a tributary of the Ganga. Thermocline[41,42] in this lake was visible below 14 to 50 m and was recorded as 7.5 to 7.6°C. Similarly, the morphology, physics, chemistry and biology of the lake measured high pH, conductivity and total hardness. The lake was classified as oligotrophic in limnological terms, meaning very slightly polluted based on the studies carried out on chlorophyll *a* estimation, total nitrogen and dissolved oxygen[40]. Trophic status and water quality in Lake Tilicho of Central Nepal was studied[43]. It is one of the largest glacier-fed lakes with slightly turbid water colour and strong chemical stratification. This study revealed a low concentration of total phosphorus (1–6 μg/l) and total nitrogen (0.16 to 0.25 μg/l) in water.

The chemistry of 31 lakes at altitudes between 4530 and 5480 m above sea level in the Khumbhu and Imja Khola valleys was considered, around a third of which was reported to have been made up of Na^+ and Cl^- of marine origin transported by the summer monsoon[44]. Three groups of lakes with different levels of ion concentrations and silica were highlighted using cluster analysis.

Palaeo-limnological analysis of four Himalayan lakes (Piramide Superiore, Piramide Inferiore, Lake N. 40 and Lake N. 70) was carried out[45] in the Everest region. Despite being characterized by very slightly polluted chemical conditions, the sedimentary record of phytoplankton and benthic algae in lake Piramide Inferiore and Lake N. 40, showed that there have been periods of high productivity.

Lakes and ponds in Kathmandu Valley: The phytoplankton and water chemistry of Taudah pond in Kathmandu Valley have been studied[46]. Similarly, ponds in Kirtipur has been studied[47] both chemically and microbiologically. They reported high levels of chloride and phosphate as well as coliform bacteria. The compositions of benthic macroinvertebrates of two ponds in Mahottari district were studied[48]. Thirty-one taxa were recorded and the pond was classified as eutrophic. A more detailed investigation on chemical aspects of Taudaha and Nagdaha – the largest ponds in the valley was performed[49,50]. Water quality of 70 water samples from 5 shallow pumps, 3 shallow wells, 14 stone spouts and 48 dug wells in the urban area of Patan city was studied[51]. Total coliform bacteria were detected in 85.6% of the samples and 68.6% contained faecal coliforms.

Lakes and ponds in Pokhara Valley: Phewa, Rupa, Begnas and Khaste lakes in Pokhara Valley, which finally drain their water into the Saptagandaki river system, are well studied compared to other regions. Temperature, transparency, electrical conductivity, pH and alkalinity of the lakes were investigated followed by species composition, vertical distribution and seasonal variations of phytoplankton[46]. Three major lakes (Phewa Tal, Begnas Tal, and Rupa

Tal) were investigated in two seasons[49] to examine the influence of monsoon on their limnological conditions. Calcium concentration in Phewa Tal accounted for 66.3% of the cation and 43% in Begnas Tal and Rupa Tal; anions were predominantly bicarbonate in all three lakes. The most complete limnological investigation was carried out in Nepal in 1989, in which 50 lakes were surveyed, including the lakes from Pokhara Valley[50].

Lakes and ponds of Terai and inner valleys: Devital, Lamital and Tamortal were investigated in Royal Chitwan National Park and classified as oligotrophic[52]. Limnological work on the lakes of far western region of Nepal is limited[40–42,53].

Monitoring groundwater quality

Groundwater of Kathmandu Valley: The groundwater of Kathmandu Valley is under immense pressure as it is being heavily exploited for drinking as well as for other activities resulting in a decline of its water level. The recharge areas in the surrounding hills, which were once densely forested, have been turned into agricultural land so that there is little support from the surrounding watershed areas to replenish the groundwater in the valley. The total sustainable withdrawal of groundwater from aquifers in the valley[32] is approximately 26.3 mld, but the total groundwater currently extracted[53] is about 58.6 mld. The studies indicate that groundwater in the valley is overexploited. Since studies are not carried out on a regular basis, it is difficult to determine the real degree of exploitation.

Groundwater monitoring in Kathmandu Valley: The first comprehensive groundwater quality assessment of the Kathmandu Valley was carried out by a Nepalese–Australian team using 75 monitoring points; analysis of 30 chemical and microbiological parameters was also done during the period. Water samples from four out of twenty tubewells in the deeper, confined aquifer contained faecal bacteria[54]. Similarly, a groundwater survey of over 100 water sources was conducted, including public stone spouts, municipal taps, dug wells, and tube wells in Kathmandu Valley[55]. At each water source site characteristics, including type, age and depth of the well, depth to water table, age of settlement, drinking-water preferences, perceptions of water quality and proximity to potential contamination sources were measured or obtained through interviews. A water quality field kit was used to measure the concentrations of nitrate, nitrite, ammonia, phosphate, sulphate, manganese, iron, faecal coliform, and *E. coli*, all indicators of contamination from sewage, agriculture and/or industry. In the shallow groundwaters of Kathmandu Valley, nitrate and other pollutants were high, the sources of which could be from domestic and agricultural infiltration. In the deep aquifers of Kathmandu Valley, high observed concentrations of ammonia are of natural rather than human-induced origin. Iron concentrations in the range of <0.5–9 mg/l and manganese concentrations in the range of <0.1–0.7 mg/l have been found in the groundwaters from the deep aquifers of Kathmandu Valley[56].

Groundwater monitoring in Terai: High ammonium concentrations and low nitrate and nitrite concentrations are also likely to be found in the deep aquifers of the Terai[57]. High ammonium concentrations are indicative of anaerobic aquifer conditions. Deep aquifers in the Terai become anaerobic due to overlying poorly permeable thick layers of clayey soil. Groundwater arsenic problem in Nepal is a relatively new issue. It was only in the late 1990s that the problem of arsenic contamination in the groundwater of Terai district, Nepal was identified. The Department of Water Supply and Wewerage (DWSS), with assistance from WHO, conducted for the first time, a systematic study on possible arsenic contamination in groundwater of Jhapa, Morang, Sunsari district, eastern Terai. So far 263,336 samples have been tested among which 221,315 samples are below 10 ppb; 33,539 are within 10–50 ppb and 8482 above 50 ppb (Sudan Panthi, DWSS, pers. commun.).

Rainwater quality monitoring

To cope with the looming crisis of water for drinking purposes, it is felt that Nepal needs to go for alternatives such as rainwater harvesting[35,58–60]. Although the need has been felt, little effort on rainwater quality monitoring has been made. In one of the studies[60], nineteen rainwater samples were collected and analysed for four trace metals (Pb, Cd, Cu and Zn) at different locations in Kathmandu Valley and at different times, where significant levels of metals were detected indicating that the valley atmosphere is under increasing pressure of heavy metal pollution. The major source of heavy metal pollution in Kathmandu Valley, particularly for Pb, was automotive exhaust. Similarly, Zn, Cd, and Cu were found in the parts of motor vehicles which are subject to wear and tear. Although rainwater in the countryside is not analysed for heavy metals, pH, conductivity, NO_3–N, PO_4–P and SO_4 of water stored in the ferro-cement jars (Figure 6) are within the permissible range of WHO[59]. However, out of 87 jars investigated in pre-monsoon period for microbial contamination[58], 73 were found to be microbiologically contaminated, i.e. water in 84% of the jars was found unsuitable for drinking purpose based on recommendations made by WHO[61,62].

Monitoring of the public water supply systems

Eastern development region: DWSS, with assistance from WHO, Nepal, conducted for the first time, a systematic research study on possible arsenic contamination in the groundwaters of Jhapa, Morang and Sunsari districts of the Eastern Terai of Nepal bordering the Indian state of West Bengal in 1999. The result of the study showed that out of

Table 4. Standards for industrial effluents discharge into inland surface-waters

Characteristic	Tolerance limit	Characteristic	Tolerance limit
Total suspended solids (mg/l)	30–200	Arsenic (as As) (mg/l), max.	0.2
Particle size of total suspended particle (mg/l)	850 micron sieve	Cadmium (as Cd) (mg/l), max.	2.0
pH	5.5–9.0	Hexavalent chromium (as Cr) (mg/l)	0.1
Temperature	Shall not exceed 40°C	Copper (as Cu) (mg/l), max.	3.0
BOD for 5 days at 20°C (mg/l), max.	30–100 mg/l	Lead (as Pb), (mg/l), max.	0.1
Oils and grease (mg/l), max.	10	Mercury (as Hg), (mg/l), max.	0.01
Phenolic compounds (mg/l), max.	1.0	Nickel (as Ni), (mg/l), max.	3.0
Cyanides (as CN) (mg/l), max.	1.0	Selenium (as Se), (mg/l), max.	0.05
Sulphides (as S) (mg/l), max.	2.0	Zinc (as Zn), (mg/l), max.	5.0
Radioactives			
Alpha emitters, c/ml, max.	10–7	Ammoniacal nitrogen (mg/l), max.	50
Beta emitters, c/ml, max.	10-8b		
Insecticides	Absent	COD (mg/l), max.	250
Total residual chlorine (mg/l), max.	1.0	Silver (as Ag), [mg/l], max.	0.1
Fluorides (as F) (mg/l), max.	2.0		

Figure 6. Rainwater harvesting in ferro-cement jars gaining popularity in the Himalayan region.

268 water samples tested for arsenic, 24 samples exceeded WHO guideline value of 10 ppb, with even two of them showing a concentration level higher than 50 ppb, which is the interim national drinking-water standard for arsenic in Nepal and national standard for arsenic in India and Bangladesh[63]. Environment and Public Health Organisation (ENPHO) with its laboratory in Kathmandu, is involved in monitoring of the public water supply systems in eastern development regions of Nepal[64–72].

Central development region: Kathmandu city water supply monitoring, including stone taps has been performed in an organized way by ENPHO[73,74]. Water quality status of river and ponds in and around Kathmandu valley was also performed on individual basis[75,76]. Phytoplankton, nutrient level and bacteriological quality of three ponds in Kathmandu Valley were investigated[76]. Two ponds in the valley were monitored[46] on a regular basis from January to June 1968. Ranipokhari, a historical pond situated in the centre of Kathmandu city was also surveyed in 1983 for its water quality[77]. Water samples from the urban, industrial regions of Birganj, remote rural areas, and heavy agricultural regions along the city's periphery were collected by a team of experts from Massachusetts Institute of Technology, USA[37]. Only one well was found in Parsa that was contaminated with nitrates and ammonia; it was a 24-foot deep, hand-dug well contaminated with nitrates at 16 mg/l. All other wells tested were tube wells varying from 50 to 250 ft in depth.

A detailed study of arsenic contamination was performed in groundwaters of Rautahat district, Central Nepal[78]. Out of 32 samples analysed during pre-monsoon (July) period, 15 sites showed arsenic concentration of 0–0.01 mg/l, 14 sites showed >0.01–0.05 mg/l and three sites showed >0.05 mg/l. Similarly, out of 89 sites studied during post-monsoon period (November), 54 sites showed arsenic concentration of 0.01 mg/l, 27 sites showed >0.01–0.05 mg/l, and 8 sites showed >0.05 mg/l. High arsenic was found associated with high iron, but not vice versa. Not many public drinking-water supply projects have been found in other development regions of the country.

Conclusion

The rivers in Nepal have extensively been used as sources of construction materials. Rocks, sand and gravel are extracted from every accessible river section and sold to the markets for a livelihood. There is a large population settled illegally along river banks, who sustain their livelihood solely by selling sands and gravels from rivers. This population has migrated from the hills to the valleys and the number seems to be increasing each year. Although this is a subject of research, women are found to be more attracted towards gravel extraction and men are involved in extracting sand. Removing sand and gravel from river bed is considered an illegal activity by the HM Government of Nepal. Still at local level, it is being practised regularly in an organized way. No regular monitoring or surveillance has been done so far on the impact brought about to the aquatic environment by such activities.

Similarly, lakes and ponds are being used as receptacles for all kind of wastes. Morphological disturbance through water abstraction for irrigation, industrial and domestic pollution, toxic contamination, hydropower generation are some of the notably established impairments seen in Nepalese water bodies.

An essential component of an effective surface water quality management is an appropriate institutional structure for monitoring, surveillance and enforcement which is lacking or, when present, is inefficient and inactive in this country. Although in some places in the Terai bordering India and midhills surveillance systems are in place at selected points to monitor water quality of wells and taps, in rivers and lakes in rural areas, the quality of water for drinking purpose is not monitored. Even in the capital city, laboratory facilities for analysis of water quality are limited and poorly equipped. Water quality testing laboratory at Sundarijal Water Treatment Plant was most probably the first laboratory in Nepal established in 1965, to control water treatment systems[79]. Standards or tolerance limits for industrial effluents discharged into inland surface waters are proposed by Government of Nepal[80]. DISVI, is a non-governmental organization, which was actively involved in water quality monitoring of Kathmandu Valley rivers and traditional drinking-water sources from 1987 to 1990. DISVI was later merged with ENPHO. An advanced water testing laboratory was also set up by DISVI in 1986/87. Different departments under Tribhuvan University, CEDA and RONAST were also engaged in urban water quality studies in the late 80s. WHO conducted a National Workshop on Drinking water quality in 1988 and emphasized on the establishment of five regional laboratories. UNICEF was involved in testing of iron and detailed investigation of tubewells in the eastern region. The ODA-funded rural water supply project was also involved in testing of water in the Eastern region. PLAN International, FINNIDA, HELVETAS, NRCS, NEWAH, Water Aid, RWSSFDB are some of the organizations involved in water quality monitoring status. Some of them are even reported to have set a field-based laboratory.

Nepal has not seen any improvements in the quality of its water bodies even at the end of the ninth five year plan. As stated in the tenth five year plan (2003–2008) published by the National Planning Commission, one of the priorities identified in the field of environmental management is control of river pollution. Bagmati Bishnumati, and Manahara rivers in Kathmandu Valley have been identified as those which need immediate rehabilitation. Necessary programmes need to be introduced on consultation with concerned agencies for their sustainable use in future. The Government should plan, organize, execute, operate and manage projects that will provide safe, adequate and sustained water supply to all people for drinking and personal hygiene, through proper protection and conservation of surface-water resources.

To summarize, following challenges have been identified in different regions of Nepal while reviewing the findings of different researchers in the water sectors.

(i) Inner-Himalaya and Fore Himalaya: Study showed a vulnerability of water resources due to faecal pollution in this region added by touristic influence.
(ii) Midhills: Study showed that the agricultural intensification, urbanization, and industrialization has caused an increase in fertilizer and pesticide contents in the rivers of rural areas and untreated domestic and industrial pollution has increased in cities.
(iii) Terai: Shallow groundwaters in Terai are at risk due to pathogenic bacteria, pesticides, nitrate and industrial effluents. Deep groundwaters in Kathmandu and Terai are largely anaerobic and hence vulnerable to increased concentrations of iron, manganese, and ammonium. Arsenic is becoming a problem in some parts of Terai.

Recommendations

The following recommendations are put forward for effective water quality management in Nepal.

(i) Protection of water resources: Treatment of human wastes and industrial effluents before they are discharged into natural water resources, and management of run-off from agriculture should be initiated.
(ii) Efficient water use: A system of incentives and disincentives should be adopted to encourage efficient water use.
(iii) Water safety: WHO guidelines should be adopted and community-level simple, but effective methods should be designed in providing adequate safe water to people. An extended Nepalese standard for the classification of surface-water to ensure ecological integrity of aquatic life must be introduced.
(iv) Capacity building: Facilities should be created to educate and train personnel in water management skills. Mechanism of laboratory inspection and accreditation must be introduced for ensuring the quality of data generated.
(v) Public awareness: The public should be made aware of the dangers of pollution and academia, NGOs, and local communities should be involved in extension.
(vi) Water security: Water security should be achieved by harvesting of rainwater and recycling of municipal waste water.

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