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Providing Safe Drinking Water in the Himalayas: A Tale of Two Cities

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Abstract

Water contamination and the associated morbidity and mortality are among the major areas of concern for the planners and policy makers in the developing countries. Situation in the Himalayan region is no different. This study focuses on the analysis of water quality in the two major cities in the western Himalayas namely Shimla and Kathmandu. Divided in four parts, part II of the paper presents the study context and problem diagnostics. Part III is devoted to key concerns and the way forward. Finally, part IV presents conclusions and the research agenda. It is argued that among the factors that are responsible for this outcome are: primitive water treatment technologies, lack of good sanitary practices, lack of ecosystem focused water governance, and absence of effective water quality monitoring and surveillance. Therefore, effective water and sanitation management requires a holistic approach that takes a multidimensional view beyond the traditional confines of technology.

Keywords: Water Contamination and Health Effects; Risk Management and Integrated Water Management; Treatment Technologies

Introduction

Water links us in ways that underpin healthy communities, economies and ecosystems even as challenges and opportunities facing pollution control and water quality are diverse and evolving. Quality of drinking water has been an area of concern world over ever since the World Health Organisation (WHO) first published International Standards for Drinking Water in 1958. Subsequently, many reports on the impact of waterborne diseases in countries worldwide revealing numerous outbreaks due to bacterial, viral and parasitic micro-organisms associated with the consumption of untreated or improperly treated drinking water were published [1-4]. The real sensation occurred with WHO quantifying the damage [4] by projecting that every eight seconds a child died from a water borne disease and about five million people died from illness linked to unsafe drinking water and inadequate sanitation. Later, highlighting the significance of safe drinking water, WHO [5] suggested that every year there will be 200 million fewer diarrhoeal episodes, 2.1 million fewer deaths, 76000 fewer dracanculiasis cases, 150 million fewer schistosomiasis cases and 75 million fewer trachoma cases; if sustainable safe drinking water and sanitation services could be provided. However, actual benefits may be far more if savings on account of medical costs associated with burden of disease are also added.

In terms of water quality, the focus has been on chemical and physical aspects of water quality as well as the microbiological aspects which have lately become very important with climate change related debate getting heated up. The World Health Organization [5] identifies a variety of pathogens that are cause of concern from the standpoint of providing safe drinking water. It is highlighted that a vast majority of pathogens have high significance from the water quality and safety point of view and most of them have moderate persistence in water and high resistance to chlorine, the sole water treatment method in case of most developing countries. Further, the emphasis on water quality management has therefore shifted to prevention of faecal pollution and development of good engineering practices that resulted in development of end product standards for 'faecal indicator organisms' and operational guidelines for source water protection and adequate treatment.

The selection of faecal indicator organism is justified on the ground that even though risk to health depends on multiple factors including the extent of presence of pathogens and innate and acquired immunity of the host, but the presence of pathogenic microorganism itself renders drinking water unsafe no matter however low the presence of concentration [4]. *Escherichia coli* and to a lesser extent thermo-tolerant coliform bacteria are considered to best fulfil the criteria to be satisfied by an ideal indicator. While the most often reported disease associated with drinking water remains gastroenteritis, enteric micro organisms are associated with a wide range of symptoms and diseases, for instance, liver and brain infections caused by protozoan parasites, and Helicobactor pylori transmitted through the water route [6].

With pathogens being dominating water contaminants, the role of sanitation also gets important in water quality and reduction in water borne disease. The global Burden of Disease study highlighted that Disability Adjusted Life Years (DALY) were ascribed to 10 selected factors of which water, sanitation and hygiene accounted for the second biggest percentage of DALYs behind malnutrition [7]. In the case of developing countries, it gets even more complicated as with the presence of malnutrition, poverty and lack of awareness, the morbidity and mortality gets multiplied manifold. Therefore, effective excreta management coupled with behavioural modification programs have the capacity to reduce disease transmission via drinking water, contact with recreational water and via the food chain. Hence, any effort to improve water quality has not only to focus and confine itself to the water treatment procedures, but in order to be effective and sustainable, has to include technical sanitation solutions and behavioural management aspects also in its scope.

The Himalayan region represents one of the most dynamic and complex mountain systems and extremely vulnerable to global warming [8]. Preliminary studies indicate (e.g. Liu and Chen; Shrestha, et al.) [9,10] that temperature increases are greater during the winter and autumn than summers and the increases are larger at higher altitudes. It is attributed to (e.g World Climate News) [11] exponential increase in Green House Gases (GHGs) such as carbon dioxide, methane, nitrous oxide, water vapour and chlorofloro carbons. Climate change is severely impacting the hydrological cycle and, consequently, water management by substantially affecting both water resource availability and quality. These changes are likely to be increasingly powerful drivers of water availability, acting with other drivers that are already having serious impacts on water quality and availability. Increased water-related risks associated with the changes in frequency and intensity of extreme events (e.g., droughts, floods, storm surges and landslides) will put additional strain on water resource management and increase uncertainty about quantity and quality of water supplies. This is further expected to increase the health effects of water and in turn the morbidity-induced income and welfare impacts.

Much in line with global thinking, management of Water, Sanitation and Hygiene (WASH) has been among the few major concerns of planners and policy makers throughout the globe including the Himalayan region. Over the years, it has been observed that unscientific disposal of human excreta has been a major source of water contamination resulting in frequent episodes of morbidity in the area [12,13]. The problem gets compounded with the Himalayan landscape being exposed to a large scale influx of visitors from outside (especially during summers and winters) which results in excessive waste generation and exerts pressure on already strained civic infrastructure like water, sewage, and roads. The problems of water scarcity, rise of temperature and outbreak of bacterial/ microbial infections and other waterborne diseases are among the most common repercussions faced by the local population in the Himalayan region. This not only increases the burden of out of pocket medical expenses and loss of earnings (during hospitalization), but also results in putting the already poverty ridden population into a debt trap. Thus, water governance, distribution and water quality are all very important from the public health and human welfare perspectives.

Focusing on the specific problems of water quality in the Himalayan region, this paper takes up two large cities in the western Himalayas namely Shimla and Kathmandu for an in-depth analysis. Both these cities have experienced rapid spurt in urbanisation due to rural-urban migration and tourism. Aimed at finding out workable solutions to the problems relating to water quality in these areas by going into the genesis of the problem, the paper identifies possible options for the future. Divided in four parts, part II of the paper presents the study context and problem diagnostics. Part III is devoted to key concerns and the way forward. Finally, part IV presents conclusions and the research agenda.

It is argued that among the factors that are responsible for this outcome are: primitive water treatment technologies, lack of good sanitary practices, lack of ecosystem focussed water governance, and absence of effective water quality monitoring and surveillance. The paper makes a case for pursuing effective water and sanitation management requiring a holistic approach that takes a multidimensional view beyond the traditional confines of technology.

The Study Context

The Himalayan region lies at the junction between the Indian sub-continent and Asia, and contains one of the youngest and most dynamic mountain systems in the world with geo-tectonic activity still ongoing [14]. With its mountain ranges extending from Afghanistan in the West to Mynamar in the East, the region is a source of ten large Asian river systems. Studying water resource management in the context of Himalayas makes it important for following reasons. First, the Himalayan ranges are the youngest and loftiest among the mountain systems of the world and represent a highly complex and diversified system both in terms of biological and physical attributes. The region has a discrete geographic and ecological entity. It produces a distinctive climate of its own and influences the climate and water resources of much of Asia. Second, the Himalayan landscape systems are unique as with their steep slopes and sharp gradients, these are often heterogeneous and exhibit sharp and most often systemic changes in climatic variables over very short distances. These features consequently result into enhanced changes in hydrological processes, with accelerated direct runoff and erosion. Major rivers of the region have their origin from these mountains and are the source of water for a large proportion of the human population within and outside the mountain region. Natural wealth in the region, including geological assets, forms an important part of the Himalayan eco-system. Finally, the region is largely inhabited by indigenous societies. Recognition of the Himalaya as one among 34 global biodiversity hotspots aptly reflects its' wide ranging ecological significance. Equally significant are the environmental and ecosystem resources like the protection of watersheds and aesthetic attraction that has led to the extensive development of tourism.

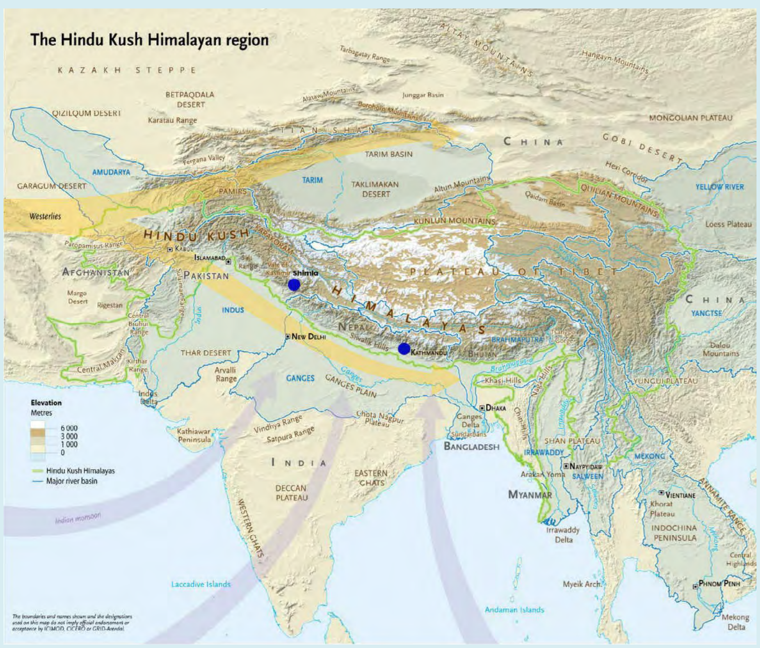

Figure 1: The Himalayan Region.

However, with rising population pressure, urbanisation, industrialisation and changing agricultural practices, water quality in the Himalayan region and in some case even the area falling in Indo Gangetic plains, has been substantially affected [15]. It is estimated that 210 million people living within and 1.3 billion people living downstream of the Hindu Kush Himalayas rely on fresh water obtained directly or indirectly from river systems of this region. Already water related morbidity and mortality in the Himalayan region is a major cause of concern [16]. The problem gets compounded with climate change related developments as the region gets warmer three times faster than the world average [17]. Climate change is expected to have a powerful impact on human health directly (due to thermal stress and floods) and indirectly through changes in ranges of disease vectors, water borne pathogens, water quality, air quality, and food availability and quality [8]. Therefore, studying water quality and ways to improve and maintain water quality and sanitation is crucial from the Himalayan perspective.

Problem Diagnostics

- **Shimla City, Himachal Pradesh (India)**

Water governance in India faces the twin challenges of water availability and water quality. The Water Resource Group [18] projects a 50 % gap between demand and supply in India by 2030 which is estimated to be 755 billion cubic meters. While possibilities of supply side augmentation are limited (because of over abstraction and overuse in multiple geographies), demand side management is often suggested as the only available option. Owing to this, concerns with regard to water quality and conservation have been reflected in National Water Policies of 1987, 2002, and 2012. All through, it has been unequivocally emphasised that both ground water and surface water quality should be monitored regularly and steps should be taken through a phased program to improve the quality of water [19-21]. Even though the access to water has improved in India in the past decade, the adverse impact of unsafe water on health continues [22] more so due to non availability of surface water, people resort to ground water which may have controlled microbiological problems, but is marred by other problems like fluorosis and arsenic contamination. Water quality is affected by both point and non point sources of pollution.

Shimla is the capital of Himachal Pradesh: a province in the Indian federation. With an altitude of 2424 meters, the city is located in the Himalayas at the latitude of $30^0 6''$ N and longitude $77^0 11''$ E. The municipal area of the city is 31.6 sq km having a population of 0.3 million. It is estimated [23] about 0.15 million tourists visit the city every year. Drinking water to the Shimla Municipal Corporation is provided by the Irrigation and Public Health Department of the state which is distributed among the consumers by the Corporation. There are seven surface water sources supplying raw water and about 80% of the population of the city is served by these sources [24]. The treatment plants and the technology used are as per Table 1 below.

Sr. No.	Treatment Plant	Location	Raw Water source	Design Capacity (MLD)	Treatment
1	Dhalli WTP -I	Dhalli	Spring sources in catchment area	4.5	Slow sand filtration
2	Dhalli WTP -II	Dhalli	Cherot Nallah and Kufri Nallah	4.85	Rapid gravity filter (conventional treatment)
3	Ashwani Khad WTP	Ashwani Khad	Ashwani Khad	10.8	Conventional
4	Chairh WTP	Chairh	Chairh Nallah	2.5	Conventional
5	Gumma WTP	Gumma	Nauti Khad and Kalyan Nallah	24.06	Conventional

Table 1: Water Sources and Treatment Plants for Shimla City
Source: CPHEEO [24].

One of the serious concerns often expressed in the case of water supplied in Shimla city is in terms of quality emanating from lack of a well equipped laboratory facility for examining the quality of water [24]. It is noted (e.g CPHEEO) [24] that there are no on-site laboratories at the treatment plants and the only one available is located at Dhalli which too is grossly under staffed and has outdated equipments. Alongside water quality surveillance, water distribution is yet another area of concern. The water is supplied through trunk mains emerging from three main reservoirs feeding the network on the way to the break pressure tanks. There are ten service reservoirs having a total capacity of 26.48 million litres. The length of distribution networks is 105 kilometres. With aged distribution network mostly reported leaking, the water wastage in the city is quite high at 35% [24]. As water is supplied to the reservoirs through the pumping stations, it entails a lot of energy consumption which becomes a serious concern as the Corporation is not allowed to charge full cost recovery charges for political considerations [24].

Serious concerns have been expressed on the water quality and the resultant water related morbidity in Shimla city in studies carried out in the past few years [24]. The latest study by NCDC was carried out after the outbreak of jaundice in the city between December 2015 and April 2016. The study concluded that as many as 1681 cases of hepatitis E were reported from areas of city being supplied water from Ashwani Khad source. The studies have also observed (e.g. GIZ; CPHEEO) [24] that in the absence of an organised solid waste management system, solid waste is disposed off in the open which ultimately affects the water sources. Also that in areas not connected with sewage network, households have constructed septic tanks which are mostly leaking and overflowing resulting in contamination of surface and ground water. Even the practice of open defecation followed by the villages in the catchment areas contributes to contamination of water sources. The agencies charged with responsibility of water management do not have the mandate to control these practices as these areas are mostly out of the Municipal boundaries.

- **Kathmandu (Nepal)**

With more than 6000 rivers supplying water, water is the largest known natural resource of Nepal [25]. The total average runoff from all these rivers is estimated to be 275 billion cubic metres. Though 98% of the total withdrawal from rivers is used for agricultural purposes, the rest is used by the population for potable requirements without treatment since it is vulnerable to pollution caused by untreated sewage, industrial waste, and agricultural run offs. As a result the faecal contamination found in the water samples was very high [25]. Table 2 presents high risk principle contaminants and nuisance constituents found in the water samples in Nepal.

High Risk Contaminants	Nuisance Constituents
Microbiological Contamination	Iron and Manganese
Arsenic	Chlorine
Nitrate	pH
Fluoride	Ammonia
	Turbidity
	Hardness
	Color, taste and odor

Table 2: Water Pollutants in river waters of Nepal.
Source: UNU [25].

Here again, the main causes of surface water contamination are due to open defecation, hanging latrines and direct sewage discharge [25].

Kathmandu Upatyaka Khanapani Limited (KUKL) is responsible for operation and management of water supply and waste water services in the valley. Even though the government of Nepal's capital investment and asset management program of 2010 aims to provide 135 litres per capita per day (lpcd) of domestic water to the residents of the valley by 2025, unplanned development, population growth, lack of sustainable water sources and poor management systems have resulted in low availability of water. ADB [26,27] has concluded that this inadequate access has led to increased disease incidence, health risks and associated economic burdens with disproportionate impact to poor and vulnerable population. Forced by inadequate water availability, the natural recourse is to resort to shallow and deep ground water sources. It is estimated [28] that nearly half of the valley water supply during wet season and over 70% during the dry season comes from ground water sources.

On the water quality, the findings of the studies are unequivocal: contamination was found in almost all sources. The ground water analysis has revealed the presence of arsenic and ammonia in deep waters and nitrate and E coli in shallow waters [29,30], presence of E coli in all water from rivers and wells [31]. Others for instance Jha, et al. [32], Dongal, et al., Kannel, et al. and Shrestha, et al. [33-35] have found biological and chemical contamination. With contamination comes morbidity. Studies have (e.g. Khadka; Warner, et al.) [36,37] concluded that throughout Nepal people are exposed to severe health threats resulting from water contamination by sewage, agriculture, and industry. Owing to the impact of sewage, typhoid, dysentery, and cholera are endemic every summer. Chief concerns in the Kathmandu valley are identified [32] as contamination from sewage lines, septic tanks, and open pit toilets. Surface water is found to have been polluted by direct disposal of sewage waste [38]. It is estimated that approximately 50% of the water supply in Kathmandu Valley is sourced from ground water sources of which Dhunge Dharas are a major source and Khadka [36] found widespread sewage contamination based on indicator bacteria, pH, iron and ammonia in water flowing from Dhunge Dharas.

The most recent work in the area of quality of water being supplied to the local population has revealed (e.g. UNU) [25] that water resources are being increasingly polluted by domestic, agricultural and industrial wastes. The available data on water quality testing has revealed [25] that faecal coli form contamination found to be widespread in majority of gravity fed schemes and the position with regard to contamination remained unchanged despite the changes in intake system. With regard to health risk, UNU [25] finds 38% samples containing faecal count of 101-1000 which is very high. The report recommends that owing to limited resources available for testing [25] priority should be given to testing contaminants that pose serious health risk.

Karan and Harada and Warner, et al. [37,38] have studied the sanitation management system of Kathmandu. While Karan and Harada [38] conclude that solid waste is not collected and scientifically disposed, Warner, et al. [37] conclude that sanitation and waste management in the Kathmandu Valley are found to be non-existent. Warner, et al. [37] report that, "personal sanitation in the developing neighbourhoods is poor with several instances of drop toilets co-located with the drinking water source for the household. When wells are not near a population centre or household, they are occasionally located near agricultural fields in which manure and chemical fertilizers are spread in excess quantities".

- **Key Concerns**

From the discussions above, the following key concerns arise for consideration.

a) Faecal contamination is one of the main factors in water quality in both the cities. Its effect is not only confined to the surface water, but even the ground water is severely affected due to open disposal of untreated sewage. Sanitation practices are therefore of paramount importance from the water quality and health point of view. Despite the technological advancements and spread of education, open defecation is a matter of concern in both India and Nepal. Studies in both the countries reveal [25,39] that the major factor in water quality and spread of disease is open sewage disposal, open defecation, unscientific disposal of waste and industrial and agricultural pollution. Once polluted, the infection gets transferred through various routes. Figure 2 presents alternate ways of transfer of infections to the humans.

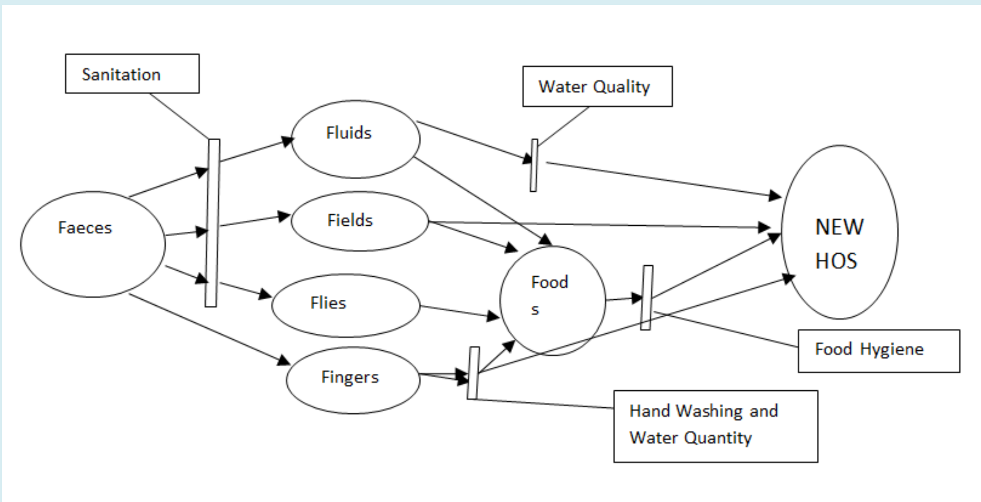

Figure 2: The F-diagram: faecal contamination paths and barriers

In the case of developing countries as in India and Nepal, the problem gets compounded as other socio-economic factors like poverty, illiteracy, malnutrition, and unhygienic practices also contribute to water contamination. The damage therefore raises manifold with low levels of immunity caused due to malnutrition and lack of personal hygiene. Studies have concluded (e.g. Coignard, et al. Benenson) [40,41] that the infection transfers mostly via hands. While some actions have been taken in both the countries in the recent past for promoting hygiene practices, enough remains to be done. In India, for instance, the sanitation coverage is still close to 60% only and the government of India has launched Swatch Bharat Abhiyan to promote individual household toilet construction. Nepal has also drawn an elaborate plan under the National Water Supply and Sanitation Sector Policy 2014 [42]. Under the policy, an ambitious plan to construct toilets through public private partnership is rolled out.

b) Water treatment technology is an important area of concern in both the study areas with twin problems: both in terms of technology selection as well as use. The current system of putting up treatment plants is not preceded by any detailed analysis of risk assessment and identification of possible contaminants. For cost consideration, the technology choice is also very restricted to natural filtration coupled with use of chemical disinfectants. There is no concept of multi-layered processes so that failure of the sole process leads to sudden episodes of outbreak of diseases. Besides, there are serious concerns in terms of maintenance and use. Of the ten plants studied by UNU [25] in Kathmandu, 8 were found to be out of use. In the case of Shimla city as well, one of the major treatment plants supplying water to the city had to be shut down during the peak summers due to technical problems. All this created shortage of water supply forcing people to resort to other sources of untreated water supply like the ground water and waste water.

c) Both the cities have substantial infrastructure for treatment and delivery of drinking water which is conventionally operated by government employees even though privatization of water supply is a growing trend [43-45]. In both cities, alongside treatment, delivery is an equally serious problem. Distribution networks are poorly constructed and sporadically maintained, and unauthorized connections are commonplace. Public water supply points and mains are frequently damaged. Typically, at least 30% and as much as 60% of water produced can be lost during distribution. Such distribution networks not only result in distribution losses and are thus not only inefficient and economically unsustainable, but lead to low pressure and infiltration of surface water heavily polluted with faecal material [46]. Thus, this itself becomes a major bottleneck in technology improvement since it would be a mistake to spend a lot of money on producing top-quality water, for example using reverse osmosis, only to have it contaminated during distribution (e.g., Semenza, et al.) Wagner and Pinheiro [47,48] offer a useful resource for optimizing and upgrading municipal treatment plants.

d) Increasing effects of climate change could potentially further aggravate the problem in two ways. First, with increased temperature and enhanced evaporation, the availability of water will further be reduced. Mountain springs have been reported to have gone dry due to increase in temperatures and erratic rainfall in the recent past. Kulkarni, et al. [49,50] have observed a massive glacial retreat rates of 178m per year in Parbati Glacier in Kullu District of Himachal Pradesh during 1962-2000. Similar observations have been recorded by Raina [51] in respect of Gangotri glacier and Shukla and Siddiqui [52] for Milam glacier for Kumaon Himalayas. This water scarcity will force the people to resort to untreated sources of water. Second, with enhanced temperatures, there will be changes in range of disease vectors, and water borne pathogens. With sanitation practices remaining unchanged, the temperature increases will enhance the morbidity and mortality associated with water borne diseases.

e) Water energy and food nexus further complicates the problem. With water resources getting scarce and polluted, there will be deficiency in water availability for agriculture and hydro electricity. This will reduce the food production and affect livelihood of the people leading to the problem of malnutrition and hence the reduced immunity to fight against the water borne diseases. ICIMOD [53] argues that for sustaining ecosystem services that support agriculture production, water security, and clean energy development downstream, management of Himalayan watersheds and their forests, and wetlands is crucial.

f) Problem of cost recovery is a serious bottleneck in management of the systems. This problem arises out of the fact that water is being supplied as a 'public good' Khemka by the municipal entities in both the cities. These entities are not even able to recover the cost of water supplied as a result they are not able to pay their energy charges and maintain the plants as well. It not only affects the quantity and quality of water supplied, but has a serious impact on the demand of water in the long run. With water being supplied at a very low cost or for free, the households and the commercial entities tend to demand more and waste water. This is therefore an important policy consideration for making improvements in both quality and quantity of water supplied. One long term impact of lack of system of cost recovery from water supply is that it inherently discourages private investment in the sector.

g) Lack of effective quality monitoring and transparency of data leaves much to be desired. Even though the problem of water related morbidity is a regular phenomenon in both the cities [25,39], none of the stakeholders (local bodies, water users, and the government) make efforts to check the water quality in frequent intervals and share it with the public. Their indifference to have quality checking and sharing the same despite its obvious benefits is typical of 'ostrich effect' [54,55]. This tendency of information avoidance [56] further enhances the morbidity since people are not able to take adequate precautions and remedial measures.

➢ **The Way Forward**

(i) Choosing an appropriate treatment technology is an important task in the entire process of water treatment. Over the years, different treatment technologies have been developed world over and choosing appropriate technology is also a big challenge. While the drinking water regulations in many countries specify parametric values for various chemicals in the treatment of drinking water, compliance of microbiological parametric values are of primary concern in the protection of human health from drinking water. Among the major technological options available are discussed hereunder with their pros and cons.

Conventionally, the most popular water treatment systems in the developing countries and more so in the mountain areas are river bank filtration and slow sand filtration. The current system adopted in both the cities is river bank filtration. The river bank filtration takes advantage of infiltration of river water into a well through the river bed and underlying aquifer material. This again is a natural filtration process in which physic-chemical and biological processes play a role in improving the quality of percolating water. Even though the quality of water is best through this process, however, its major limitation is huge energy costs because it uses pumps to transfer water and its inability to treat highly turbid water. Nonetheless, it is still useful in removing 99% of pathogens and could work well in a multi-staged process if followed by disinfection with chlorine [57]. Both the cities are facing problems of coping up with huge energy costs ([25,39]. It pushes the entire system in a vicious cycle since these unmet energy costs dry out budget for maintenance.

The recent innovations in water treatment revolve around membrane filtration technology, solar pasteurization, and UV irradiation. The membrane filtration technology uses sieve or a semi-permeable layer so that water molecules pass through and bacteria, chemical and viruses are prevented from passing. The sophistication of the membrane technology ranges from using sand filled T-shirt fed by gravity to highly advanced pressurized systems relying on nano-technology to screen microbes. It mostly uses pressurized systems using electrical and mechanical systems required to maintain the pressure of the system. The common application of this technology is RO systems which are mostly used for desalination, but are equally effective in removing contaminants. Its major limitation is its high energy requirements. However, this method is considered to be wasting a lot of water (only 10-20% of water passes through the sieve and it also results in waste of energy [58].

One way to address energy related problems is using solar energy. Solar distillation utilizes natural process of evaporation to capture purified water. The structure used in solar distillation is called a solar still often has a slanted glass cover over a black painted water filled basin. As sunlight penetrates the device the solar energy is absorbed by the basin liner and transferred to the water via conduction and convection. However, solar distillation requires high amount of solar energy than the solar pasteurization and UV irradiation since UV irradiation could potentially operate by storing solar flux during the sunshine and then use it later through batteries. Apart from the zero energy costs, it is very low on maintenance since the equipment required is very less.

Though pasteurization is akin to boiling, yet the major difference between the two is in the temperature requirements since pasteurization temperature is lower than the boiling temperature. Therefore, the energy requirements are also less. The temperature requirements for pasteurization are as per Table 3 below.

Temperature	Result
55°C	Worms, Protozoa cysts. D value =~ 1 minute
60°C	E coli, rotavirus, salmonella typhi, vibrio Cholerae , shingella sp.
	D Value =~ 1 minute.
65°C	Hepatitis A virus
	D Value =~ 1 minute.

Table 3: Temperature Requirements for various Pathogens.
Source: Ray and Jain [59].

D values represent the time required to kill 90% of the contaminants. This itself is the advantage of the technology since it uses less energy compared to boiling. Pasteurization is shown to have significantly improved the quality of water in developing countries [58,60].

Just like pasteurization does not require boiling of water, the UV irradiation technology does not require heat input for water treatment. Instead, this technology relies on applying light at specific wavelengths to contaminated water to deactivate bacteria and protozoa. This process has been found to be highly effective and inexpensive while producing a reasonable volume of water per unit area UV light source. It could be done in two ways: directly and indirectly. While direct method utilizes the sun energy during the sunshine to deactivate contaminants, the indirect method uses PV panels to store energy and then use it during the time when there is no sunshine. This technique also known as SOLDIS [58] solar disinfection is very cost effective and has shown significant water quality improvements and drops in diarrhoea morbidity in field tests [61].

(ii) Even with the technological initiatives two distinct problems still remain unaddressed: knowledge of potential pollutants to plan for treatment systems accordingly; and over dependence on single stage water treatment since any lapse or failure here could lead to public health catastrophe. Recent developments in the field of water and sanitation have brought risk based approach and integration of disinfection with overall treatment into focus. The provision of drinking water free from harmful micro-organisms has traditionally been assured by monitoring the number of bacteria which are indicators of faecal contamination with this monitoring done at a fixed location in the whole system. However, with the introduction of WHO Drinking Water Safety Plan (DWSP), this approach for ensuring that drinking water is 'safe' and 'secure' is increasingly being substituted with development and adoption of risk management plans. As per this concept, a drinking water supply scheme is deemed to be safe if it meets quality standards every time and at every stage. It is deemed to be secure if there is in place a management system that has identified all potential risks and reduction measures to manage these risks. Among the benefits of this approach are: it emphasises prevention through good management practice so less reliance is placed on testing the end product, offers systematic approach to managing the quality of drinking water at all stages, and provides transparency that helps increasing confidence and trust. Typically, a risk assessment plan undertakes hazard assessment, exposure assessment, dose-response analysis, risk characterization and risk management. The hazard assessment is a straightforward task which attempts identification of a pathogen as an agent of potential significance. One outcome of hazard analysis is a decision as to the principal consequences to be quantified in the formal risk assessment (e.g. consequences may include morbidity and mortality, and may affect the entire population or a sub-population) (Figure 3).

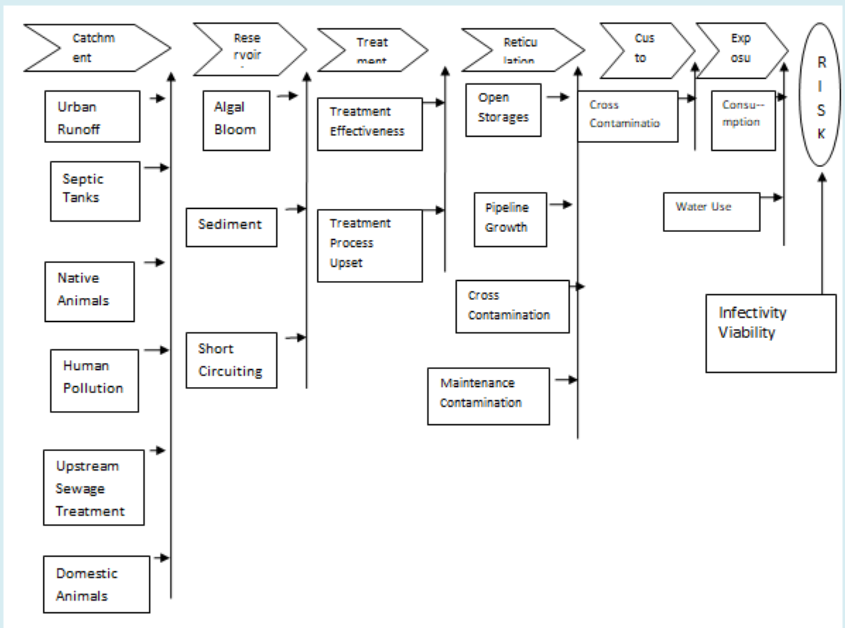

Figure 3: Generic Flow diagram for sources of microbiological risk in drinking water context Source: Adapted from WHO [7].

The purpose of exposure assessment is to determine the microbial doses consumed by the direct consumer of water. It is suggested (e.g. Regli, et al.) [62] that this may necessitate the estimation of likely changes in microbial concentrations with treatment, storage and distribution to the end user. Dose response analysis is generally necessary to fit a parametric dose response relationship to experimental data since the desired risk which will serve to protect public health is often far lower than can be directly measured in experimental subjects. It therefore, requires extrapolation. The process of risk characterisation combines the information on exposure and dose response into an overall estimation of a likelihood of adverse consequence. Finally, the results of risk characterisation are used in risk management.

(iii) The concept of integration of disinfection within the overall treatment plan is based on the notion of multi-barrier approach to water purification. The basic premise of the approach is that failure of an upstream process such as clarification or filtration may mean that chlorination stage will not achieve disinfection. The approach therefore emphasises on selection of technology having regard to the following process [63]:

- The assessment of catchment and source risks with respect to the clarity, organic content, and the likely risk of pathogenic micro-organisms in the source water. It is very relevant from the point of view of the multiple sources of contamination (F-diagram) and integration of water in the overall development process. Such evaluation of particular source risk following analysis of raw water monitoring helps in determining the extent of pathogen removal/inactivation required of the proposed disinfection system. The guiding principle for the disinfection technology is that it must be capable of removing or inactivating all pathogens potentially present in the final water;
- It also helps in determination of the pre-treatment process(es), necessary to ensure the required pre-treatment of the water (with respect to colour, turbidity and TOC) and/or inorganic chemical removal, upstream of the disinfection system to ensure it is capable of performing adequately;
- It is then followed by an assessment of the adequacy of

contact time for chemical disinfection technologies and the necessity to ensure that minimum contact times required for disinfection are achieved;

- The verification of the efficiency of the disinfection treatment. Any disinfection technology used must be capable of being verified, and that such verification is recorded;
- An assessment of the requirement to ensure that a residual disinfectant is present in the distribution network for all but very small distribution networks;
- Finally, assessment of the capital and operational cost of the disinfection technology is very important. Where disinfection technologies achieve equally effective outcomes, the water supplier should have regard to the financial implications from the capital and ongoing operational aspects to ensure that the most cost effective solution is selected.

(iv) Water scarcity, aging infrastructure, environmental pressures, and rising water treatment costs are some of the factors requiring changing water management practices. Water conservation and reuse program could potentially help the local governments in meeting the ever rising demands for water and achieve multiple goals: increase efficiency for both energy and water; reduce demand on water sources and reduce energy consumption; reduce costs associated with finding more costly water sources; and reduce costs associated with water treatment. Water conservation and reuse and improved catchment and distribution system could play a key role in meeting the future water demand. This however, offers a limited solution that can be useful for meeting a limited demand. It is therefore essential that alternate ways of finding sources that complement better water management measures are identified. The treatment of previously unusable water sources is likely to become a key component of the solution to long term water supply shortages [64].

Following a step by step approach in doing so will help a great deal. The process will ideally start with conducting a baseline survey of water resources and community demand. The goal of such an exercise is to evaluate the adequacy and reliability of freshwater resources based on the rate of community consumption. A comprehensive assessment would therefore help the local governments in these cities to better understand existing water resources, current uses and inefficiencies and projected water demand. The next step would be to maximize watershed recharge by maintaining local forests, wetlands and other areas that infiltrate water. It is a cost effective way for local governments to maximize recharge. Besides, healthy water contributes to local ecosystem resiliency and helps to mitigate potential climate change effects. It has then to be followed by improving water supply and distribution system. As has been noticed in both the cities in this study, impaired water supply and distribution systems waste water through pipe leakages and also pose a potential threat of contamination. This will help the local governments in the two cities to reduce the potable water lost, which is identified as ‘unaccounted water’.

(v) Technological innovation is another area requiring attention. With the rising population, urbanization, industrialisation, and food security led enhanced water demand by agriculture; entities handling water can expect rising demand for innovative solutions and technologies. SIWW [65] identifies eight key drivers of technology innovation in the water sector. These are: protection of water quality, climate change, demand management, need for non-conventional water sources, water -food- energy nexus, waste minimization and resource recovery, fit for local context, and water governance. Innovation prioritizing developed by SIWW [65] is as per Figure 4.

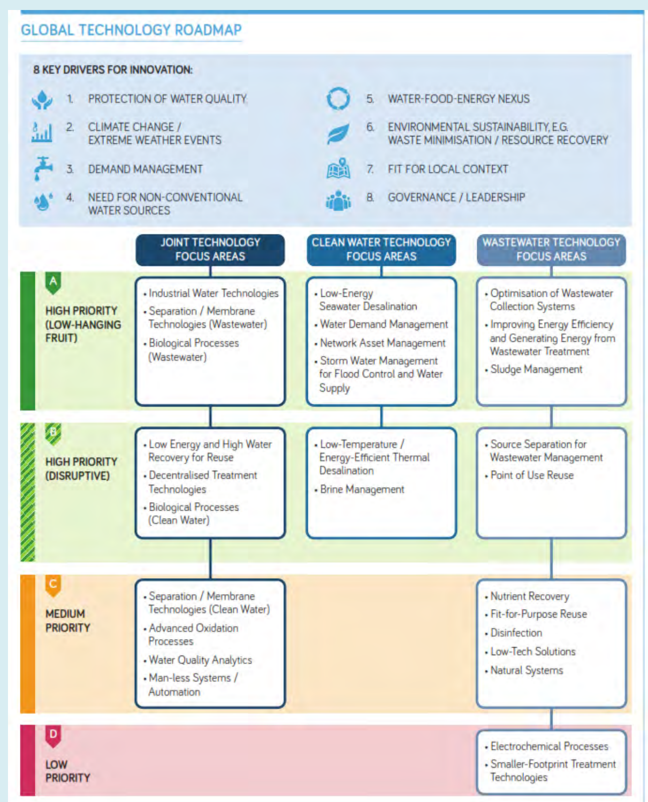

Figure 4: Innovation prioritizing. Source: SIWW (2015).

Appropriate policies will have to be put in place to encourage innovation in the above priority areas.

(vi) Community awareness and pricing of water is essential from water governance point of view. It is generally recommended (e.g. Erriksson, et al.) that the best approach to adaptation is bottom up community led processes built on local knowledge, innovation and practices. Such an approach based on good science derived from credible, salient and legitimate knowledge can often lead to good policies in the context of climate change and policy [66]. Equally important is the pricing regime in water services which should ensure full cost recovery to the water entities. It is also important for promoting innovation and technological development including private investment in the area.

Conclusion

It is clearly established from the discussions above that water quantity and quality are the twin issues faced by the planners and policy makers in these two cities. Owing to their common geo-economic attributes (Himalayan landscape) and economic potentials (tourism centric economies), both the cities face a common predicament: water shortages and deteriorating water quality led morbidity and mortality. Among the factors that are responsible for this outcome are: primitive water treatment technologies, lack of good sanitary practices, lack of ecosystem focussed water governance, and absence of effective water quality monitoring and surveillance.

As the review of literature reveals, the process of selection of water treatment technologies is required to be integrated into the overall water management system. The exercise has to begin with assessment of the water sources, water demand and the present and potential water pollutants in the sources. This effort will help bring clarity in the dimension of the problem and ultimately guide the selection of technology. Alternate technologies ranging from the most primitive natural filtration to the latest solar pasteurization and UV irradiation are basically applied to achieve physical removal of chemical oxidization of organic and inorganic impurities and the attendant consequent reduction of pathogens. These also help in controlling the residual organic or inorganic compounds in treated water as a means of limiting regulated disinfection by products in final drinking water to consumers. The end result may be achieved through chemical disinfection (e.g. by chlorination, ozonation, chlorine dioxide) or through non chemical disinfection (e.g. by UV treatment for full spectrum inactivation of pathogens). Among the factors that are often used to decide the choice of a technology are [59] flow rate (m^3/day), cost of implementation, maintainability including cost of maintenance and availability of spare parts, energy consumed (kW/h), and reliability. Technologies that involve low energy and high water recovery for reuse are in demand in municipal and industrial markets. One of the most promising developments in the field is Forward Osmosis (FO). The chief advantages of FO system are [65] their lower energy consumption and low temperature heat source so that it can be powered by renewable energy. However, the technological improvement has to be an ongoing process. Technological innovations in these cities have to focus on low cost technological options and require engagement with local entrepreneurs having in depth understanding of the local issues. The scope of innovation should also cover intelligent use of asset management. Appropriate policies have therefore to be put in place that encourage innovation.

Pursuing healthy sanitary practices is a major challenge. The problem is not confined to stopping open defecation practice alone as it requires a much broader framework that guides establishing and managing sewerage systems and technically sound septic tanks in the region. It is observed in both the cities [35,67] that inefficient sewerage systems and leaking septic tanks are responsible for pollution of the ground and surface water. Therefore, merely focussing on construction of toilets offers no solution to the problem. The failure of earlier versions of Indian sanitation program (central rural sanitation program) offers a typical example of this kind. The program focussed on construction of toilets only by offering subsidy which the people availed and in many cases did not construct and where constructed, did not use the toilets. Later version of the program namely the Total Sanitation Campaign focussed on construction and usage of toilets but did not emphasise the environmental friendly septic tanks which resulted in construction of earthen pit toilets which continued percolating faecal material in the ground water sources. Therefore, the entire issue needs to be mainstreamed and planned in a holistic manner. Emphasis has to be placed on both controlling overall pollution in general as well as preventing the pollutants from entering the water sources. This has to be done in the entire chain from water source to the household level.

Sound water governance is critical to both water supply and demand of water resources. Hydro-economic analysis offers the inherent benefit of integrating the costs, benefits and risks of various solutions aimed at enhancing the economic productivity of water. One major step in this direction is imputing an ecosystem value to the water resources to force the users to take into account the real value of water. For instance, the 80% of water used in agriculture could be is largely saved by crop protection technologies and reducing over irrigation. These measures obviate the need for costly supply side interventions. Further, integrated decision making allows for an analysis of synergies and trade-offs between water, agriculture, energy, environment and livelihood. WRI [68-70] presents interesting case studies in sound water governance.

Finally, integration of disinfection in the overall treatment plan should also be accompanied by appointment of an independent agency for monitoring and surveillance of water quality. The agency should be charged with responsibility of sharing water quality data with the consumers. Multiple ways of quality surveillance could be put in place which can include special quality assessment surveys on single as well as multiple parameters and surveys by the community could also be a part of the framework. UNICEF [58] offers a detailed quality audit framework which could be very useful.

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