Contamination of surface water resources by wastewater in Bhutan: A review

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Abstract
Wastewater is one of the most significant issues that arise as a result of increased economic activity, urbanization, and population density. Depending on the source, wastewater may contain organic waste, pathogens, nutrients, pesticides, heavy metals, and other chemicals related to pharmaceuticals, personal care products, industrial, and household products. In recent years, wastewater from both point and non-point sources has increasingly begun to contaminate Bhutan's surface water resources. Open disposal of untreated wastewater into the environment pollutes the environment, which then poses a threat to human and ecological health. This review article aimed to present the current state of wastewater generation and contamination of surface water resources in Bhutan. A review of secondary data sources, including published research, media reports, government legislations and regulations, and policy documents revealed that wastewater contaminants are increasingly polluting Bhutan's surface water resources, necessitating immediate remediation. The Bhutan Environmental Standards (2020) does not contain discharge standards for all emerging contaminants that may cause chronic toxicity, endocrine disruption in humans and aquatic fauna, and disease outbreaks. Therefore, regular monitoring and controlling of contaminants discharged into the surface water bodies should be a national priority for Bhutan.

Keywords: Bhutan, water resources, wastewater, water pollution.

Introduction

Bhutan, a small landlocked country in South Asia's Eastern Himalayas, located between 88° 54 and 92° 10 East and latitude 26°40 and 28°15 North (Figure 1), is also affected by surface water pollution. Bhutan is part of the Hindu Kush Himalayan(HKH) region, which has one of the world's highest per capita water availability rates, with an average flow of 2,238m^3/s generating 70,572 million cubic meters per year (Dorji 2016). Rich high altitude glaciers, glacial lakes, and summer monsoons continuously feed these water resources in the form of rivers, streams, lakes, ponds, and springs (Dorji 2016). Bhutan has five major river systems that flow out of the country to join the Brahmaputra River in India: the Amo Chhu; the Wang Chhu; the Punatshang Chhu; the Mangde Chhu; and the Drangme Chhu (NEC 2016). Rivers are extremely important economically for the country because major rivers have been tapped for hydropower generation, while smaller rivers, streams, and springs are primarily used for domestic water supply and irrigation. Most of Bhutan's surface water bodies, however, have become discharge points for solid waste, sewerage, and wastewater as a result of growing economic activities, industrialization, and population.

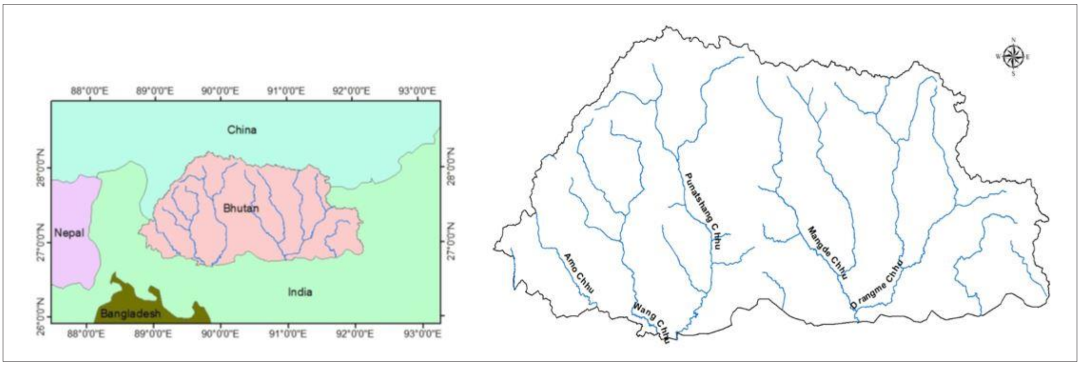

Figure 1: An outline map of Bhutan and the major river systems in Bhutan.

The great civilizations of the world such as Mesopotamia, Egypt, and Indus Valley began and flourished in river valleys because rivers provided a consistent source of water for drinking and agriculture (Angelakıs et al. 2020). Similarly, river valleys fed by glacial melts and monsoon rains have played a significant role in shaping the economy of Bhutan. The Bhutanese people's subsistence farming practice flourished in the valleys due to easy access to water. Furthermore, with the implementation of the first five-year plan in 1961, extensive development activities began in river valleys such as Thimphu, Bumthang, and Paro, to name a few, which today represent the pinnacle of Bhutan's modernization and urbanization. Unfortunately, rivers that once supported subsistence farming and provided potable water are no longer fit for these purposes because their roles have been altered by humans. Currently, these rivers, particularly Wang Chhu in Thimphu and Paa Chhu in Paro, receive wastewater containing high concentrations of man-made contaminants (Giri & Singh 2013; Pradhan & Mandal 2015; Rai et al. 2020).

Wastewater generation is an unintended consequence associated with increased economic activity, urbanization, and high population density. Any type of water whose quality has been affected by human activity is referred to as wastewater. Depending on the type of anthropogenic disturbance, wastewater may contain chemicals, biological pathogens, and other solids. Water resources around the world are becoming increasingly contaminated by wastewater containing organic waste, pathogens, fertilizers, pesticides, heavy metals, and emerging contaminants such as chemicals found in pharmaceuticals, personal care products, industrial and household products (UN-Water 2020). Water quality is critical for the proper operation of various ecosystems, climate regulation, human health, food production, and social and economic development. However, according to the United Nations World Water Development Report (2020), it is estimated that approximately 80 percent to 90 percent of wastewater worldwide is discharged into the environment without any form of treatment. The potential negative effects of wastewater discharged into the environment are determined by the volume, chemical and microbiological concentrations, and effluent composition. Untreated wastewater discharge not only pollutes the environment, but also endangers human health, well-being, and economic activities.

Bhutan's rapid socio-economic development, increasing population, and urbanization are accompanied by an increasing amount of wastewater that threatens the country's pristine environment. In recent years, the amount of wastewater from both point and non-point sources has increased at an alarming rate in Bhutan. The main point sources include wastewater from residences, commercial establishments such as vehicle wash centers, institutions, hospitals, and other industries (Rai et al. 2018). Nonpoint sources include stormwater, mining wastewater, and agriculture runoff. Agriculture runoff is Bhutan's most common non-point source of water pollution, and according to Atapattu and Kodituwakku (2009), it is a major concern due to the use of fertilizers in farming and the impact of runoff on downstream communities and water bodies. Open disposal of untreated wastewater into the environment pollutes soil and surface water bodies, which then pose a threat to human and ecological health. Bhutan's freshwater resources are increasingly polluted due to the pollutants present in the wastewater.

This paper will present the current status of wastewater generation and subsequent contamination of surface water resources in Bhutan. A review of secondary data sources such as published research, media reports, government legislation, and regulations governing wastewater management will be conducted. Further, it is expected that the recommendations made in this paper will be useful to Bhutanese policymakers and concerned agencies dealing with surface water quality and wastewater issues.

Methods

A review of secondary data sources such as published research, media reports, government legislation and regulations, and policy documents, is presented in this paper. Selected literature was compared, analyzed, and summarized based on the author's experience, existing theories, and models. This article is divided into the following sections: Bhutan's Policies and Regulatory Frameworks for the Management of Water Resources and Wastewater; and Different types of wastewater and their effects—domestic wastewater, industrial wastewater, mining wastewater, agriculture runoff, and stormwater runoff.

Discussion

Bhutan's Policies and Regulatory Frameworks for the Management of Water Resources and Wastewater

Bhutan has numerous legislations and regulations governing water resources conservation and wastewater management, including the *Water Regulation of Bhutan 2014;* the *Waste Prevention and Management Regulation 2016;* the *Waste Prevention and Management Act of Bhutan 2009;* the *Water Act of Bhutan 2011;* the *Bhutan Drinking Water Quality Standard 2016;* the *Revised Water Quality Standard 2018;* and the *Revised Water Quality Standard 2019.* Bhutan's first environmental institution, the National Environment Commission (NEC), enforces all of the aforementioned policies and regulations in collaboration with relevant stakeholders. Bhutan's water governance framework has evolved, from a single-purpose focus on hydropower projects or irrigation schemes to multi-purpose water resource management that took environmental concerns and stakeholders into account, and finally to a comprehensive water management system that focuses on coordinated development and management of water, land, and environment (Tariq et al. 2021).

Although Bhutan has a plethora of policies and regulations directing the appropriate management of water resources and wastewater, actual reports on how these policies and regulations are implemented are not maintained regularly in the form of an authentic database. Data on how water resources and wastewater are managed using the policies and regulations in place should be kept in chronological order and made publicly available. Such information will be useful when evaluating the effectiveness of specific policies and regulations. In Bhutan, it is common practice for only some media organizations and researchers to investigate whether policies and regulations are being implemented or not. Otherwise, Section 41(a, b& c) of the *Water Act of Bhutan 2011* states that, A person may not discharge any effluent directly or indirectly to any water resource unless the discharge complies with the effluent discharge standard stated in the Environmental Standards of Bhutan. Effluents must be treated using the best available technology before discharging into the environment. Notwithstanding any other provisions, it shall be unlawful to discharge any chemical, radiological, radioactive, medical, or any other hazardous waste into water bodies (RGoB 2011, p.21&22).

According to Tariq et al. (2021), the *Water Act 2011* is a significant achievement in the improvement of the legal structure for water resources in Bhutan because it aims to propel a reasonable, coordinated, and transparent effort to deal with the various aspects of water resources sustainably. However, the significance of the above clauses of the *Water Act (2011)* has been emphasized by a few media organizations (Zangmo 2016a, 2016b; Dendup 2017) and researchers (Giri & Singh 2013; Pradhan & Mandal 2015; Rai et al. 2018) only, who have called for the proper implementation of the act and associated regulations. The competent authorities, organizations, or agencies covered by the Act must monitor the effective enforcement and implementation of the provisions outlined in this Act. The *Water Act (2011)* of Bhutan's competent authorities' negligence to fulfill their responsibilities is visible at vehicle wash centers across the country, where heavily contaminated wastewater is simply disposed into the environment and water bodies.

Similarly, section 46 (c) of the *Waste Prevention and Management Act 2009* (RGoB 2009, p.30) treats the dumping of hazardous waste into water bodies and land as a misdemeanor, and the offender is subject to punishment under Bhutan's Penal Code. Hazardous waste is a waste with properties that make it dangerous or capable of causing harm to human health or the environment (US EPA 2021). However, even under such legislative provisions, stormwater, agricultural runoffs, and wastewater from industries, hospitals, laboratories, residences, and vehicle wash centers containing hazardous waste are ultimately released into the environment without treatment. Hazardous contaminants in wastewater generated from point and nonpoint sources should be carefully monitored before being discharged into the environment.

Another important aspect of protecting the environment and water resources from contaminated wastewater is the establishment and enforcement of appropriate and affordable effluent discharge standards (Johnstone 2003). Although Bhutan's *Environmental Standards 2010* (NEC 2010) had been recently reviewed and upgraded to *Environmental Standards 2020* (NEC 2020), it still lacks discharge standards for all emerging contaminants derived from PPCPs, industrial, and household products. Specific standards for effluents such as vehicle wash wastewater contaminants are missing in the upgraded standards as well, and are covered only by generic industrial effluents discharge standards. Another fact is that Bhutan still lacks the laboratory capacity to analyze all of the parameters listed in the *Environmental Standards 2020*. Moreover, many competent agencies operating under the discretion of Bhutan's Water Act repeat the same tests. For instance, different agencies conduct water quality tests regularly, resulting in resource waste. Instead, competent organizations should pool their resources, manpower and upgrade their laboratory facilities, conduct tests systematically, and keep a database for future reference and policy decisions.

Though Bhutan's environmental conservation policies and regulations prioritize the protection of water resources from anthropogenic activities, surface water pollution caused by wastewater disposal remains a topical issue that requires focused attention. A great deal of harm is expected to the environment, human health, and the economy unless both natural water resources and generated wastewater are addressed through the already established policies and regulations. Therefore, the current state of affairs involving the implementation of existing ordinances and regulations of water resources and wastewater management necessitates the development of effective strategies to ensure their proper implementation.

Different types of wastewater and their effects

Wastewater is defined as used water originating from domestic, industrial, commercial, or agricultural activities, as well as surface runoff/stormwater and any sewer inflow or sewer infiltration (Tilley et al. 2014). Any type of wastewater contains a high concentration of chemical and biological pollutants, along with other solids (dissolved and suspended) and debris. In Bhutan, the primary point sources are wastewater from residences, commercial establishments, institutions, hospitals, industries, and sewage treatment plants while nonpoint sources include stormwater, agricultural runoff, mining wastewater, monsoon flash floods, and glacial lake outburst floods (Figure 2).

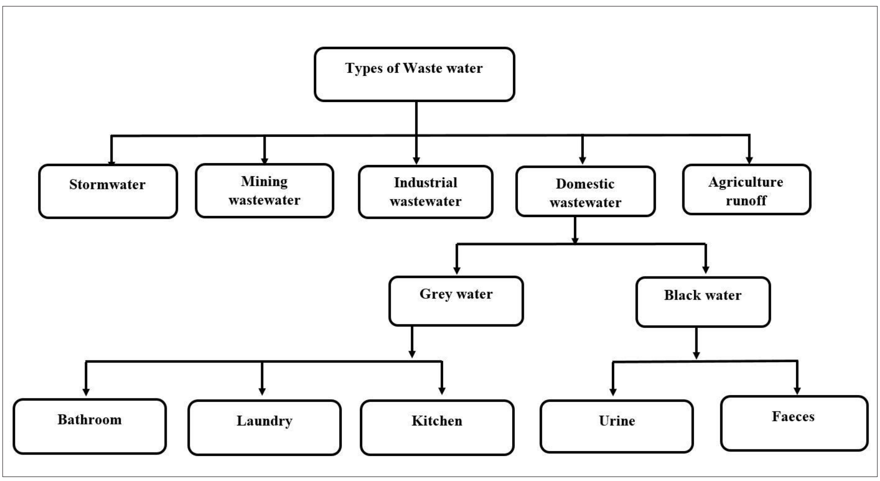

Figure 2: Types of wastewater produced in Bhutan.

The potential deleterious results of wastewater discharged into the environment are determined by the volume, chemical, and microbiological concentrations, and other characteristics of the effluents. A list of the contaminants found in various types of wastewater is presented in Table 1.

Table 1: Lists the contaminants found in various types of wastewater.

Type of wastewater	**Contaminants (Physical/chemical/organic)**	**Reference**
Domestic wastewater	Blackwater (urine, feces, flush water, toilet paper) and greywater (kitchen, bathroom, and laundry effluents). Pathogens, BOD, COD, E.coli, detergents, lipids, phenols, solids	UN-Water (2015); Boutin & Eme (2016).
Vehicle wash centers	pH, EC, DO, TSS, TDS, turbidity, BOD, COD, TN, TP, oil & grease, anionic surfactants, PAHs, TA, sulfate, Cd, Cr, Cu, Fe, Mn, Pb, Zn.	Sablayrolles et al. (2010); Hashim & Zayadi (2016); Rai et al. (2020).
Iron and Steel industries	BOD, COD, oils, metals, acids, phenols, and cyanide.	Hanchang (2009).
Pulp, Paper, and Wood Industries	chlorinated organic compounds, pH, COD, BOD, Total solids, TSS, chloride, Fe, phenols, tannins/lignin, sulfate, cellulose, organic acids, Furfural, and alcohols.	Hanchang (2009); Toczyłowska-Mamińska (2020).
Cement Industry	Alkaline wastewater, solids (TDS & TSS), fly ash, lime, sulfate, toxic metals like Zinc, Lead, and Chromium.	Arachchige (2019)
Plastic Industry	pH, BOD, COD, TSS, P, organic nitrogen, phenols, oil & grease.	Nasr et al. (2005)
Textile and dyeing Industry	pH regulators, dyes, de-foamers, bleaches, detergents, optical brighteners, equalizers, acids, bases, salts., etc	Khan & Malik (2014)
Pharmaceutical Industry	pH, EC, TDS, BOD, COD, phenols, drugs, organic compounds, heavy metals (Cu, Co, Cd, Ni, Pb, Mn, Cr, Zn, Fe, As, and Hg).	Kumari & Tripathi (2019)
Mining wastewater	pH, EC, TSS, Ca, Mg, Na, K, Al, Fe, Mn, Chloride, sulfate, silica, and Zn	Thiruvenkatachari & Su (2017).
Stormwater	COD,TSS, TN,TP, heavy metals. Chemicals, microplastics, cigarette butts, Styrofoam, sewage overflow, cooking oil, bacteria, motor oil, fertilizers, paint, and construction debris.	Lee & Bang (2000) Li et al. (2015).
Agriculture runoff	Nitrates, ammonium, phosphorus compounds, heavy metals, and persistent organic pollutants.	Xia et al.(2020)

(Abbreviations: BOD- Biological Oxygen Demand, COD- Chemical Oxygen Demand, pH- Power of Hydrogen, DO- Dissolved Oxygen, TS- Total Solids, TN-total Nitrogen, TP-Total Phosphorus, TDS- Total Dissolved Solids, TSS- Total Suspended Solids, TOC- Total Organic Carbon, EC- Electrical Conductivity, PAHs-Polycyclic Aromatic Hydrocarbons, Cd- Cadmium, Cr- Chromium Cu- Copper, Fe- Iron, Mn- Manganese, Pb- Lead, Zn-Zinc, and E. coli- Escherichia coli)

Domestic wastewater generation in Bhutan has increased in recent years as a result of rapid population growth and urbanization. Blackwater and greywater are the two main categories of domestic wastewater. Greywater includes wastewater from kitchen and laundry activities, as well as bathroom effluents, while black water includes flush water, urine, feces, and toilet paper (Boutin & Eme, 2016). By 2030, the United Nations (UN) Agenda for Sustainable Development Goal 6 aims to ensure that everyone has access to adequate and equitable sanitation and hygiene, eliminate open defecation, and improve water quality by reducing pollution, eliminating dumping, and minimizing the release of hazardous chemicals and materials into water bodies (UN Water 2015). However, public sewerage systems currently exist only in some of Bhutan's urban areas (20percent), with the rest of the country still relying on on-site sanitation systems for the disposal of domestic wastewater (Dorji et al. 2019).

Onsite sanitation system comprises of the septic tank and soak pit system that tackle only black water (from toilets) while greywater (from bathrooms and kitchen) is simply discharged into the environment. If blackwater from toilets is not properly treated and disposed of, it will endanger public health as well as pollute the environment. Reports on overflowing sewerage waste and wastewater on Thimphu's roads (Seldon 2019) necessitate the upgrading and maintenance of the sewerage network, as this sewerage wastewater poses a serious health hazard to the public. Although an on-site sanitation system that provides partial treatment is considered a temporary solution, according to Dorji et al. (2019), if properly constructed, it can be highly beneficial for Bhutan because of its cost-effectiveness in managing domestic wastewater.

Dorji et al. (2019) have reported that about 75 percent of Bhutanese households have access to improved sanitation. Some rural people continue to use pit latrines, which pose high risks of contaminating the environment, particularly the country's surface water resources. Infact, wastewater from such on-site sanitation facilities seeps into the soil, polluting aquifers, groundwater, and surface watercourses (Ajibola 2019). Untreated domestic wastewater contains high concentrations of excreted pathogens (UN-Water 2015), which can degrade water quality by depleting oxygen levels due to microbial decomposition of organic matter, making it unsafe to drink and causing diseases such as dysentery, cholera, and typhoid [Ajibuah & Terdoo 2013].

Although the sewerage treatment system in Thimphu (capital city) has been upgraded from an open sewerage pond to an automated sewerage system with the installation of a sequential batch reactor (Wangmo 2020), the fact that only 20 percent (Dorji et al. 2019) of the population is served by a sewerage system in Bhutan is a major concern.

Industrial Wastewater

Industrial wastewater is a major source of pollution in the environment and surface water bodies, negatively impacting ecosystems and human health. Every year, industries dump millions of tonnes of heavy metals, chemical solvents, toxic sludge, and other waste into water bodies (WWAP 2017). Depending on the nature of the industries, the composition of industrial wastewater varies (Table 1). With the rapid development of industries, a large amount of fresh water is used as raw material, and wastewater is simply disposed into the environment. Industrial wastewater can be regulated, controlled, and treated if

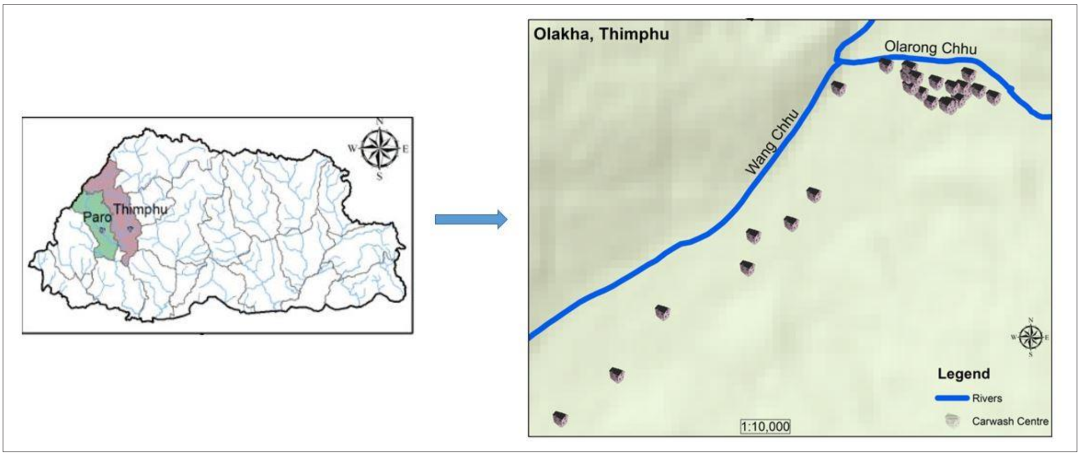

Figure 3:Location of vehicle wash centers at Olakha, Thimphu. (Source Rai et al. 2016).

there are enough political will, regulatory power, and resources (economic and human capacity) to ensure compliance (UN Water, 2015).

Among the different types of water, surface water pollution caused by vehicle wash wastewater (VWW) discharge is a topical issue in Bhutan (Rai et al. 2018, 2021). The majority of vehicle wash centers in urban areas are located along streams and rivers, from which they draw water for washing vehicles and discharge untreated wastewater back into the same water bodies (Figure 3).

VWW contains a wide range of contaminants, including polycyclic aromatic hydrocarbons (PAHs), nutrients (TP and TN), suspended and dissolved solids, detergents, heavy metals, sand, dust, surfactants, phosphates, waxes, hydrofluoric acid, and petroleum hydrocarbon wastes such as motor oil, diesel, and petrol (Bhatti et al. 2011; Boluarte et al. 2016; Tekere et al. 2016). VWW discharge into surface water bodies disrupts water chemistry (Danha et al. 2014), degrades ecological habitats (Shah et al. 2008), and has an impact on aquatic biota (Rai et al. 2020). Heavy metals are also associated with vehicle body parts, fuels, and lubricants (Talebzadeh et al. 2021), which enter the wastewater while washing worn-out body surfaces, auto brake linings, tires, vehicle exhausts, and fluid leakages.

Till date, only Thimphu has an effluent treatment plant (ETP) for separating oil & grease and sludge, which also remains frequently inoperative, allowing untreated VWW to enter the nearby water bodies (Rai et al. 2018). Only a few automated vehicle wash centers maintain environmentally friendly washing facilities, which include recycling and reusing approximately 80percent of the wastewater. The regulations governing the operation of wash centers and the management of wastewater are not being implemented effectively. Due to the high levels of contaminants in VWW (Table 1), Bhutan should establish VWW standards, as the current Environmental Standards (2020) do not include them. Bhutan should concentrate on VWW treatment and monitoring of contaminant levels before discharging into surface water or the environment.

Wastewater from Pulp, Paper, and Wood Product Industries

The pulp and paper industry consumes a significant amount of water and wood, and produces wastewater containing a high concentration of toxic chemicals, which raises biological oxygen demand (BOD) and chemical oxygen demand (COD) levels, causes toxic effects on fish and other aquatic organisms, and causes unacceptable changes in the color, temperature, and solid content of receiving water bodies (Hubbe et al. 2016). The high organic load and solid content of wastewater from pulp and paper industries affect the aquatic ecosystem in a variety of ways, including localized damage to the benthic community, widespread oxygen depletion- BOD and COD, and numerous changes in fish reproduction and physiology (Cabrera 2017). Wood residues in sawmills also produce leachate, a black liquid with a petroleum-like odor that causes foaming water and can disrupt or destroy fish habitat (Arimoro et al. 2007). There are currently 136 sawmills in the country, including 16 mobile sawmills and eight integrated wood processing units (Wangmo, 2021), and the concerned authorities should monitor their locations and wastewater discharged as they are a major source of environmental pollution.

Pharmaceutical wastewater

The term “pharmaceutical wastewater” primarily refers to effluents and waste generated during pharmaceutical manufacturing. Pharmaceuticals, a life-saving discovery of human scientific advancement, have now emerged as rapidly growing environmental contaminants (Balakrishna 2017). Pharmaceutical contaminants have been found in groundwaters, surface waters (lakes, rivers, and streams), seawater, wastewater treatment plants (influents and effluents), soils, and sludges (Farré et al. 2001). Bhutan has also recently begun to establish pharmaceutical companies, so their environmental impact and remediation must be understood to avoid pollution and harm to human health through the food chain.

Plastic pollutants in wastewater

Plastic waste is a widespread and persistent global issue that has negative consequences for the environment, economy, human health, and aesthetics. Recognizing the harmful effects of plastic carry bags on the environment, Bhutan banned the use and sale of plastic carry bags in 1999, got reinforced twice in 2005 and 2009 due to its unsuccessful enactment (Tshering 2019). It is still not successful because the plastic ban policy is not strictly enforced. Bhutan banned plastic bags due to their hazardous and non-biodegradable properties (Tshering 2019), but recently, plastic particles known as Microplastics (sized 1 nm to 5 mm) have been identified as an emerging threat, as well as an ecotoxicological and ecological risk for water ecosystems (Mrowiec 2018). The extensive application of plastic in human life brings about microplastic (MP) pollution in the environment (Wang et al. 2020). It is estimated that 70-80 percent of plastic contaminants originate on land and enter surface waters through multiple pathways, while municipal wastewater treatment plants (WWTPs) are the primary point sources of microplastics in an aquatic environment (da Costa et al. 2016).

Stormwater runoff

Although urbanization brings many benefits, it also causes numerous environmental issues such as the generation of polluted urban stormwater, a major non-point pollution source in an urban setting. Large stretches of imperviousness or water-resistant surfaces made of asphalt, concrete, brick, and stone characterize urban areas, which greatly increase accumulations of pollutants during the dry period and lead to a high pollutant loaded runoff during precipitation events (Deng 2020). Stormwater runoff is induced by rain and snowmelt that flow over less vegetated land or impervious surfaces such as paved streets, parking lots, and building rooftops rather than soaking into the ground.

Trash, chemicals, dirt, sediments, toxic heavy metals, synthetic organic pollutants (SOCs), nutrients, and pathogens are some of the most common pollutants found in urban runoff (Lee & Bang 2000). Stormwater pollutants can come from a variety of sources, including construction sites, lawns, improperly stored hazardous waste and illegal dumping. These contaminants can pollute soil and groundwater during infiltration through soil and surface water when runoff enters receiving water bodies; harm wildlife habitats; and make recreational water unsafe, posing a serious threat to ecological and public health in urban areas (Deng 2020).

In light of the damage caused by stormwater runoff, Bhutan should implement some long-term stormwater management strategies to manage the quality and quantity of stormwater. Low impact development (LID) techniques, such as bioretention basins, low-cost adsorbents, green roofs, and grassed swales, use small-sized and distributed treatment components to preserve or mimic the site's pre-developed hydrologic response to precipitation, allowing for runoff infiltration (NJDEP 2020). Other stormwater management practices that protect water resources and ecological health include: educating the public about proper storage of hazardous materials and landscaping; preventing sediment, chemicals, and nutrients from construction sites from washing off; and proper land use and limiting impervious surfaces (US EPA 2020).

Mining wastewater

Although environmental conservation remains a key principle of Bhutan's middle path development and one of the four pillars of the country's Gross National Happiness philosophy, the fact that mineral resources are the material basis of economic development cannot be also overlooked. Mining activities deforest vast swaths of land (Figure 4), threaten ground stability, and pollute the water resources. Further, all mines in Bhutan extract minerals from an open pit, which has a particularly negative impact on landscapes, wildlife, and water systems, as they are frequently altered and polluted (Gyelmo 2021).

Figure 4: Typical mining site in Bhutan (source Google Earth).

Apart from deforestation and landscape destruction, the process of ore mining generates a large number of pollutants, which diffuse into the surrounding environment and cause water, air, and soil pollution problems (Li et al. 2017). When rainwater fills the mining pits, it produces a large amount of highly concentrated wastewater due to mineral dissolution in the collected water. Mining wastewater has a wide range of acidic and alkaline properties depending on its dissolved and suspended solid levels (Thiruvenkatachari et al. 2020). In some cases, specific ore types being mined expose the pyrite or sulfidic mineral materials, which interact with oxygen and water to form acid mine drainage (AMD) with low pH and elevated sulfate and metal concentrations (Thiruvenkatachari & Su 2017). Organic compounds, metals, heavy metals, and metalloids such as arsenic, iron, and manganese are all common contaminants. Some mining wastewater, particularly for coal, can be unacceptably saline, necessitating desalination.

With better monitoring and compliance with associated water quality license conditions, the mining industry can reduce the potential environmental impacts caused by the resulting wastewater (Northey et al. 2019). Similarly, water stored in mining pits after mining operations can be recycled and reused by treating it with efficient treatment technologies, thereby reducing reliance on freshwater, the water footprint, and the risk of wet season runoffs.

Agriculture runoff

Agriculture, which accounts for 70 percent of global water abstractions, contributes wastewater containing large amounts of agrochemicals, organic matter, drug residues, sediments, and saline drainage into water bodies at the same time (Mateo-Sagasta et al. 2017). Water pollution as a result disturbs aquatic ecosystems, human health, and hinders productive farming activities. In many countries, agricultural runoff has surpassed the extent of contamination caused by settlements and industries in degrading the quality of inland and coastal waters, primarily due to eutrophication (Mateo-Sagasta et al. 2017).

As nearly 70 percent of Bhutan's population is directly or indirectly dependent on subsistence agriculture, agriculture consumes 86 percent of the country's total water (Tariq et al. 2021). Farming is difficult in mountainous Bhutan due to the rugged topography and steep-sloped land, which is further hampered by the loss of topsoil and added nutrients. Bhutan's land degradation is a major concern, with the country losing more than 3 tonnes of topsoil per hectare each year, resulting in a loss of land productivity (UNDP 2019). Sustainable Land Management (SLM) interventions, such as bench terracing and hedgerow plantation, are among the new practices adopted in Bhutan to improve soil fertility, as the terraces prevent topsoil from being washed away by rain (UNDP 2019). Surface water pollution can be reduced to some extent when agricultural runoff is limited through such sustainable land management practices. Similarly, other best practices such as check dams, contour stone bunds, and plantation of bamboo trees could be scaled up and incorporated into government policy to prevent soil erosion and reduce agricultural runoff volumes.

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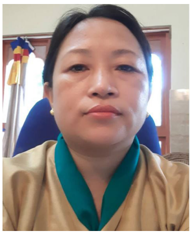

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