

Chapter 14

Gray Water Footprint and Water Pollution

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Abstract This chapter starts with the description of water pollution in relation to its use, the interrelation of contaminants with the water environment and the existence, as well with the lack of pollutant concentration regulations in water and its environment. It is described how the study of pollutant dynamics and decision-making for its control in the water environment can be performed with greater success when considering the entire basin. The gray water footprint concept is summarized, defined by Hoekstra/Chapagain (2008), and then some situations are discussed where, from the point of view of the author, this tool may use to better understand the impact of direct and indirect pollution caused by men and to obtain useful values for decision-making regarding pollutant loads and uses of water in basins.

Keywords Hydrologic basins · Water pollution assessment · Water pollution regulation · Grey water footprint · GWF application areas

14.1 Introduction

Pollutant accumulation into water bodies may represent a risk to biota and water as a source of supply for various uses. Many pollutants have high affinity to the mineral components or organic matter in sediment and soil so that the interaction of these solids with contaminated water can cause a cumulative process of contaminants. Other processes, that alter water features, can reverse this balance, causing the release of contaminants accumulated in sediment or soil. Thus, sediment and soil act as contaminant reservoirs, from where they can be released back into the water and become available, accumulate in the biota, or be eliminated through biological or photochemical degradation processes, form degradation products or metabolites, or be completely mineralized.

Water quality requirements vary according to the use it is given, including aquatic life protection, recreation, and water as a supply source for different uses. Sediment quality is almost always related to ecological health. Although the interactions

between water and sediment are dynamic processes, which vary according to the different conditions of the water body, there are currently no regulations that relate quality of sediment and water.

14.2 Hydrologic Basins

The “Hydrologic Basin” is the basic unit for water management in Mexico and, therefore, for the assessment of water. It is defined as the surface that receives water, which flows to a collector, whether a canal or a river. “Hydrographic basins” are separated from each other by water catchment divisions. When the water comes from underground streams that are independent of surface structure, hydrologic basins are distinguished from topographic ones. This is particularly the case in limestone regions, where the hydrologic basin area often exceeds that of the hydrographic basin (Mauch et al. 2000).

When contaminants are introduced into a river, they are transported and transformed by physical, chemical, biochemical, and biological processes. Therefore, to determine the impact of these substances on water, the processes of transport, their transformation, and rates at which they are removed must be known (Chapman 1996).

Strategies for assessing water quality in Mexico are related to the different uses it is given, considering both ecosystems and society. It must be considered that there may be multiple uses of water in a hydrologic basin and that each use involves different requirements for its quality, which can lead to conflicts between different users. Ideally, water quality must meet the most demanding requirements for use as is the provision of good quality water for its purification and healthy ecosystems. It should be the responsibility of upstream users to ensure adequate water quality for downstream users in the same hydrologic basin.

14.3 Water Pollution

Water does not exist in pure form in nature given its ease to dissolve chemical substances. However, the main causes of water pollution are various human activities. Water pollution usually refers to the presence of contaminants coming from anthropogenic sources, causing it to be unfit for human consumption or to sustain aquatic life; but some natural phenomena such as volcanic activity, storms, or earthquakes can also cause changes in water quality.

Water pollution occurs when pollutants are discharged from individual and diffuse sources to water bodies, causing physical, chemical, and biological changes that produce adverse effects on humans and ecosystems. Individual sources of pollution are those that enter the water body by a pipe or channel discharge; they include municipal and industrial wastewater discharges, with or without

pretreatment, or urban runoff drains. Diffuse sources refer to pollution that does not come from a single source; they are the accumulation of pollutants from runoff of areas with different land uses and can cause water eutrophication, which refers to the increase in the concentration of nutrients, which in turn can increase the primary productivity in water bodies, causing anoxic conditions and decreasing water quality, affecting the ecosystem and other water uses.

Despite the importance of water and sanitation, worldwide there is a population of 2.6 billion people without access to basic sanitation while 884 million have no access to drinking water (UNICEF/WHO 2010). The substances that contaminate water are organic and inorganic chemicals as pathogens. Some are found naturally in water bodies and their concentration is key in determining their natural origin or classification as a pollutant. Many chemicals are toxic and some of them are degradable, thus consuming the oxygen dissolved in water. These substances can be man-made or have natural origin, such as plant residues.

Pathogens can cause diseases in humans or animals. Each year, 1.4 million children die from diarrheal diseases, 88 % of them related to contaminated water, inadequate sanitation, or insufficient hygiene (UNICEF/WHO 2009). In addition to this, each year 860,000 children die from malnutrition, 50 % of them due to diarrhea or infections, also caused by contaminated water, inadequate sanitation, or insufficient hygiene (De Onis et al. 2004). Children are more vulnerable than other population groups to diseases caused by exposure to chemicals, which in total cause 4.9 million deaths annually, some of them from exposure to contaminated water (Prüss-Ustün et al. 2011).

14.4 Regulation and Assessment of Pollution in Water Bodies

Water bodies are exposed to thousands of pollutants from industrial, pharmaceutical, agricultural, and natural sources. Therefore, countries have implemented programs to regulate water quality to prevent contamination by substances with unacceptable concentrations.

Water politics in our country establish the following priorities: 1. To have sufficient water with appropriate quality, 2. To recognize the strategic value of water, 3. To use water efficiently, 4. To protect water bodies, and 5. To ensure sustainable development and environmental conservation (Conagua 2008).

The National Water Law (DOF 2012) states that water quality requirements depend on its use and that human consumption has priority over other uses. The standards NOM-127-SSA1-1994 (Permissible limits of quality and treatments to which water should be subjected to purification) and NOM-179-SSA1-1998 (Monitoring and evaluation of quality control of water for human use and consumption, distributed by public supply systems) set limits for human use and consumption. For their part, the NOM-001-SEMARNAT-1996 sets limits for

discharges to waters and domestic goods, and NOM-002-SEMARNAT-1996 sets limits for discharges to urban and municipal sewage systems. The ecological criteria for water quality, CE-CCA-001/89, include limits for urban public use, recreation with direct contact, irrigation, livestock, and aquatic life.

Hansen/Corzo (2011) highlight the priorities and needs for the evaluation of pollution in hydrologic basins, referring to the water management policy, with its laws and regulations, in Mexico. They mention that the National Programme for Monitoring and Assessing (Proname in Spanish) persistent and bioaccumulative toxic substances (PBTS) is just being implemented; hence, there is no inventory or even formal assessments of exposures and risks associated with these substances. They propose a methodology for selecting substances in a PBTS monitoring program for water (Oswald-Spring 2011).

14.5 Gray Water Footprint Definition

The term gray water footprint (GWF) was introduced by Hoekstra/Chapagain (2008) to indicate the degree of water pollution. It is defined as the water volume required to assimilate a contaminant to acceptable water quality standards as defined in the criteria and standards.

Unlike “virtual water,” GWF is a multidimensional indicator, which not only refers to the volume of contaminated water but also the place where it occurs (Hoekstra et al. 2011). It indicates the degree of water pollution in a particular process, site, or hydrologic basin. Although it is defined as the water volume required to assimilate the pollution load, it is calculated as the water volume required to dilute pollutants until concentrations are below the limits established in water quality standards.

GWF is calculated by dividing the amount of pollutant (L , mass/time) by the difference between the maximum allowable concentration for this pollutant (C_{max} mass/volume) and its natural concentration in the receiving water body (C_{nat} , mass/volume) (Hoekstra et al. 2011):

$$GWF = L / (C_{max} - C_{nat})$$

The natural concentration of dissolved substances in water systems is the concentration that it would have in the absence of human intervention. Assimilative capacity of water with respect to a pollutant depends on the difference between the desired concentration (e.g., the maximum allowable concentration) and the contaminant natural concentration.

GWF can be determined directly from pollutants that are discharged into surface water bodies. However, when contaminants are discharged to the ground, as in the case of fertilizers or pesticides, a fraction is attenuated in the soil, while others drain superficially or infiltrate the soil into groundwater. In these cases, the pollution load and the corresponding GWF is the sum of the infiltrated and drain fractions.

14.6 Application Areas

As with blue and green water footprints, GWF can be calculated for a product, a person, or an area. GWF of a product indicates the water volume that pollutes the entire production chain. Thus, the specific processes where GWF can be reduced can be identified. This allows to inform consumers about the water volume contaminated during product manufacture and serves to know how much contaminated water is bought or sold when importing and exporting products.

On the other hand, GWF of a consumer, a consumer group or a company, serves to illustrate which process pollutes more water. Usually food has the greatest impact on water footprint (Dourte/Fraisse 2012).

An area can represent a municipality, a hydrologic basin or a country. GWF allows to estimate the contaminated water inside and outside the area. This allows to calculate the purchase and sale of contaminated water from product trading. GWF of culture allows to compare agricultural systems in different regions, different agricultural practices and management systems.

Currently, the concept of GWF has been used to calculate the water footprint resulting from contamination by total nitrogen and phosphorus of the major hydrologic basins in the world (Liu et al. 2012). These authors found high levels of pollution in rivers of tropical and subtropical areas and they also found that the main problems for nitrogen and phosphorus are located in the Southern Hemisphere. The results suggest that the degree of contamination of rivers with nutrients is increasing.

Next, there are some thoughts for other applications of this tool.

14.6.1 *GWF of Reactive Contaminants*

Currently, there is a lack of methods to describe the destiny of other pollutants in water systems, such as reactive transport processes that include transformations by physical, chemical, biological, and biochemical processes or “natural attenuation” of these substances.

“Natural attenuation” of contaminants refers to their concentration decrease by processes such as advection, dispersion, dilution, diffusion, volatilization, ion exchange, formation of complexes, abiotic transformation, and biological processes such as biodegradation and incorporation in the food chain (USGS 2012). Most contaminants tend to be adsorbed in solids suspended in water or in sediment particles, causing resistance to biodegradation, reducing volatilization, and affecting accumulation in aquatic organisms. The solubility of contaminants determines the degree of partition between sediment, interstitial water and water column. As water is a polar solvent, polar and ionic compounds dissolve more in it than nonpolar contaminants, which have a greater affinity to organic matter suspended in the water column or deposited in the sediment. Biodegradation rate indicates how fast the

substance is decomposed by biological processes. Although the bioaccumulation factor is not a chemical property, it helps to estimate the degree of incorporation of contaminants to the tissue of aquatic organisms. These processes influence the attenuation of contaminants and can be used to predict their transport, environmental fate and the GWF they cause.

Transport mechanisms of contaminants adsorbed in sediment or incorporated into organic matter depend on the type of water body, flow rate, and sediment characteristics. Contaminants associated with sediment and organic matter are transported by suspension or bottom sediment transport. Clay and silt-size particles are generally transported by suspension in the water column as suspended solids. Dissolved contaminants are transported with the water, while immiscible liquid contaminants float or sink, depending on their density. When the latter have lower densities than water, they tend to float and become susceptible to volatilization or photolysis. When immiscible contaminants are denser than water, they are transported near the bottom and can be incorporated into the sediment phase.

Biological processes also affect the stability of contaminants. These processes include sediment bioturbation and bioaccumulation. The former generally causes sediment oxidation, increasing degradation rate of organic contaminants. Bioaccumulation occurs in organisms when the absorption rate is greater than the metabolic removal, causing storage of the contaminant in the body of the organism. Biomagnification occurs in upper parts of the food chain when the contaminant is ingested by consumption.

14.6.2 GWF Comparison by Different Land Uses in a Hydrologic Basin

Diffuse sources of pollutants from runoff of soils with different use generally represent the largest pollutant source in hydrologic basins. Examples include the contributions of nitrogen and phosphorus from agricultural soils and gardens. Apart from the use of fertilizers, nutrients in food for humans and animals are imported to basins; pollutants generated outside basins can be deposited through atmospheric transport and deposition and it has been found that this mode may represent the biggest nitrogen source in hydrologic basins (Zhu et al. 2008).

Changes in land use affect not only polluting sources but also hydrology. In jungle basins, rainfall infiltrates through soil, water is lost by evapotranspiration or aquifers are recharged, which then feed rivers and streams. However, in agricultural catchments, surface runoff predominates. In urban basins, surface runoff is even more important due to the existence of impervious surfaces, reduced evapotranspiration and storm drainage systems, which carry the runoff water to rivers and streams. This situation also alters pollutant export due to the lack of biogeochemical attenuation and the related contaminant retention. The runoff path determines the contact time between pollutants, vegetation and soil, where biogeochemical

processes minimize or remove them. When the rate is high, the contact time is generally low and contaminants are transported to rivers and streams with minimal removal.

14.6.3 GWF Application to Describe Advantages and Disadvantages of Transfers Among Hydrological Basins

Water deficit can be caused by natural events or human activities. Specific geographical or hydrological conditions can prevent water supply to meet demand. When water is overexploited to the point that it is not recharged in sufficient quantity or quality and when it is interrupted or has an inequitable distribution among users, it can cause social conflicts. Water deficit may result from overexploitation of the upper parts of hydrologic basins due to the construction of dams, water transfers to other basins and extraction for irrigation, thus altering downstream natural flow of rivers and water availability in quantity and quality (Pittock et al. 2009). Water quality degradation, expertise, and user conflicts can also cause water deficit situations (UN-Water 2007).

It is important to consider that water footprint of a city includes water supply infrastructure, drainage and wastewater treatment and transfer systems between hydrological basins (Engel et al. 2011).

14.6.4 GWF as Warning System of Pollution of Water Bodies

GWF values in a hydrologic basin indicate the violation degree of the criteria or limits of water quality. UNEP/CEOWM (2011) mention that indicators describing economic costs of gray water footprint have not yet been developed.

However, Hansen et al. (2007) developed a tool to facilitate the water value estimate in Lake Chapala under various scenarios, based on modules that describe water behavior in volume and quality, ecological values, and production.

It contains a hydrological component that allows to create scenarios of lake water extraction, reaching different equilibrium volumes (van Afferden/Hansen 2004). The environmental component considers environmental services as the lake capacity to assimilate pollutants, water pollution effects on its purification costs to supply the suburban area of Guadalajara, the loss of agricultural soil because of salinization when irrigating with lake water with high salt concentration, and degradation of forests and soils in the basin of the lake when the water level decreases.

14.7 Conclusion

GWF definition was revised and new applications of this tool to describe water pollution were proposed. It is proposed to include reactive transport processes and natural attenuation for better assessment of GWF of pollutant loads; it is suggested to use this concept in land use planning, which reduces GWF; its use is considered to describe advantages and disadvantages of transfers among hydrologic basins and, finally its use is proposed as a warning system of pollution of water bodies.

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