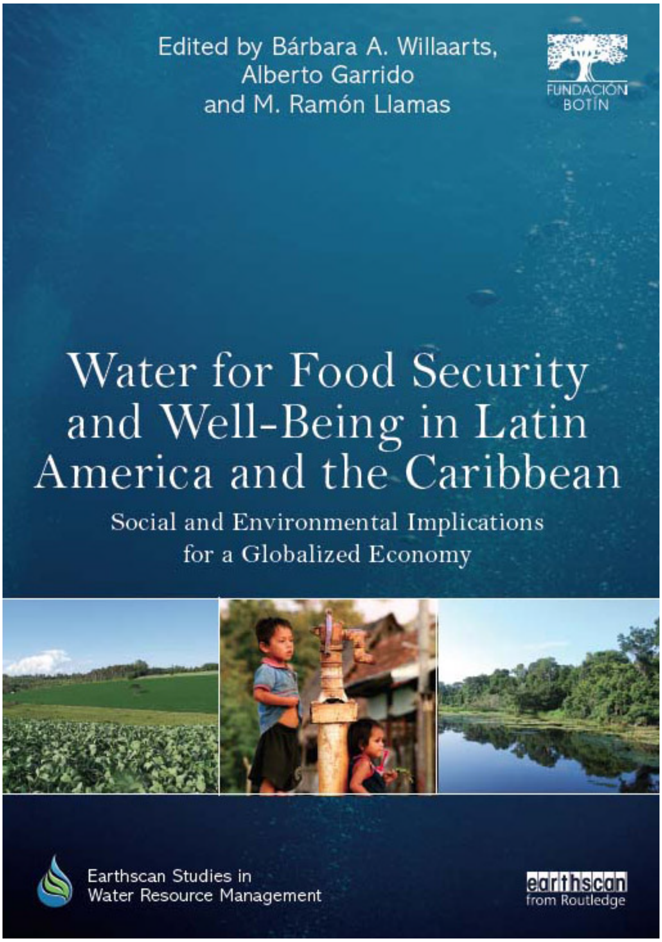

Chapter 2

Water resources assessment

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2

WATER RESOURCES ASSESSMENT

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Highlights

- Latin America boasts some of the world's largest rivers, lakes and aquifers. Overall, these store and yield more water per person than any other region in the planet.
- Climatic variability, together with urbanization patterns, generates strong asymmetries between water demands and water availability across the region. This results in severe water stress in some of the most economically dynamic areas.
- Despite the abundance of surface water resources, groundwater use is gradually increasing. This is partly because of the growing costs associated with surface water storage and treatment, and partly because the advantages of groundwater use are becoming better known and accepted.
- Water quality poses a major cause for concern across the region. Pollution management is complicated by financial constraints, as well as by the absence of adequate monitoring programmes and wastewater treatment facilities.
- A much needed step towards protecting the environment and the health of water-related ecosystems is to implement integral management systems that cater for the maintenance of forests, wetlands, lagoon systems and coastal estuaries.
- Latin American water resources face threats derived from population growth, urbanization, changes in land use patterns and climate change.

2.1 Introduction

The Latin America and Caribbean region is water-abundant. It boasts some of the world's largest rivers, lakes and aquifers, which yield more water per person than any other region in the planet. However, water is irregularly distributed in time and space due to climatic variability. While heavy rainfall takes place across the year in the Amazon rain-forests, it barely ever rains in the Atacama Desert. Besides, the majority of the population is concentrated in cities. This generates strong asymmetries between water demands and water availability. Largely as a result, many freshwater ecosystems are endangered by a wide array of different pressures. Adaptation to climate change, universal access to water and sanitation services, pollution control and an integrated approach to transboundary water resources management are the main challenges ahead.

2.2 Water availability

Latin America only accounts for 13% of the total emerged lands and 6% of the global population, but it produces over one-third of the world's total runoff (Table 2.1). This region is home to some of the world's most important rivers, including the Amazon, Parana, Orinoco, and Magdalena, as well as some of the largest lakes. Take for instance the Titicaca Lake in Bolivia and Peru, the Nicaragua Lake, and Lake Chapala in Mexico. Surface water accounts for over 80% of Latin America's renewable resources, but the region is also endowed with abundant groundwater (Table 2.2). This includes the Guarani aquifers which are shared by Argentina, Brazil, Paraguay and Uruguay. Groundwater also represents a strong environmental element, discharging an estimated 3,700km^3/year into Latin America's rivers. From an economic viewpoint, groundwater storage is particularly important because it remains relatively stable over time and is comparatively better protected from domestic, agricultural and industrial pollution sources (Rebouças, 1999).

Looking at these facts one would think that water scarcity is hardly a matter of concern in Latin America. Overall figures are, however, misleading, as Latin America is diverse within itself. The irregular distribution of water, in both time and space, natural quality problems and an asymmetric occupation of the land imply that the above situation is not representative of all basins across the region. As a result, some are subject to mounting pressures, if not already confronted with water scarcity. For instance, the basins of the Gulf of Mexico, the South Atlantic and the Río de la Plata cover some 25% of Latin America's territory and are home to more than 40% of the population, but contain just 10% of the available water resources (WWC, 2000). Meanwhile, about 53% of the region's total renewable water supply comes from just the one river, the Amazon.

Table 2.1 Approximate amount of annual precipitation, evaporation and runoff per continent in relation to the water footprint

REGION	SURFACE (1000 km^2)	POPULATION (million)	AVERAGE RAINFALL (mm)	TOTAL RAINFALL (km^3)	AVG.EVAP. (mm)	TOTAL EVAP. (km^3)	RUNOFF (km^3)	WATER FOOTPRINT (km^3)	WATER FOOTPRINT (% of rainfall)
Asia	43,820	4,216	650	28,500	410	18,000	10,500	4,850	17.0
Africa	30,370	1,072	740	22,500	630	19,000	3,500	1,400	6.2
North America	24,490	346	800	19,500	470	11,500	8,000	970	5.0
South America	17,840	596	1,600	28,500	900	16,000	12,500	1,130	4.0
Europe	10,180	740	820	8,400	590	6,000	2,400	1,250	15.0
Oceania	9,010	37	440	4,000	400	3,500	500	45	1.1

Source: Martínez-Santos et al. (2014)

Table 2.2 Renewable water resources and storage capacity in selected countries in Latin America

COUNTRY	RENEWABLE SURFACE WATER (km³/yr)	RENEWABLE GROUNDWATER (km³/yr)	RESERVOIR STORAGE CAPACITY (km³)
Belize	19	8	–
Mexico	409	139	180
Costa Rica	75	37	–
El Salvador	25	6	–
Guatemala	103	3	–
Honduras	87	39	9
Nicaragua	193	59	0.5
Panama	145	21	–
Guyana	241	103	–
Suriname	122	80	22.7
Bolivia	596	130	0.3
Colombia	2,132	510	–
Ecuador	424	134	–
Peru	1,913	303	3.9
Venezuela	1,211	227	164.1
Brazil	8,233	1,874	513.1
Argentina	814	128	–
Chile	922	140	4.7
Paraguay	336	41	37.7
Uruguay	139	23	18.8
Total	18,139	4,005	955

Source: FAO (2013)

Brazil alone generates 37% of Latin America's surface runoff, while no other country reaches 10%. In contrast, arid zones have no surface runoff, except during rare and extreme rainfall events. Rainfall averages 1,600mm/year across the region (Figure 2.1), but ranges from 20mm/yr in the Atacama Desert to over 2,000mm/yr in the mountains of southern Chile (Box 2.1). Rainfall is also characterized by its strong seasonal component. Take for instance Central America, where about half of the precipitation occurs from August to October, and only 7% between February and April. In South America, 35% of stream flows take place between May and July, whilst only 17% corresponds to the November–January period (Shiklomanov, 1999).

Seasonal variability is influenced by cyclic atmospheric phenomena known as El Niño and La Niña. Both are associated with major temperature fluctuations in the tropical Pacific Ocean. El Niño is an abnormal warming of the sea surface temperature, whereas La Niña is a cool ocean phase. During El Niño, droughts take place along the Pacific coast of Central America. Conversely, higher precipitations occur in the Caribbean coasts. In South America, El Niño generates the opposite response. In the Pacific and Southern Atlantic coasts, rains become more intense, whereas in the tropical Atlantic coast drought frequency increases. The cold phase La Niña causes different patterns. Rain events increase along the Pacific coast of Central America. The same occurs with the frequency of hurricanes in the Caribbean Sea. Along the Southern Pacific coast of South America, droughts tend to become more frequent and temperatures drop. Overall, El Niño events are more frequent than La Niña. In the last decades a higher frequency of El Niño events has been recorded, leading some experts to contend that this might be related to climate change (Magrin et al., 2007).

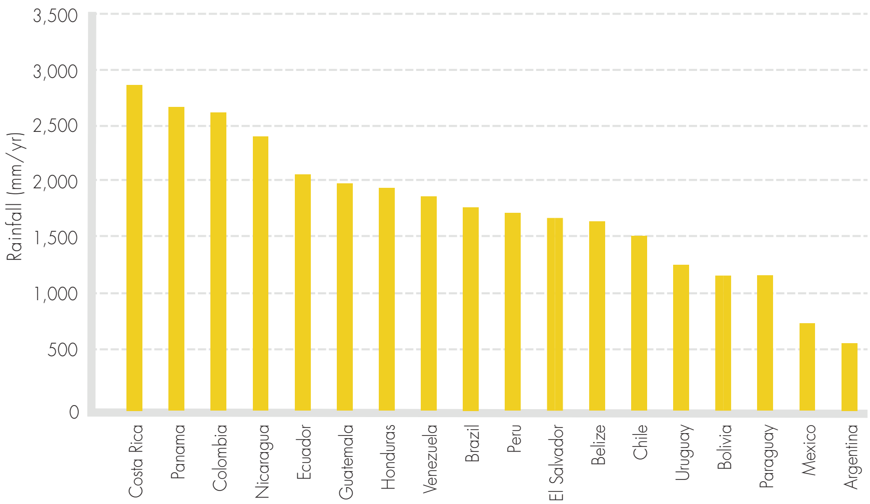

Figure 2.1 Long-term annual rainfall in selected Latin American countries. *Source: FAO (2013)*

Overall, water availability per capita has steadily decreased over the last decades, mostly due to the fact that the population has grown from 420 to 550 million inhabitants between 1992 and 2011. Currently, water availability ranges from Mexico's 3,500m^3/person/yr to Peru's 55,000m^3/person/yr (Figure 2.2). In other words, all of Latin America's countries are safely located above Falkenmark's 1,700m^3/person/yr threshold for water scarcity. The regional average is around 25,000m^3/person/yr, well above Europe's 8,500m^3/person/yr or Asia's 3,600m^3/person/yr. However, while most standard indicators underline Latin America's privileged position in terms of water resources, water scarcity does occur at the regional scale. This is because water resources are mostly located in the inland, while urbanization and land development followed the path of decisions made in colonial times. Thus, cities and economic activities were concentrated either near the coast to facilitate exports to Spain and Portugal, or close to the main cities of the Aztec and Inca empires to take advantage of the abundant labour (Mejía, 2010). In practice, this means that large countries such as Venezuela, Mexico and Peru show strong asymmetries between water availability and population density (Box 2.2).

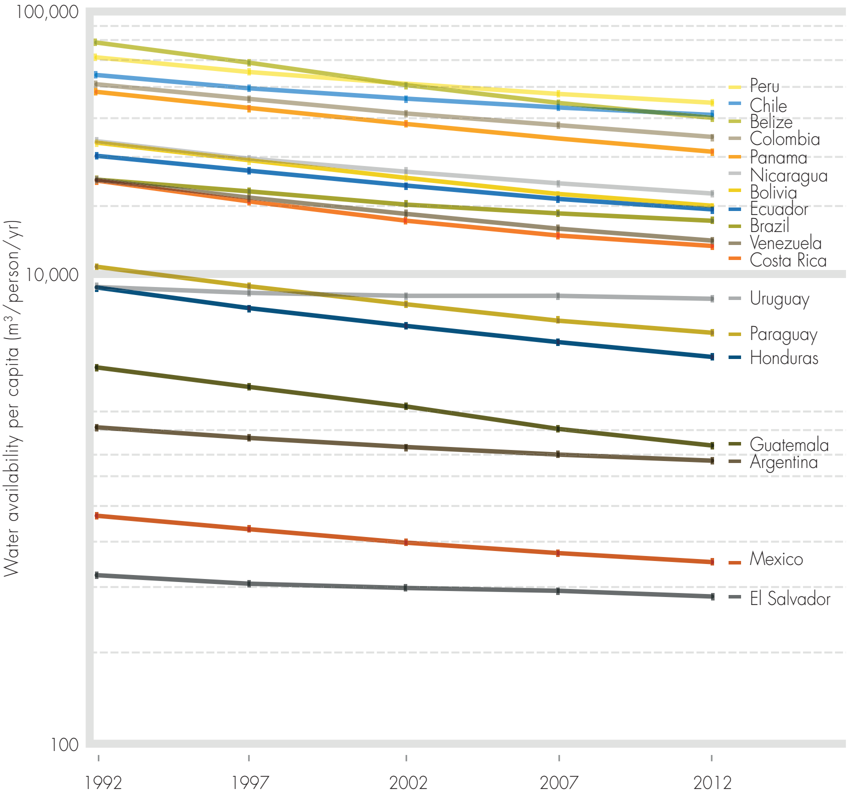

Figure 2.2 **Renewable resources per capita over the last twenty years in selected countries.**
Source: FAO (2013)

Box 2.1 Large countries are naturally diverse: rainfall variability in Chile

Although Latin America is best described as a water-rich region, average water availability is decreasing. Chile is an excellent example since the country's unique geography, including a number of short river valleys running from the Andes to the Pacific Ocean, provides a variety of climatic conditions. Two primary mountain ranges, the Andes and the Coastal Mountains, span the length of Chile and provide the limits between the coastal plain and the central valley. Average precipitation ranges from near zero in the north to about 2,000mm/yr in the south (Figure 2.3).

The rainy season is in winter, from June to September, and much of the precipitation is stored in the snowpack of the Andes. Water flows in most river basins have a mixed origin, since waters come from winter precipitations and summer snow melt, presenting highest flows in summer (November–February) due to said snow melt, and pronounced reductions in winter (from April to June). Additionally, rainfall fluctuations show greater variability in the arid and semi-arid north (between the Arica-Parinacota Region and the Coquimbo Region). South of 37°S latitude, rainfall becomes more uniform. Therefore, the hydrological regime of Chile is rather irregular.

Within the global context, Chile as a whole may be considered privileged in terms of water resources. The total runoff is on average equivalent to 53,000m^3/person/yr (World Bank, 2011a), a value considerably higher than the world average (6,600m^3/person/yr). However, there exist significant regional differences: north of the city of Santiago, arid conditions prevail with average water availability below 800m^3/person/yr, while south of Santiago the water availability is significantly higher, reaching over 10,000m^3/capita/yr.

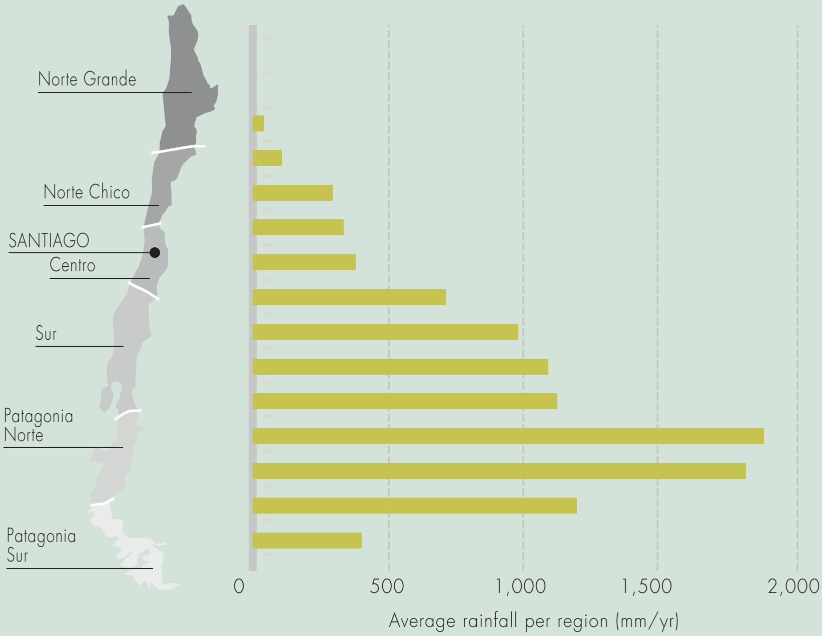

Figure 2.3 Regional rainfall variability in Chile. *Source: modified from Donoso (2014)*

Box 2.2 Water and population asymmetries: Mexico, Peru and Venezuela

Many Latin American countries show a significant disparity between water resources abailavility and the population distribution. Take for instance Mexico. In this country, 77% of the population, 84% of the economic activity and 82% of the irrigated land is located in the central and northern plateaus, some 1,000 metres above sea level. In contrast, 72% of water availability occurs in the south and below that altitude. Another example is Venezuela, where 90% of population and economic activity is located in the north of the country with less than 10% of water availability. In contrast, most of the water availability is found south of the Orinoco River away from the northern coast. But perhaps the most startling case is Peru. Rainfall in the Peruvian part of the Amazon basin, which is home to 30% of the country's population, accounts for 97.5% of the country's surface water. Conversely, the Pacific basin hosts 65% of the population and produces only 1.8% of the water resources of the nation. Rainfall in the capital, Lima, is 10mm/yr or lower. This asymmetry makes the most economically dynamic regions of Peru severely water stressed.

Table 2.3 Water availability in Peru's hydrographic regions

BASIN	AREA (1,000km^2)	RAINFALL (mm/yr)	WATER AVAILABILITY (hm^3/yr)	WATER AVAILABILITY (% of total)	POPULATION (million)	POPULATION (% of total)	WATER AVAILABILITY (m^3/person/yr)
Pacific	279.7	274	37,363	1.8	18,315,276	65	2,040
Amazon	958.5	2,061	1,998,752	97.7	8,579,112	30	232,979
Titicaca	47.2	814	10,172	0.5	1,1326,376	5	7,669
Total	**1,285.20**		**2,046,268**	**100**	**28,220,764**	**100**	**72,510**

Source: Kuroiwa et al. (2014)

Development of non-conventional water resources remains relatively uncommon. Take for instance desalination. Peru and Chile are Latin America's premier users of desalinated seawater, on which they rely for specific developments. Most of the investments in Chilean desalination projects are located in the dry north of the country. These have been designed to underpin mining activities, as well as urban supply. In coastal Peru, desalination provides water for the industrial sector, households and agriculture.

Drinking water and sanitation services reach a relatively large share of the Latin American population. Total coverage amounts to 87% in the case of water supply and 78% in the case of sanitation. However, these figures hide an uneven distribution. For instance, important variations in drinking water coverage are observed across countries.

In Brazil, Mexico, Costa Rica, and Colombia, this figure exceeds 90%, whereas in Peru it is lower than 75%. In terms of rural areas, only Mexico and Costa Rica exceed 85%. Few other countries reach 60%. Sanitation systems are largely insufficient to meet demands. Coverage is similar to that of water supply, exceeding 80% in some urban agglomerations, but rural areas rarely ever reach 50%. Chile poses a remarkable exception, having increased its water services dramatically over the last decade (World Bank, 2011a). Currently, it exceeds 95% in terms of water supply and sanitation coverage in urban areas and 60% in rural regions. The vast majority of sewage goes untreated, thus generating downstream pressures. Less than 40% of sewage is treated in countries such as Argentina, Brazil or Colombia. All these issues will be discussed in more depth in Chapters 6 and 8.

2.3 Water uses

The available water data mostly refer to water withdrawals within each country. In other words, it does not distinguish between water use for production, for domestic consumption or for producing goods for exportation, and exclude virtual water. Moreover the lack of sufficient data on climate, soils and growing seasons in most countries is often the factor limiting the ability to produce meaningful information on consumptive uses. This is most often due to inadequate databases or to the absence of data. In this sense, it is important to distinguish between consumptive uses and withdrawals. Not all water withdrawals result in consumptive water use. This is due to the fact that a large share of withdrawn waters goes back into the hydrological cycle in the form of pipeline losses, wastewater or irrigation returns. On the other hand, not all consumptive uses stem directly from withdrawals. Rain-fed agriculture, for instance, represents a significant fraction of the total water use without being responsible for any direct extraction from the water cycle.

Despite these clarifications, which apply to water figures across the world, Latin America is known to be less water-stressed than other regions (Figure 2.4). Unlike Asia, where a significant part of the water resources are already in use, a large share of Latin America's waters remains untapped. Figure 2.5 shows the distribution of water withdrawals per sector and sub region in Latin American and Caribbean regions. Agriculture comprises irrigation and livestock. Consumption due to water uses such as hydropower, navigation, fishing or recreation is considered negligible for practical purposes.

Rainwater can be split into 'green' and 'blue' water. Green water refers to the share of rainwater that stays in the soil rather than running off or recharging groundwater. In other words, green water is that which underpins rain-fed agriculture. On the other hand, blue water refers to the water in rivers, lakes, reservoirs, ponds and aquifers. Irrigated agriculture uses blue water as a supplement to rainfall. As will be discussed in Chapters 6 and 7, green and blue water have different implications for the purpose of water and food security.

The water footprint provides a useful indicator of water use. As shown in Table 2.4, green water agriculture accounts for the largest share of the region's water footprint (Mekonnen and Hoekstra, 2011). Blue water follows in magnitude, well ahead of industrial and domestic use. Irrigation efficiency is however low. Efficiency is measured by taking into account the difference between the volume of water captured and the actual delivery to the farms, and is mostly dependent on the type of irrigation system. In many Latin American countries, irrigation efficiency ranges between 30% and 40% (San Martín, 2002). Inefficient irrigation technologies do not necessarily imply a wasteful water use, as the losses return to the hydrological cycle. However, these rank among the main causes behind the loss of fertile soils and are largely a consequence of policies that promote production. This represents one of the main threats to agricultural sustainability across the region.

Table 2.4 Blue and green water footprint of countries in the Latin America and Caribbean region (those with more than one million inhabitants). All consumption figures are rounded to the nearest decimal.

COUNTRY	POPULATION (million)	CONSUMPTION OF AGRICULTURAL PRODUCTS				CONSUMPTION OF INDUSTRIAL PRODUCTS		DOMESTIC WATER CONSUMPTION
		INTERNAL (hm^3/yr)		EXTERNAL (hm^3/yr)		INTERNAL (hm^3/yr)	EXTERNAL (hm^3/yr)	(hm^3/yr)
		GREEN	BLUE	GREEN	BLUE	BLUE	BLUE	BLUE
Argentina	37.1	47,746	3,258	1,298	146	116	61	491
Bolivia	8.4	25,764	377	2,489	124	4	4	18
Brazil	175.3	288,345	8,498	27,981	2,075	420	147	1,202
Chile	15.5	6,994	2,101	5,071	278	93	32	142
Colombia	40.1	35,863	1,386	9,101	716	16	33	539
Costa Rica	4	2,725	148	1,381	187	12	11	79
Cuba	11.1	13,194	831	1,944	130	47	9	156
Dominican Rep.	8.9	6,590	826	3,263	211	2	13	109
Ecuador	12.4	17,175	1,440	2,464	134	33	12	212
El Salvador	5.9	3,441	42	1,482	215	7	7	32
Guatemala	11.4	8,137	149	1,553	202	10	13	13
Haiti	8.7	6,809	225	1,230	434	0	2	5
Honduras	6.3	5,754	113	777	172	2	4	7
Jamaica	2.6	2,162	45	1,510	164	3	6	14
Mexico	99.8	83,841	8,654	65,986	8,475	135	358	1,359
Nicaragua	5.1	3,498	134	536	99	1	4	19
Panama	3	2,226	54	928	95	1	8	55
Paraguay	5.4	9,673	214	14,	59	2	6	10
Peru	26.2	13,142	3,299	8,050	404	74	18	168
Trinidad & Tobago	1.3	0	1,588	115	2	4	21	1,590
Uruguay	3.3	177	1,286	13	2	8	8	1,268
Venezuela	24.6	21,551	1,194	12,985	547	16	21	381

Source: Mekonnen and Hoekstra (2011)

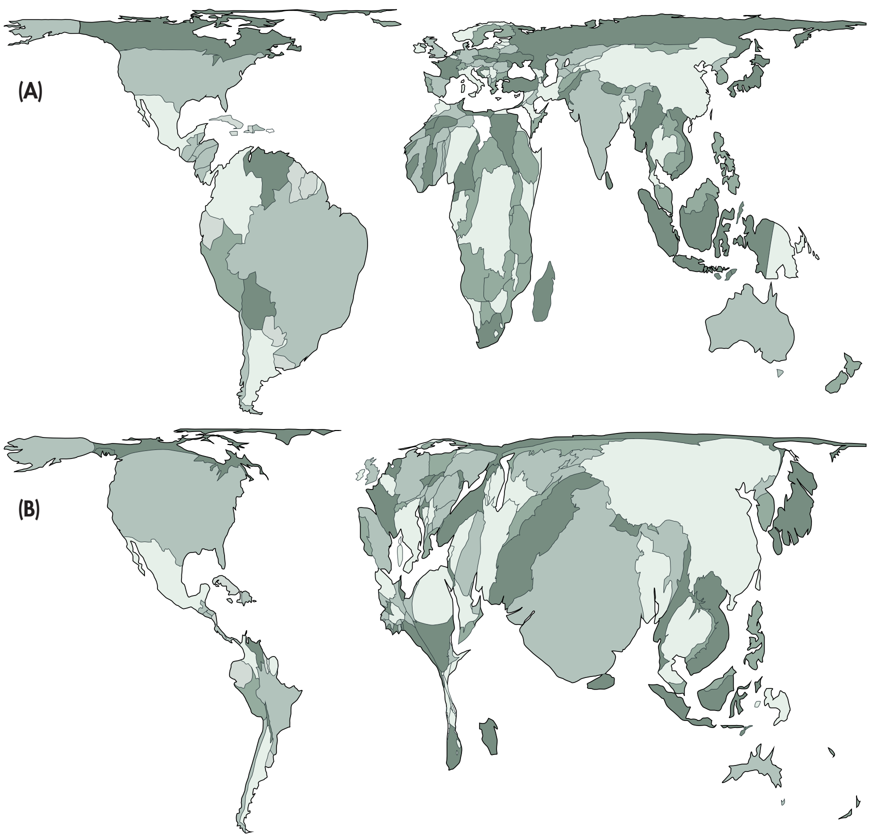

Figure 2.4 (A) Total annual rainfall (av. period 1961–1990) and (B) Water use across the world. Country areas are deformed as a function of total rainfall and water use, i.e. the larger the country is represented, the larger is its proportional share relative to other countries. Source: *modified from Sasi Group (University of Sheffield) and Mark Newman (University of Michigan)*

Industry uses relatively little water in comparison with other sectors. Water-intensive industries include food processing, pulp and paper, petro-chemical and textile sectors. These demand raw materials that are abundant in the region, creating significant multiplier effects in the local and national economies (San Martín, 2002). However, industries are responsible for environmental degradation by dumping untreated sewage into rivers and aquifers. This is particularly true of the mining industry, whose water use is relatively low, but which is considered one of the main water polluters across the region (Chapter 9).

While surface water is the preferred source of water in the region, groundwater use has increased in recent decades (Box 2.3). This is partly because of the growing costs associated with surface water storage and treatment and partly because the advantages of groundwater use are becoming more accepted (Llamas and Martínez-Santos, 2005). Most of the existing groundwater-based developments are concentrated in areas of economic or political interest, or where surface water is under stress. In contrast, fundamental hydrogeological knowledge is still under development in many parts of Latin America and there are vast regions where groundwater data are scarce or non-existent (Ballestero et al., 2007). Besides, natural water quality problems, such as elevated concentrations of arsenic, are yet to be fully assessed in countries such as Argentina, Bolivia, Chile, Ecuador, El Salvador, Mexico, Nicaragua and Peru.

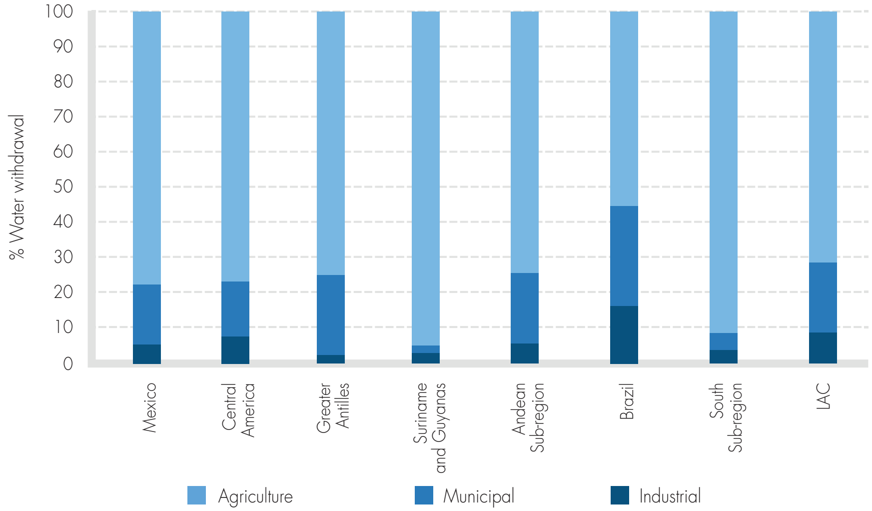

Figure 2.5 Water withdrawals per sector in the Latin American and Caribbean region. Central America comprises Costa Rica, Honduras, Guatemala, Belize, El Salvador, Panama and Nicaragua; the Greater Antilles include Cuba, Haiti, the Dominican Republic and Jamaica; the Andean sub-region refers to Colombia, Ecuador, Venezuela, Bolivia and Peru; and the South sub-region includes Paraguay, Uruguay, Argentina and Chile. *Source: FAO (2013)*

Groundwater use is especially relevant in Argentina, where it accounts for 30% of the total water withdrawals. Likewise in Chile, where it is of particular importance in the mining sector. In this country, 63% of the water used in mining and 46% of domestic water supply comes from aquifer sources. Groundwater is also the primary source for human consumption in Costa Rica and in Mexico, where groundwater accounts for 50% of industrial demands, 70% of domestic supply in cities and practically all domestic supply in rural areas.

The wealth of water resources in Latin America is reflected in the region's natural resources and the environmental services that these provide (UNEP, 2003). Natural forests cover 47% of the total surface area of the region, the northern part of the Amazon and the Guyana area being home to the largest expansion of virgin forest in the world. About 95% of the green surface corresponds to the tropical rainforests of Central America, the Caribbean and the South American sub-tropics. The remainder is located in temperate South America, primarily Argentina, Chile and Uruguay.

Box 2.3 Groundwater mining in Latin America

[By Prof Emilio Custodio (Universitat Politècnica de Catalunya, Spain)]

As is the case of diverse regions of the world, and especially in arid and semi-arid areas (Custodio, 2010, 2011), in some of the driest areas of Latin America groundwater reserves are being depleted due to intensive exploitation, at a rate much higher than they are being replenished. Groundwater mining is mostly produced in two areas. One corresponds to the hyper-arid areas of the Andean Region, comprising coastal Peru, northern Chile, southwestern Bolivia and northwestern Argentina, where groundwater renewal is scarce to nil. Groundwater abstraction takes place primarily to supply the mining of metal ores and also for brine extraction in terminal salt lakes ('salares') in order to exploit some solutes such as lithium, potassium and nitrate. The sustainability of small springs and groundwater discharges that are important for some human settlements, tourism in the area and have a significant ecological value, such as the high altitude wetlands ('bofedales'), is of special concern. Rainfall in the intermediate depressions is a few mm/yr on average and the limited replenishment is occasionally produced by some sporadic floods in gullies whose headwaters are in the highlands ('Altiplano'). Albeit rainfall in the Altiplano is scarce, a combination of almost bare soil with low humidity retention (mostly acidic ignimbrites) and rainfall retention in the seasonal snow cover favour some recharge. This manages to sustain some springs that yield water with a very long turnover time. Although mining may deplete groundwater reserves and their recovery may take centuries, there are no specific studies on groundwater reserve depletion.

Other groundwater mining areas can be found in the dry areas of Mexico, where reserves are being depleted at a rate greater than recharge, even if recharge is still significant. In this case groundwater is mostly used for irrigation, but also for mining and industrial activities. In some coastal areas freshwater in the aquifer is being replaced by laterally or vertically intruding saline water, as in Sonora's coastal aquifers. In Mexico, 104 of the existing aquifer systems are considered over-exploited by the Federal Water Authority (Comisión Nacional del Agua). Even though this is a small fraction of the existing aquifers receiving a groundwater recharge of 2,500m^3/s, these aquifers yield 800m^3/s. This amounts to 80% of used groundwater (Jiménez-Cisneros and Galizia-Tundisi (2012). About 20–25% of groundwater reserves, equivalent to171m^3/s, have been ruined, which is equivalent to about half the water used for public supply.

Some cases of groundwater resources depletion are located in the agricultural valleys of western Peru, such as Ica–Villacurí. The main problem here is the integrated management of water resources and the adequate use of the aquifer as a storage reservoir. A key issue is the mixing of freshwater and old saline water. Similar problems are found in the dry northeast of Brazil and also in the dry areas of the Argentinean Pampas (the Chaco-Pampean region), where arsenic and fluoride groundwater quality problems and deep-seated relict saline water upcoming add to periodic, non-permanent depletion of water reserves.

Other well-known groundwater problems, such as seawater intrusion in Mar del Plata and Recife, or land subsidence around Mexico City or Queretaro, are better described as they hydrodynamic results of intensive groundwater development, rather than as groundwater mining problems.

Computing environmental requirements for ecosystems is a recurrent stumbling block for academics and managers across the world. Latin America's ecosystems are no exception. Although the importance of marine and coastal flora and fauna is widely acknowledged (WSSD, 2003), there is less recognition of water needs to support ecosystems, which are themselves legitimate water users (UNEP, 2012). Ecosystems, which provide life-supporting goods and services, need water of adequate quantity and quality. Appropriate timing is also crucial in many cases. A much needed step towards protecting the environment and health of water-related ecosystems is to implement integral management systems that cater for the maintenance of forests, wetlands, lagoon systems and coastal estuaries.

Hydropower is the main non-consumptive use across the region. Take for instance Chile, whose hydropower sector has grown to account for 38% of its total energy production, and whose current flow rate is in the order of 4,190m^3/s (Ayala, 2010). This is largely explained by sustained economic growth over the last three decades, which has led to a significant increase in energy demands. About 82% of Colombia's reservoirs are devoted to energy generation, but even so, it is estimated that the country is only taking advantage of 10% of its potential for producing energy, since many of its rivers are still unregulated. Mid- and long-term developments are therefore expected, the main challenge being the need to balance environmental, social and economic constraints. Hydropower is an important water user in several other countries, including Brazil. In Costa Rica, this industry holds 82% of the water licenses.

Due to the size of many Latin American rivers, navigation is another relevant user. It is particularly important in countries such as Argentina, which operates along the Paraguay-Paraná and Alto Paraná waterways. Buenos Aires boasts South America's most important harbour. Maintaining adequate navigation conditions implies continuous work on the Río de la Plata. The Patagonian harbours, to the south of the country, have experienced notable development over the last decades in order to favour tourism.

Fishing is an important activity in many regions, allowing for the economic subsistence of local communities. It is also an established industry and features highly among tourist destinations. However, this sector has experienced setbacks in recent years due to the construction of reservoirs, over-fishing, the introduction of exotic species and contamination. Water pollution has proved particularly detrimental to recreational uses. Indeed, poor or non-existent treatment of wastewater effluents has endangered tourism and ecosystems in freshwater bodies across the region. Many Latin American lakes, including Lake Chapala in Mexico and Lake Titicaca in Bolivia and Peru, are at present severely polluted.

Water demands are leading to increasingly important conflicts between users (Chapters 11 and 15). In terms of consumptive uses, agriculture is usually displaced by the domestic and industrial sectors. In most cases, however, the environment is the net loser. There is a general consensus that contamination due to untreated wastewater, industrial and mining effluents, and widely dispersed agricultural pollutants are serious problems in many areas across the region.

2.4 Water quality

Water pollution in Latin America is caused by human activities and refers in general to the presence of pollutants from anthropogenic sources. In addition, natural phenomena such as volcanic activities, storms or earthquakes cause changes in water quality. Pollutants may cause water to be unfit for human consumption or to sustain aquatic life.

Water quality is associated with the use it is given. García (2006) explains that a water body is polluted when it contains substances that make it inadequate for certain uses, and contaminated when it contains substances that endanger human health. Therefore, a water body may be polluted and not contaminated. Conversely, if it is contaminated, it is polluted. Due to its capability to dissolve chemicals, natural and residual waters, as well as water for human consumption, always contain dissolved substances. Depending on their concentrations, all pollutants have the potential to become contaminants.

Water pollutants include both organic and inorganic chemical substances as well as pathogens. These substances can be man-made or of natural origin, such as plant residues. Some are found naturally in Latin American water bodies and their concentrations may assist in defining their natural origin or classification as contaminants. Many chemicals are toxic and some of them are biodegradable, thus consuming oxygen dissolved in water.

In Latin America pollutants are frequently discharged into water bodies from both point and non-point sources, producing physical, chemical, and biological changes that cause adverse effects in humans and in ecosystems. Point source pollutants are those that enter water bodies through discharge pipes or channels. They include municipal and industrial wastewater discharges, with or without previous treatment, and urban runoff drains. Diffuse source pollution does not come from a single source but is the accumulation of pollutants after runoff from areas with diverse land uses. This type of pollution is the main cause of water eutrophication, which refers to the increase in concentration of nutrients. This, in turn, may increase the primary production in water bodies, causing anoxia and decreased water quality, affecting ecosystems and other water uses.

Land uses in Latin American watersheds and water uses for human purposes introduce changes in the natural cycle of precipitation, absorption, water flow, infiltration, and evapotranspiration. While part of the used water is consumed, part is returned to the water bodies but most often with different quality. While agricultural use return flows contain salts, nutrients, pesticides, and organic matter, industrial discharges contain organic matter, metal ions, chemical residues and salts and what's more, at higher temperatures. Domestic discharges carry grease, detergents, dissolved solids, bacteria, and viruses (García, 2006).

Agricultural effects on water quality are mostly due to chemical contamination of fertilizers and pesticides that accumulate in some aquifers, and reuse of sewage effluents for irrigation that can transmit a number of pathogens, even after secondary water treatments (World Bank, 2011b). Significant water pollution due to irrigation has been reported in Barbados, Mexico, Nicaragua, Panama, Peru, Dominican Republic and Venezuela (Biswas and Tortajada, 2006; FAO 2004; LA-Mexico, 2012).

Salinity due to irrigation has been a serious constraint in countries such as Argentina, Cuba, Mexico, and Peru, and, to a lesser extent, in the arid regions of northeastern Brazil, north and central Chile and some small areas of Central America (ibid). The reuse of domestic wastewater for irrigation has been established as a common practice on the outskirts of the cities located in arid and semi-arid areas, where intense competition for water for agriculture and urban uses often occurs.

Arsenic and fluoride pose groundwater quality concerns in several parts of the region. Arsenic content in groundwater is sometimes natural, but can also be attributed to economic activities such as gold or lead mining or to industrial effluents. High arsenic concentrations are known to be a problem in parts of Mexico, the Andean range and Argentina. High fluoride concentrations are often associated to sodium-bicarbonate waters found in weathered alkaline and metamorphic rocks, coastal aquifers affected by cation exchange or aquifers affected by evaporation. Thus, high fluoride concentrations have been observed in parts of Brazil and the Andes.

As indicated by Biswas and Tortajada (2006), water is becoming increasingly polluted in Latin America. Such pressures vary in the different sub-regions, and some sectors, such as mining and agriculture as well as large cities, are quite conspicuous, representing specific local water quality concerns for both surface and groundwater (Box 2.4). While large mining companies recycle and treat discharges, most small and artisanal mining companies do not have control and measures of their water pollution, and constitute important sources of contaminants to adjacent water bodies (World Bank, 2011b).

Box 2.4 Pollution by metals, metalloids and other contaminants in Chile

Rivers in the north of Chile have relatively high concentrations of metals from both natural sources and mining activities. Recent studies address the variation in concentration of heavy metals and sulphates, which is also a by-product of mining, in eleven rivers in the north of Chile. These show high concentrations of heavy metals and sulphates that in many cases exceed Chilean regulations. Arsenic is an important contaminant related to natural pollution in Chile. High evaporation and increased extraction of water have caused higher contents of salts in water. Aluminium is also an important pollutant in the central zone of the country. In order to control changes in waters quality, regulations of discharges must be fulfilled and norms are being developed that specify water quality limits for these releases to aquatic systems, considering the specific conditions of the receiving water bodies (Jiménez-Cisneros and Galizia-Tundisi, 2012).

Barrios (2006) points out that water quality management is not a substitute for efficient water management but a strategic issue that requires the integration of water quantity, pollution control, efficient use of water, environmental considerations and human health implications. Since Latin American countries are heterogeneous in terms of physical, climatic, economic, social, institutional, and environmental conditions (Biswas and Tortajada, 2006), water quality management should be specifically planned and developed and be an integral component of water management policies. The region's water quality management is complicated by the lack of wastewater treatment, financial constraints, difficulties in complying with standards and criteria of receiving waters, and the lack of monitoring programmes (García, 2006).

Not all of Latin America faces the same water quality problems, since these vary according to development and types of economic activity. While standards have been established to control point source pollution, García (2006) affirms that the resulting water quality is still not adequate. Among the problems are the disposal of sewage and lack of wastewater treatment. Besides, the attention has mostly been towards industrial discharges, ignoring municipal and non-point source pollution. The lack of monitoring and assessment has prevented the development and application of receiving waters criteria for more efficient basin-wide approaches to cope with such problems.

Given the magnitude of non-point source pollution's contribution to water quality losses, there is widespread agreement that many water quality goals cannot be reached without reducing this type of pollution. The cost-effectiveness of controlling non-point source pollution is generally recognized as opposed to narrowing regulations so that tertiary treatments of point source discharges are required (Russell and Clark, 2006).

Hoekstra et al. (2011) developed the Water Pollution Level (WPL) as an indicator of the level of water pollution. WPL is defined as the ratio between the total grey water footprint in an area or a watershed to the actual runoff. In Latin America, the overall WPL related to nitrogen (N) that are close to or higher than 1.0 are widespread over the entire region (Figure 2.6), while those related to phosphorus (P) that are close to or higher than 1.0 are mostly in Mexico and to the south and east of the region (Figure 2.7).

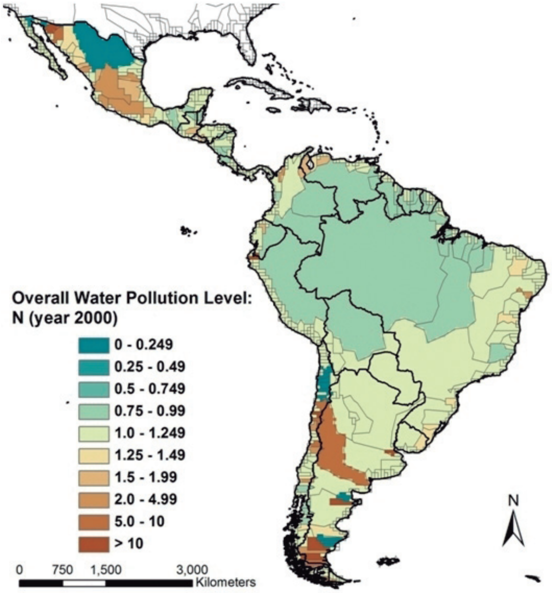

Figure 2.6 **Water Pollution Level for nitrogen (N) per river basin in Latin America (year 2000).** *Source: Liu et al. (2012)*

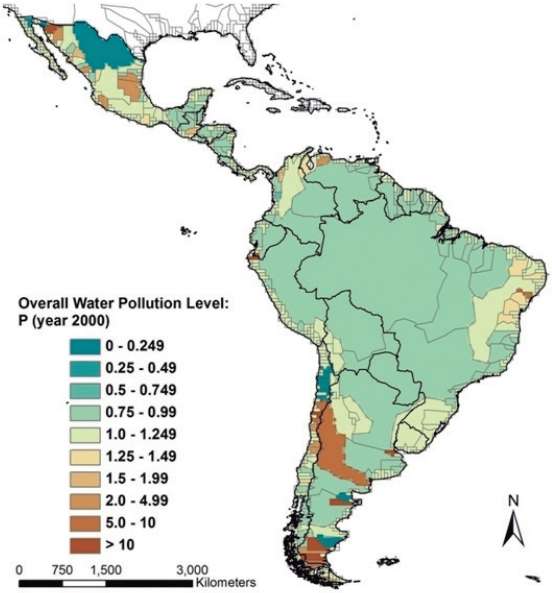

Figure 2.7 **Water Pollution Level for phosphorus (P) per river basin in Latin America (year 2000).** *Source: Liu et al. (2012)*

Water quality is acquiring great relevance because of the role of water in transporting contaminants and the growing concern over emergent forms of pollution such as endocrine-disrupting substances, in addition to persistent organic pollutants and other toxic compounds. Very few developing countries are prepared to face these concerns (Barrios, 2006) and, although there are specific case studies in Latin America that relate to the presence of these pollutants, to date there is no general overview of their presence in water bodies of the region. No permanent programmes exist for the monitoring of persistent organic pollutants, emerging pollutants, and other toxic compounds, and there are therefore no inventories or formal valuations of the exposure and risks associated with these substances (Box 2.5).

Box 2.5 Water quality policies in Mexico

The priorities of the Mexican water policy are to assure enough water of appropriate quality, recognize the strategic value of water, efficient use of water, protect water bodies, and to ensure the sustainable development and environmental conservation (CONAGUA, 2008).

The National Water Law (DOF, 2012) establishes the water quality requirements depending on its use, with the priority on human consumption relative to other uses of water. The norm NOM-127-SSA1-1994 (permissible limits of water quality and treatments for water purification) and NOM-179-SSA1-1998 (monitoring and evaluation of water quality control for human use and consumption, of water distributed by public supply systems), establish limits for human use and consumption. On the other hand, NOM-001-SEMARNAT-1996 establishes the limits for discharges to waters and national properties and NOM-002-SEMARNAT-1996 establishes the limits for discharges to municipal and urban 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.

Currently, the evaluation of water quality in Mexico is based on three basic indicators: biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS). In 2009, twenty-one of 1,471 river basins were classified as heavily contaminated according at least one of these indicators. Nearly 13% of the Mexican surface water was polluted owing to BOD, 31%, to COD, and 7.5%, to TSS.

Hansen and Corzo-Juárez (2011) highlighted the priorities and requirements for the evaluation of pollution of watersheds, referring to the policy of water management in Mexico, and the above-mentioned regulations. They remark that the national programme for monitoring and evaluation of toxic persistent and bioaccumulable substances (STPB) is recently being implemented and up until now there had been no formal valuations or cataloguing of the substances and the associated risks. A proposed list of substances to be included in a monitoring program of STPB in watersheds and aquifers has been presented by Hansen (2012).

Water quality problems are not only solved by constructing and operating wastewater treatment plants. Water quality management should include the formulation and implementation of water policies, monitoring and evaluation of water quality, installation of appropriate legal and institutional frameworks, capacity building, and evaluation and control of non-point sources pollutants.

2.5 Transboundary resources

A significant number of the region's basins are shared by two or more countries. These transboundary basins cover an area where a relatively large fraction of the population is concentrated. Take for instance South America, where there are thirty-eight international water basins that cover almost 60% of the continent area and that are home to more than one hundred million people (nearly 30% the population) (UNEP, 2007). Despite this, only four transboundary basins in South America have transboundary agreements in place (La Plata, Titicaca, Amazon and Lagoon Mirim). Remarkably, the Orinoco and Essequibo basins, i.e. the third and fourth largest of the continent, are not governed by international treaties (De Stefano et al., 2012).

Another important factor influencing the territorial structure of water management is that four of the largest countries in the continent are federal (Brazil, Mexico, Argentina and Venezuela). This means that most transboundary basins are directly or indirectly influenced by federalism. In those cases, strong state-level authorities will determine land and water use based on social, economic and political interests that may not take into account the interests of upstream or downstream users.

The distribution of water management responsibilities in Latin American countries is diverse (Table 2.5). Water resources commissions and river basin organizations have often demonstrated themselves to be useful bodies to coordinate inputs from sectors and stakeholders acting at the chosen management scale. This can be seen in the institutional evolution of several countries in Latin America. In Mexico, for example, management units include basins and sub-basins, and basin organizations at both scales. Mexico together with Brazil and Argentina have a tradition of river basin organizations, whereas in other countries, e.g. Peru, such entities are still being set up. River basin organizations have had deficiencies since their creation, partly due to weak institutional and policy frameworks, weak investment or financing methods (Dourojeanni, 2011). Take for instance Argentina, where the lack of financial autonomy of the river basin committees makes them highly dependent on provincial and local governments (OECD, 2012). In some cases, decentralized watershed management exists but is isolated and not formally recognized, stemming from local initiatives or pursued by sub-national authorities through informal processes and without the support of national political elites (see for instance Ecuador, Kauffman, 2011). Dourojeanni (2001) identified several challenges for river basin organizations, including the clarification of their role (and the potential competition with other authorities), economic viability and funding.

Table 2.5 **Distribution of water responsibilities in selected countries**

COUNTRY	WATER RESOURCES	DOMESTIC SUPPLY	RIVER BASIN ORGANIZATIONS	WATER USER ASSOCIATIONS
Argentina	Provinces	Provinces, municipalities	Yes	Yes
Brazil	Central Government, Water-specific bodies, RBO	Municipalities	Yes	Yes
Chile	Central Government	Central Government, water-specific bodies, local rural, committees	No	Yes
Costa Rica	Central Government	Municipalities	No	No
El Salvador	None	Municipalities, inter-municipal bodies, water-specific bodies, RBOs	n/a	No
Guatemala	RBOs	Municipalities	Yes	Yes
Honduras	Municipalities, inter-municipal bodies, water-specific bodies	Municipalities, inter-municipal bodies, water-specific bodies	n/a	No
Mexico	Regions, municipalities, inter-municipal bodies, RBOs	Regions, municipalities, inter-municipal bodies, RBOs	Yes	Yes
Nicaragua	Regions, municipalities, inter-municipal bodies, water-specific bodies, RBOs	Regions, municipalities, RBOs	Yes	Yes
Panama	None	Municipalities, others	n/a	No
Peru	Regions, municipalities, water-specific bodies, RBOs	Regions, municipalities, water-specific bodies, RBOs	Yes	Yes

Source: OECD (2012); OECD (2011); LA–Chile (2012); LA–Costa Rica (2012)

2.6 Climate change and water resources

Many countries of LAC have reported multiple evidences of a changing climate.[1] The most frequent impacts reported include an increase in average temperature, higher frequency of extreme rainfalls, sea level rise and coastal retreat, droughts, hurricanes and strong winds, and glacier melting. The magnitude and importance of each impact differs across regions and within countries (see Figure 2.8).

Based on the number and frequency of recorded impacts, the Andean region is the most vulnerable zone to climate change. Mean temperature has increased in all countries,

1 Most of the information under this heading stems from National Communication reports (NCs) in compliance with the United Framework Convention on Climate Chagne (UNFCCC) by twenty LAC countries (Non-annex I parties), including: Mexico, Belize, Guatemala, Honduras, El Salvador, Costa Rica, Panama, Nicaragua, Peru, Bolivia, Colombia, Ecuador, Venezuela, Brazil, Suriname, Guyana, Chile, Argentina, Paraguay and Uruguay.

most importantly in the higher altitudes, e.g. in the Bolivian Andean altiplano (between 1.1 to 1.7ºC) and in the high Colombian plains (up to 1ºC). In these parts of the Andes rainfall has decreased and droughts are becoming more frequent. Such trends are probably behind observed glacier melts, particularly in Peru and Colombia. In contrast, the Andean lowlands are becoming wetter and more prone to extreme rainfall. These changes have been linked to the intensification of El Niño events.

The South Cone also appears to be suffering important changes. The most frequently recorded phenomenon is an increase in extreme rainfall events, particularly in the northern part of the region. In central and northern Argentina the number of extreme rainfalls has increased fourfold since the 1960s. Also, a sea level rise of up to 4mm/year has been recorded on the coast of Rio de la Plata during the last two decades. The persistence of both trends is worrisome given the population density in this area. Elsewhere, along the Andean mountains of Chile and Argentina, the frequency and length of droughts have increased. Dryness has been associated with the intensification of La Niña. In Chile for instance, the number of dry years has increased substantially over the last century, e.g. during the first quarter of the 20th century the frequency of dry years was 15%, during the last fifty years, the frequency has increased to 50%. In the South Cone, an increase in mean temperature has mostly occurred in the Patagonian region (up to 1ºC) and the Andean Mountains (+0.25ºC) but not along the coastal areas. Eighty-seven out of one hundred glaciers under study along the Andean region have receded during the last century.

The intensification of El Niño events has been linked to the increasing frequency of extreme rainfall events and hurricanes along the Caribbean Coast. In Belize, for instance, four out of the eight major storms recorded during the 20th century have occurred in the last twenty five years. Likewise, Honduras is the third country in the world with the highest record of extreme event occurrence between 1990 and 2008. Extreme rainfall has caused nearly sixty floods in Costa Rica over the last six decades. While the Caribbean coast is becoming wetter and rain events more extreme, droughts are increasing along much of the Pacific coast of Central America. In the north of Costa Rica the frequency of dry years has increased remarkably between 1960 and 2005, and the average reduction in precipitation during these dry years surpasses 32% of the mean annual precipitation.

These observed trends largely coincide with the climate projections made by the Intergovernmental Panel on Climate Change (IPCC) for the region (Figure 2.8). According to Galindo et al. (2010), 2100 climate projections show an increasing frequency of hurricanes in the Caribbean and Central America, as well as a higher drought frequency and a reduction in annual rainfall. Glacier melting will continue along much of the Andean tropical glaciers of Colombia, Ecuador, Peru, as well as in Chile and Argentina.

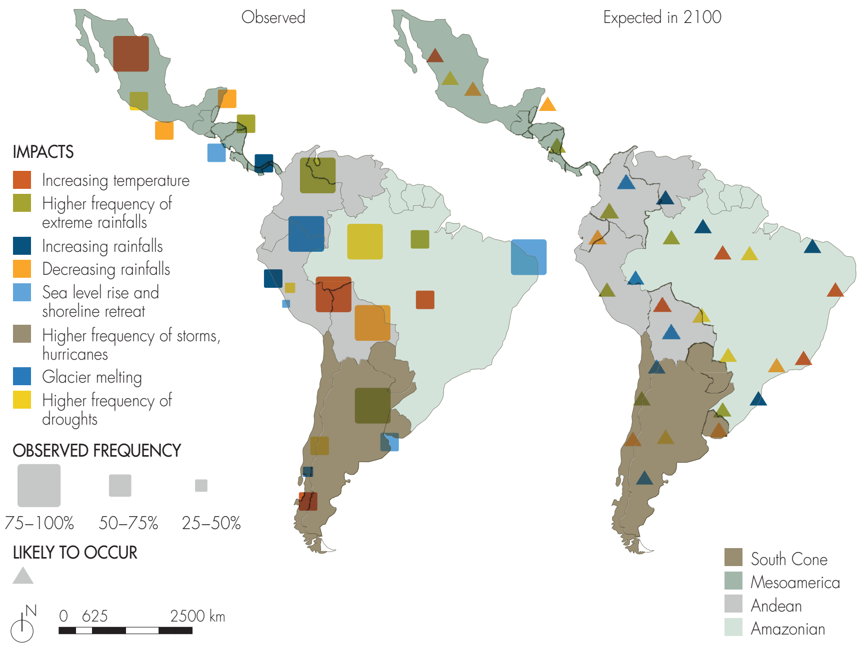

Figure 2.8 Observed (left) and expected (right) impacts linked to Climate Change in Latin America. *Source: own elaboration based on the information on observed impacts recorded from the National Communications (NCs) performed by twenty Latin American countries and summarized by major regions (UNFCCC, 2013); and expected climate change impact projections for the year 2100 in LAC as summarized in Galindo et al. (2010).*

2.7 Future challenges

Latin American water resources face important threats derived from population growth, urbanization, land use patterns and climate change, among others (Jones and Scarpati, 2007). United Nations' estimates suggest that the population will increase significantly in the coming years. By 2030, the population in northwest South America, from Venezuela to Bolivia, is expected to grow by one-third. Countries such as Brazil, Argentina or Chile will experience a demographic growth of about 20%. In addition, Latin America is experiencing other changes, namely, the shift of population from the countryside into the cities. As a result, per capita water consumption is rising dramatically in urban areas (see Chapter 8). This increases the pressure on local resources, such as Mexico City's aquifer, leading to problems of groundwater quality degradation, aquifer depletion and subsidence. Besides, the increase in paved areas, coupled with inadequate drainage, favours devastating floods such as the ones that have occurred in Sao Paulo, Mexico City, Rio de Janeiro or Buenos Aires in the recent past (Regional Process of the Americas, 2012).

Climate change is likely to cause increasing variability in precipitation and runoff, in both time and space, resulting in the excess or scarcity of water, and extreme events.

Inevitably this will cause changes in hydropower generation, agriculture, industry and domestic water supply. Some of the practical effects of climate change include the gradual substitution of Amazon rainforest with savannahs, changes in crop patterns and yields across the region, increased vulnerability to floods and droughts in Central and South America, augmented effects of the El Niño and La Niña oscillation phenomena and glacier melting in the Andes (EuropeAid, 2009).

In a context of unevenly distributed water resources and increasing drought in some regions and precipitation in others, enhanced water efficiency and management poses a major challenge, not only for direct water users and managers, but also for indirect water users such as policy makers, businesses, agricultural commodity trading companies and consumers. In contrast, consistent water accounting systems are yet to be developed. Quantifying and accounting for water flows within the economy (including environmental needs) and related impacts on the appropriate time and spatial scales would allow transparent information to be attained and thus contribute to the development of robust allocation and management systems needed to underpin a green economy (UNEP, 2010).

Deteriorating water quality due to urban and agricultural waste has long threatened public health and ecosystems. Full integration of water quality into the management debate is needed in order to ensure the preservation of water resources for the future. In this regard, systematic water quality monitoring, pollution control and wastewater treatment programmes are perceived as both urgent and essential.

Although some encouraging steps have been taken in the last few years, integrated water resources management is still absent in most countries (Chapter 15). Water governance opportunities are associated with the administration of water resources, the need to broaden and strengthen the capacity of public institutions, the establishment of clear and effective regulations for the provision of efficient services or the formulation and implementation of effective policies, with the subsidiary action of governments and with the participation of all water users including public–private cooperation strategies at local, sub-national and national levels (Regional Process of the Americas, 2012). Amongst all the challenges not least is the need to devise adequate governance frameworks for shared basins.

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