

NICARAGUA

Cost of Environmental Degradation (CoED): Trends and Economic Analysis

PRELIMINARY REPORT



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Table of Contents

EXECUTIVE SUMMARY	4
Objective and Scope	4
Approach	4
Results of the analysis	5
INTRODUCTION	7
1. SPECIFICS OF NATURAL CAPITAL IN NICARAGUA	10
2. COST OF UNSAFE WATER SUPPLY, SANITATION AND HYGIENE	11
3. COST OF HOUSEHOLD AIR POLLUTION	16
4. COST OF DEFORESTATION	21
5. COST OF SOIL EROSION (LAKE NICARAGUA CASE)	25
6. COST OF NATURAL DISASTERS	27
7. CONCLUSIONS	31
REFERENCES	32
ANNEX 1. ESTIMATION OF ECONOMIC VALUE OF THE HEALTH BURDEN OF POLLUTION	34
ANNEX 2. THE AQUEDUCT GLOBAL FLOOD ANALYZER	36

Executive summary

Objective and Scope

Over the past decade Nicaragua has achieved remarkable economic development, primarily due to export-oriented high-value crop agriculture and tourism. However, as is typical in many countries, economic growth has placed significant pressure on the physical environment, e.g., through air pollution and land degradation, adding to and exacerbating natural stresses, like flooding and erosion. This paper provides an order of magnitude estimate of the cost of environmental degradation (COED) in Nicaragua.

The report estimates Nicaragua’s annual COED at the national level and regional levels wherever possible in monetary terms. Specifically, it values the impacts of environmental degradation on Nicaragua’s national society as a result of air and water pollution, agricultural land degradation, deforestation, and meteorological natural disasters. The analysis captures the cost of degradation induced by anthropogenic (e.g. air pollution due to industrial activities, water pollution due to discharges of untreated wastewater) and natural factors (e.g. flooding and erosion).

This study estimated the present value (PV) of both short-term and long-term impacts caused by the activities occurring for one year—the latest year for which data were available. Certain activities cause short-term impacts, for example, air pollution causes certain health problems that last from a few weeks to several months (bronchitis, respiratory symptoms). Other activities have long-term impacts, such deforestation, which causes ecosystem losses that may take years or decades to recover. The analysis uses a six percent discount rate (World Bank, 2016) and a time horizon of 30 years. The final results are expressed in absolute terms (US\$, 2016 prices) and relative terms (as a percentage of the Nicaragua’s GDP) to benchmark the extent of the damage against macroeconomic indicators.

The study assessed damages at three levels: social, such as morbidity and mortality due to air and water pollution; economic, including losses of agricultural productivity due to soil erosion, and of fishing rents due to overfishing; and environmental, such as reduced value of watershed services due to deforestation.

Approach

The study, which was based exclusively on secondary information, estimated the COED using a variety of methods (ES1). Data sources included consultations with government officials, official publications, and scientific articles. Priority was given to country-level information if available, such as the MARENA, FCPF Carbon Fund (2018). When this was unavailable, information was complemented by regional and global datasets, like the CEPAL and World Bank’s Hidden Dimensions of Poverty database, the Institute for Health

Metrics and Evaluation's Global Burden of Disease (GBD), the World Research Institute's Global Forest Watch, and FAOSTAT.

Table ES1: Environmental degradation and valuation methods used

Categories	Impacts	Valuation method
IMPACTS ON HEALTH		
Air	<p>Impact of household air pollution</p> <ul style="list-style-type: none"> • <u>mortality</u> due to exposure of fine particulate matter (PM_{2.5}): ischemic heart disease; stroke; chronic obstructive pulmonary disease; tracheal, bronchus and lung cancer; and diabetes mellitus type 2 • <u>morbidity</u> due to exposure to air pollutants 	<p>VSL for mortality</p> <p>Benefits transfer for morbidity</p>
Water	<p>Impact of inadequate water supply, sanitation and hygiene*</p> <ul style="list-style-type: none"> • mortality due to water borne diseases (diarrhea, typhoid, schistosomiasis, malnutrition) • morbidity due to water-borne diseases 	<p>VSL for mortality</p> <p>Cost of illness for morbidity</p>
IMPACTS ON NATURAL RESOURCES		
Agricultural land	Annual sediment yield	Transfer of sediment removal cost
Forests	<p>Impact of deforestation</p> <ul style="list-style-type: none"> • losses of wood, non-wood forest products, watershed services 	Benefits transfer
Natural disasters	Impact of inland floods	GDP loss
Notes: VSL = Value of Statistical Life		

Several data limitations affected the study, which imposed the use of rough approximations or precluded the calculation of certain cost components. Examples relate to the physical quantification of damages: in some cases, available publications revealed lack of data (e.g., regarding yield loss due to soil erosion or floods impact by region). In other cases, available data were collected based on different studies (e.g., sediment production versus sediments removal). Data limitations affected also the monetary valuation, for example, valuation of damages related to forests is based on benefits transfer estimates obtained from other studies. Finally, these limitations prevented the valuation of other impacts, notably, the effects of air pollutants other than PM2.5, exposure to heavy metals, reduced recreational opportunities and property values due to water pollution, impacts at the macro level on food security, exports, GDP growth, etc. Therefore, the results of this study are **conservative** estimates which only partially capture the real value of the COED in Nicaragua.

Results of the analysis

The COED to Nicaraguan society is estimated at about US\$0.9 billion, or 6.7 percent of the country's GDP in 2016. Among the costs, it is important to note that:

- **Air pollution** stands out as the most important driver of degradation (3.8 percent of GDP). This is primarily due to the impacts caused by household air pollution (about 1,060 premature deaths).
- **Unsafe water supply, sanitation and hygiene** causes significant damage (1 percent of GDP) largely due to the effects of inadequate water supply, sanitation, and hygiene on health (about 260 deaths).
- Agricultural **land degradation, deforestation, and natural disasters** are also noteworthy, due to their negative effects on resource productivity and ecosystem services.
- In case of **devastating natural disaster scenario, cost of natural disasters** will be comparable to the average annual total national cost.
- **All zones in Nicaragua appear to have similar CoED**, but environmental health cost dominate in Pacific and Central zones, while natural resource degradation dominates in the Atlantic zone.

Table ES2. Estimated annual COED in Nicaragua (US\$ million, 2016)

	Pacific	Central	Atlantic	National average	% of GDP
Air	66-376	75-245	36-206	502	3.8%
Forests	6	16	140	162	1.2%
WASH	15-79	17-91	10-51	132	1.0%
Agricultural land	n/a	5-26	n/a	15.5	0.1%
Natural disasters	n/a	n/a	n/a	66	0.5%
Total average annual cost	273.5	245.5	291.5	877.5	6.7%

Introduction

Nicaragua is the largest country in Central America, with an area of 120,000 km² and a population of 6.1 million. Although poverty has declined steadily in recent years, it is still high. Per capita GDP is only \$2,150, compared to \$12,4400 for the Latin America and Caribbean region as a whole in 2016. Forty-one (41) percent of the population lives in rural areas and one out of four people (25 percent) are defined as living in poverty. Last 7 years an average GDP growth exceeds 5 percent, however, the economy is still relying on the depletion of natural capital as one of the major sources of growth.

The World Bank Group is using a new indicator - *wealth per capita* - to measure whether progress toward the two goals - eradicating poverty and promoting shared prosperity - is made in a sustainable manner in the country (Lange et al. 2018) At the heart of determining whether development in a country is sustainable, is the issue of accumulation of wealth. Wealth - broadly defined to include produced capital and urban land¹, natural capital (including forests)², human capital³, and net foreign assets⁴ - all of which underlie the accumulation of wealth (Figure 1). Assessments of economic performance need to be based on both measures of annual growth (such as the traditional GDP) and measures of the comprehensive wealth of a country, which indicate whether that growth is sustainable in the long term. Countries should aim to sustain per-capita wealth by saving enough assets to meet the needs of their growing population.

Total wealth has been growing over time in Nicaragua, with greater contributions from human and natural capital, but less from produced capital. Natural capital has been growing since 2005, from 40 to 81 billion constant USD in 2014, representing an increase of around 104 percent. While human and produced capital have also increased in absolute value in the same time period, they all maintain a relatively stable share of total wealth, compare to natural capital. These numbers indicate that Nicaragua is still reliant on natural capital, it is not substituted by other factors of production. Land, including cropland and pasturelands, make up the largest share of natural capital, followed by protected areas, and then others such as forest resources and mineral resources. The share of national wealth in timber and non-timber forest values is drastically decreasing (each for about 40% from 1995). Natural capital is an important source of income for the poor and bottom 40 percent in terms of rural agricultural farmers and forest-dependent communities rely on ecosystem services from land and forest resources.

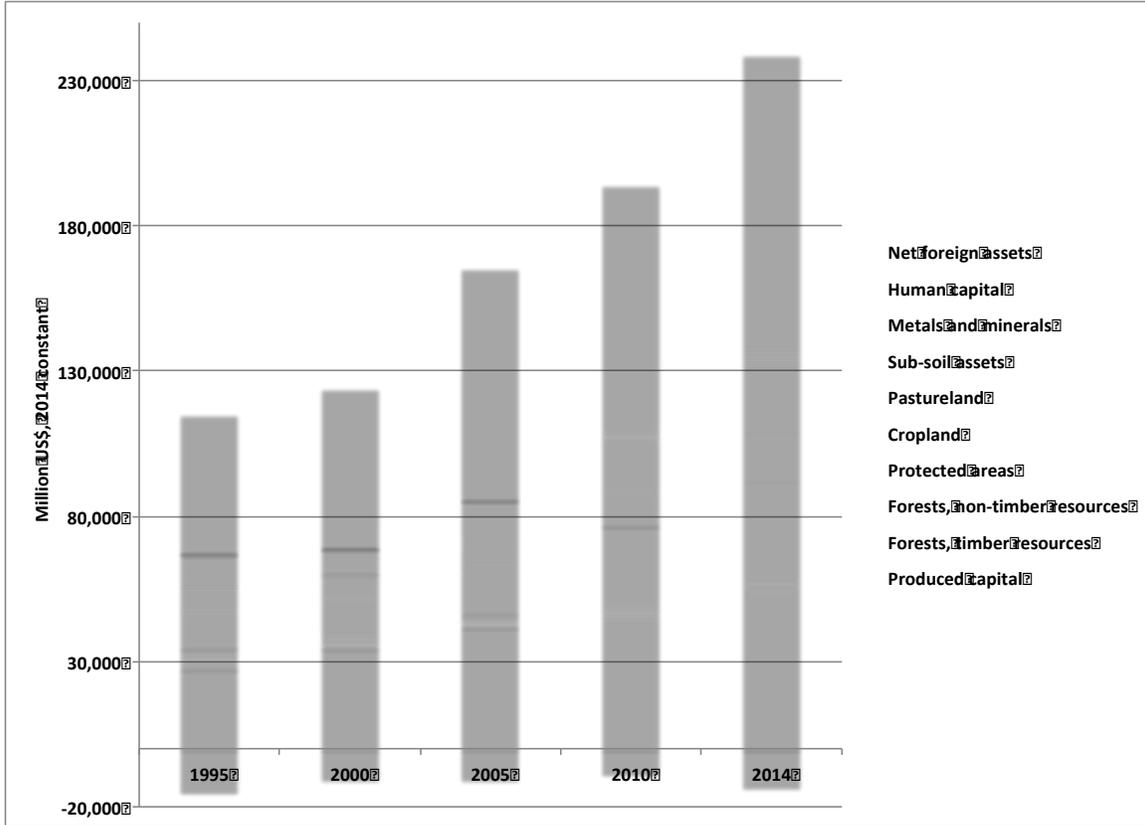
¹ Produced capital and urban land—machinery, buildings, equipment, and residential and nonresidential urban land, measured at market prices (Lange et al. 2018).

² Natural capital including agricultural land and forests, is measured as the discounted sum of the value of the rents generated over the lifetime of the asset (Lange et al. 2018).

³ Human capital is measured as the discounted value of the life-time earnings of a person participating in the labor force (Lange et al. 2018).

⁴ Net foreign assets are measured as the sum of a country's external assets and liabilities (Lange et al. 2018)

Figure 1. National Wealth, Nicaragua

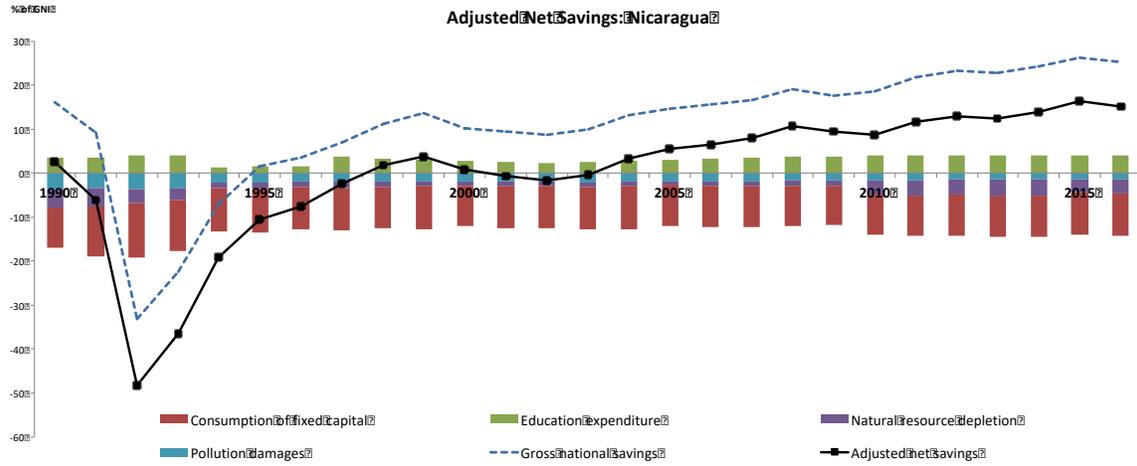


Source: WB WDI, 2018

Economic development that depletes its natural resource base cannot be sustainable even when total wealth of the country is increasing. Adjusted net saving is an indicator that aims to assess an economy’s sustainability based on the concepts of extended national accounts that include natural and human capital accounts. Adjusted net saving (ANS) measures the true rate of saving in an economy after taking into account investments in human capital, depletion of natural resources and damages caused by pollution. Positive savings allow wealth to grow over time thus ensuring that future generations enjoy at least as many opportunities as current generations. The adjusted net savings (ANS) for Nicaragua (Figure 2) has been improving over time, reaching 15.1 percent of gross national income (GNI) as of 2015. This is up from 8.6 percent in 2010, and -0.7 percent in 2001.

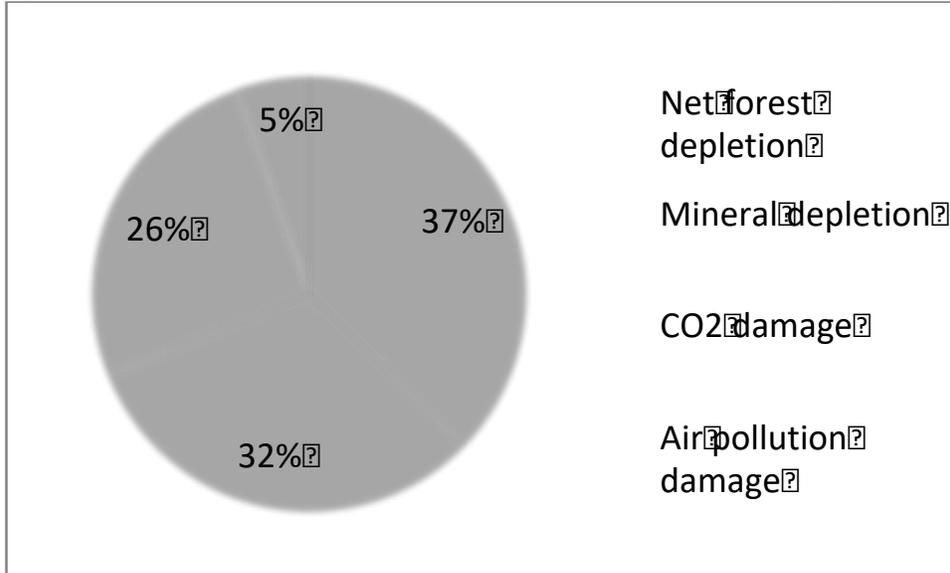
This increase is driven partly by an increase in adjusted savings, which was relatively high for 2016, at 25.2 percent, compared to 18.6 percent in 2010 and 9.4 percent in 2001. Despite a recent increase in adjusted net savings, natural capital depletion is nonetheless persistent. Natural resource depletion reaches 3.2 percent of GNI in 2016. Net forest depletion contributes the highest share of natural capital depletion (37 percent- figure 3).

Figure 2. Adjusted Net Savings: Nicaragua



Source: Adjusted Net Savings Database. Lange et al. 2018

Figure 3. Components of natural resource depletion and air pollution damage in Nicaragua, 2016



Source: Adjusted Net Savings Database. Lange et al, 2018

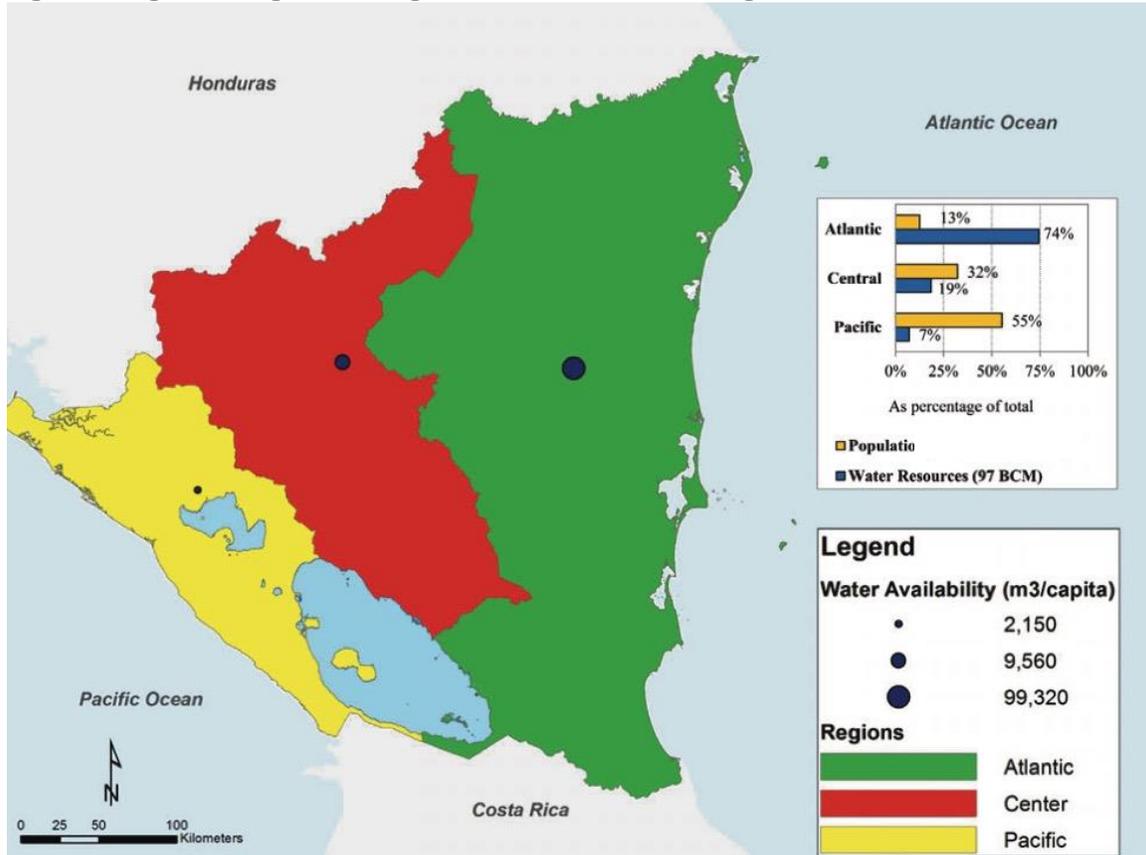
1. Specifics of Natural Capital in Nicaragua

Nicaragua is divided into three agro ecological zones⁵:

- (a) The Pacific Caribbean Zone that has a tropical savanna climate; annual precipitation ranging from 700 to 1500 mm; and soils of great agricultural potential. 55 percent of population lives in this zone, but there is only 7 percent of the total water resources there,
- (b) The Central Zone which has areas of tropical savanna and humid tropical forests where annual precipitation ranges from 700 to 2000 mm; it also comprises a zone of climatic transition which is related to steep mountains and highlands; soils having the greatest agricultural potential are mainly those in the valley bottoms. This zone provides home for the 32 percent of population, but they have only 19 percent of the total water resources, and
- (c) The Coastal Atlantic Zone which is comprised of tropical forests and has a very humid climate with annual precipitation ranging from 2500 to 6000 mm; because of the excessive rainfall, the soils are highly leached, acidic, and contain phytotoxic levels of aluminum; this zone traditionally was limited to forestry and a subsistence-type of agriculture, but nowadays it is under conversion into livestock production. This zone is abundant in water resources (74 percent), but only 13 percent of population lives on the Atlantic Coast.

⁵ Rojas E. Alternative Agriculture and Agroecology in Nicaragua E. Environmental Movement of Nicaragua, Managua, Nicaragua (not dated).

Figure 4. Agro ecological zoning and water use in Nicaragua



Source: World Bank. 2013a.

2. Cost of unsafe water supply, sanitation and hygiene

Because of uneven water distribution in the country, accessing safe water can be a difficult daily challenge for many families, particularly in rural Nicaragua. The challenge becomes even greater during the dry season. About 17 percent of the country total and 40 percent of the population in rural Nicaragua does not have potable water (WHO/UNICEF JMP, 2017). Many households in rural areas are dependent upon shallow hand-dug wells or natural springs and rivers, streams and lakes. However, many of the rivers, streams, and lakes are polluted with pesticides, residential sewerage and industrial waste and toxins. Sewerage coverage is also limited, serving only 79 percent of the population and the condition of many sewerage collection systems has deteriorated. Sewerage coverage is limited to a few intermediate cities. The lack of safe water and sanitation treatment causes a public health problem.

Table 1. Water access and sanitation in Nicaragua

	Water access			Sanitation		
	National	Rural	Urban	National	Rural	Urban
	2015	2015	2015	2015	2015	2015
Safely managed	59	30	79	-	-	-
Basic service	24	31	18	76	63	86
Limited service	1	2	0	3	2	3
Unimproved	13	30	2	14	20	10
No service	3	8	0	7	15	1

Source: WHO/UNICEF JMP (2017)

In urban areas, most people (about 98 percent) have piped water. However, some of these connections, particularly in the marginal settlements, are informal or unauthorized and may only provide an intermittent supply of water. Uneven distribution of water resources is exacerbated by unsustainable agricultural practices and mining practices in the country.

In this study we estimate cost of inadequate WASH in Nicaragua that is associated with lack of services, especially in the rural areas, but also with high level of toxic pollution in agricultural areas and mining areas. Health burden from inadequate WASH is also reduced by hygiene that is defined as a basic handwashing facility with soap and water.

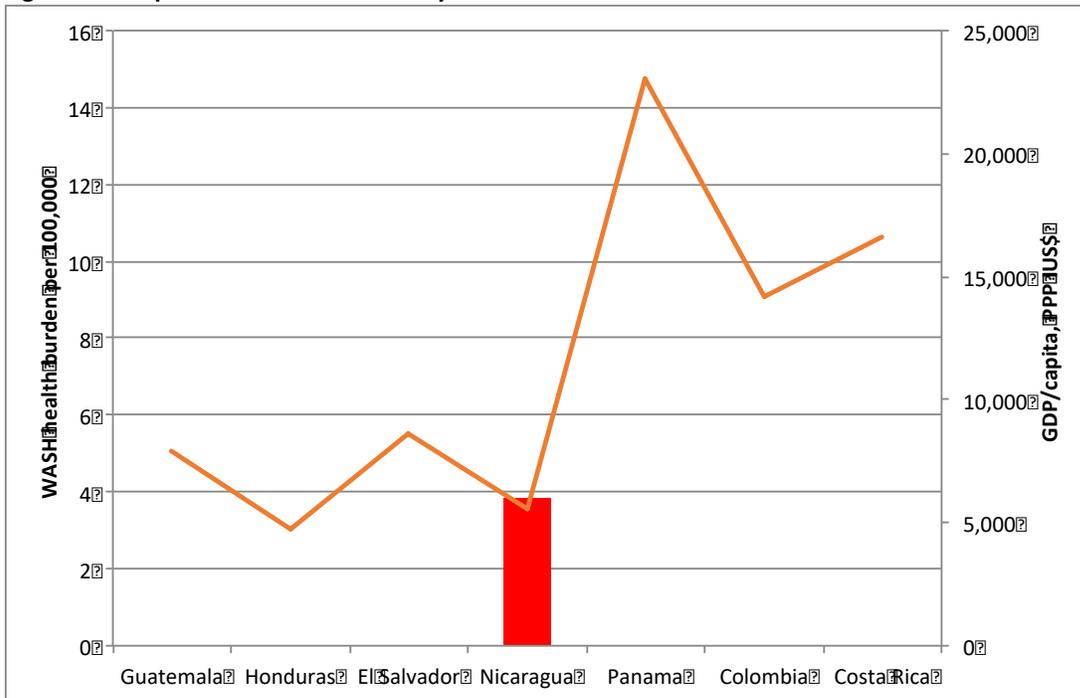
WHO confirms that health impact attributed to inadequate drinking water supply and sanitation is correlated with the population coverage with so called improved water supply and improved sanitation and good hygiene practices (see, for example, WHO, 2008). Improved water supply, sanitation and hygiene reduce transfer of harmful pathogens through water and sanitation facility and reduce negative effect on human health.

As explained above, the exposure to the WASH tiers defines relative risk attributed to unsafe water access and sanitation. To examine the burden of disease attributable to pollution risk factors, this study relies on the GBD 2016 results coordinated by the Institute for Health Metrics and Evaluation. The Global Burden of Disease (GBD) project analyses the environmental risks for the period 1990-2016 for the most countries and by major aggregates, linking these risks with the burden of disease attributable to them. Methodology of the GBD analysis is presented on the IHME website (<http://www.healthdata.org/gbd/publications>). GBD 2016 presents the new assessment of relative risk of diarrheal, typhoid, and some other disease reduction in population attributed to WASH. These relative risks almost twice reduced compare to the old methodology, which reflects new understanding of health burden from unsafe WASH, supported by the recent epidemiological studies (Wolf et al, 2014).

The positioning of Nicaragua among other Central America countries and the trends of the WASH health burden (WASH) reduction in the country are reflected in the Global Burden of Disease (GBD 2016) database.

Figure 5 presents the GBD estimates for the additional mortality attributed to unsafe WASH in the selected Central America countries. The countries are compared by the attributable deaths burden per 100,000. The GBD 2016 results suggest that health burden attributable to HAP risks in Nicaragua is at about 4 deaths per 100,000 that is 4 times lower than in Honduras and Guatemala, but 4 times higher than in Columbia, and Costa Rica. Last two countries have significantly higher GDP per capita (measures in PPP) than Nicaragua.

Figure 5. Comparison of WASH mortality risk in the Central America countries

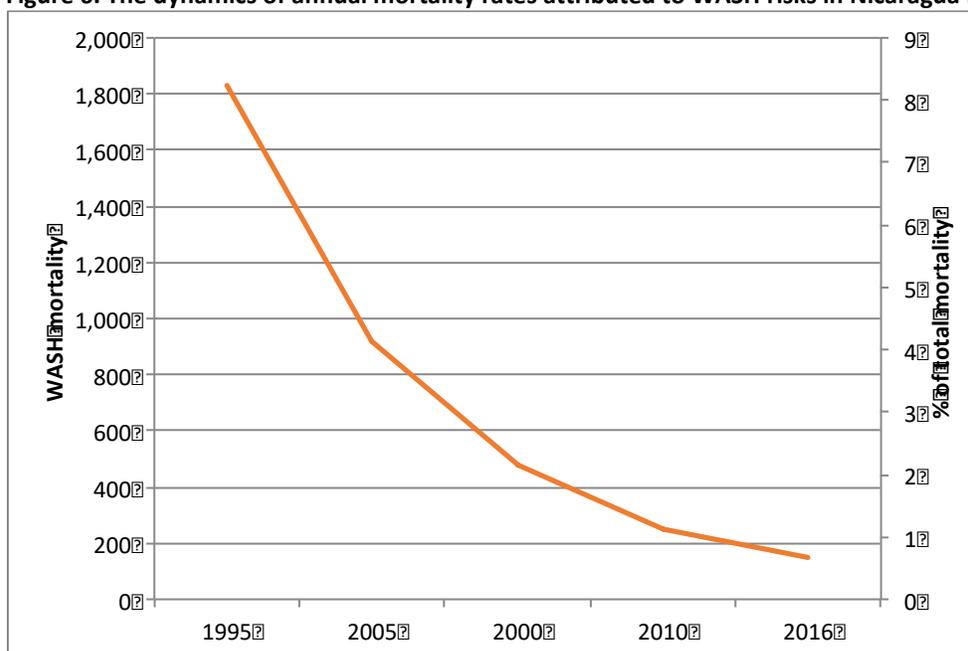


Source: Compiled by the author from GBD 2016

Nicaragua has been reducing health burden from WASH starting from 1995. Figure 6 presents the dynamics of health burden (additional annual mortality) attributed to WASH in Nicaragua in 1995-2016. In this time period HAP mortality rates reduced 8 times. At the same time, this risk is at 1 percent of the total mortality.

Diarrheal disease and lower respiratory mortality are associated with unsafe WASH in Nicaragua as in GBD 2016.

Figure 6. The dynamics of annual mortality rates attributed to WASH risks in Nicaragua in 1995-2016



Source: Compiled by the author from GBD 2016

The health burden attributed to inadequate water supply, sanitation and hygiene (WASH) in Nicaragua is estimated at 166-358 additional mortality cases in GBD 2016. We use Hidden Dimension of Poverty (HDP) database that presents the latest estimates of the share of population with unimproved water supply, unimproved sanitation, and those who has to travel more than 30 min to get water, we distribute this total estimate by the department in Nicaragua. Because of the lack of the latest household survey data on population health in Nicaragua, we apply the latest diarrheal prevalence estimate from GBD 2016 for morbidity burden. We estimate morbidity burden, applying 0.46 PAF (as in Pruss-Ustun et al, 2014) for diarrheal disease morbidity from GBD 2016, distributed by department. Then annual health burden attributed to WASH in Nicaragua is presented in table 2.

Table 2. Health burden from unsafe WASH by department in Nicaragua

	Low mortality	High mortality	Low morbidity	High Morbidity
Pacific Zone	59	128	9760	11258
Chinandega	11	24	1855	2140
Leon	9	20	1539	1775
Managua	19	41	3103	3580
Masaya	7	16	1182	1363
Granada	3	7	544	627
Carazo	4	8	621	717
Rivas	4	10	738	852

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Environment and Natural Resources Global Practice

Lago Nicaragua	1	2	178	205
Central and North Zone	68	147	11200	12920
Boaco	6	13	974	1124
Chontales	4	10	731	843
Esteli	6	13	1023	1180
Jinotega	19	41	3108	3586
Madriz	5	12	882	1018
Matagalpa	18	39	2957	3411
Nueva Segovia	9	20	1524	1758
Atlantic zone	38	83	6313	7282
Atlantico Sur	14	30	2274	2623
Atlantico Norte	20	43	3253	3753
Rio San Juan	5	10	785	906

Source: Estimated by the author using GBD 2016

Studies in different low-income countries with similar water supply, sanitation and hygiene problems suggest that measures to reduce environmental damages are justified in a number of areas on cost-benefit grounds as well on grounds of benefiting the poor. For water supply and sanitation, improvements in facilities in rural areas yield benefits in excess of costs under most assumptions. In urban areas, the focus should be on the monitoring of drinking-water monitoring and on the rehabilitation of piped water supply and sewage systems. Hygiene programs have estimated benefits far in excess of costs and should receive the highest priority. The same applies to programs aimed at encouraging the disinfection of drinking water.

To value the health burden of inadequate WASH, the same method as for air pollution (VSL for annual mortality valuation) is applied (see Annex 1 for methodology). To estimate the cost of illness (COI) for diarrhea we added cost of medical treatment and value of income and time lost to illness. Table 3 presents the estimated annual cost of inadequate WASH in Nicaragua.

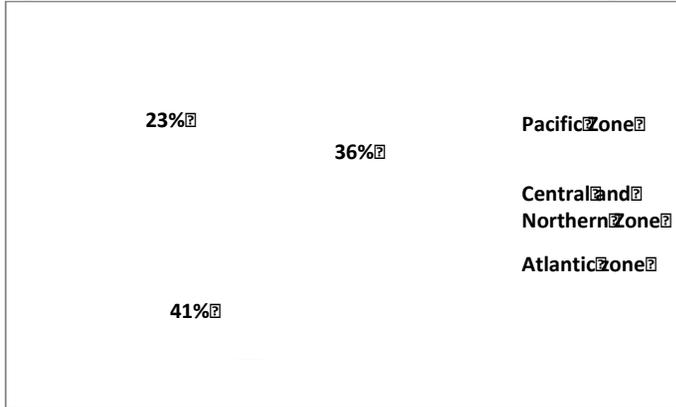
Table 3. The estimated annual cost of inadequate WASH in Nicaragua (Mn. US\$)

Zone	Pacific		Central and Northern		Atlantic	
	Low	High	Low	High	Low	High
Mortality	15	79	17.2	90.4	9.7	51.0
Morbidity	0.05	0.08	0.1	0.1	0.1	0.1
Total	15	79	17	91	10	51

Source: Estimated by the author

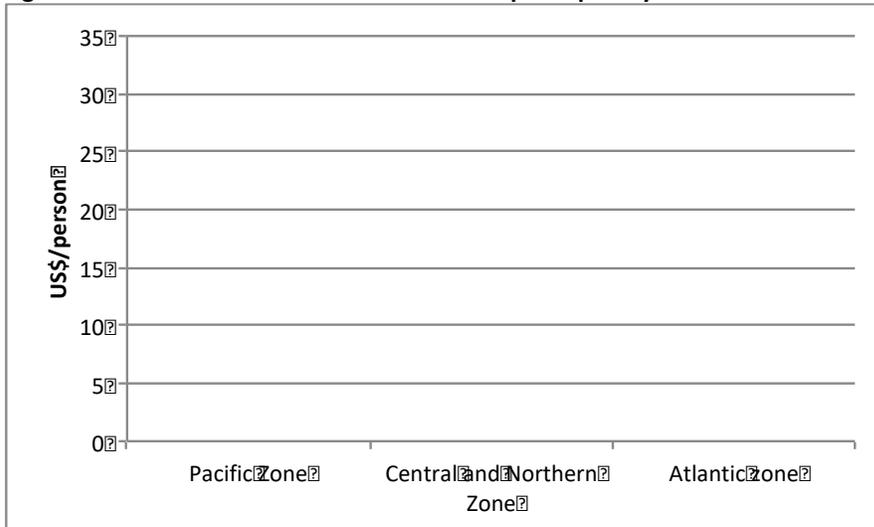
On average, the estimated annual cost of inadequate WASH in Nicaragua is US\$131 Mn. (1 percent of GDP in 2016), Central and Northern zone contributes 41 percent of the total, Pacific zone – 36 percent of the total, and Atlantic zone – 23 percent of the total.

Figure 7. The Estimated annual cost of WASH in Nicaragua



Source: Estimated by the author

Figure 8. The Estimated annual cost of WASH per capita by zone



Source: Estimated by the author

On per capita basis, the estimated cost is the highest in the Atlantic zone (about US\$30 per person), they are twice less in Pacific zone.

3. Cost of household air pollution

Deforestation in Nicaragua is driven by the need of new grazing lands for cattle and a heavy dependence on biofuels. Biomass and its derivatives constitute about 40% of the

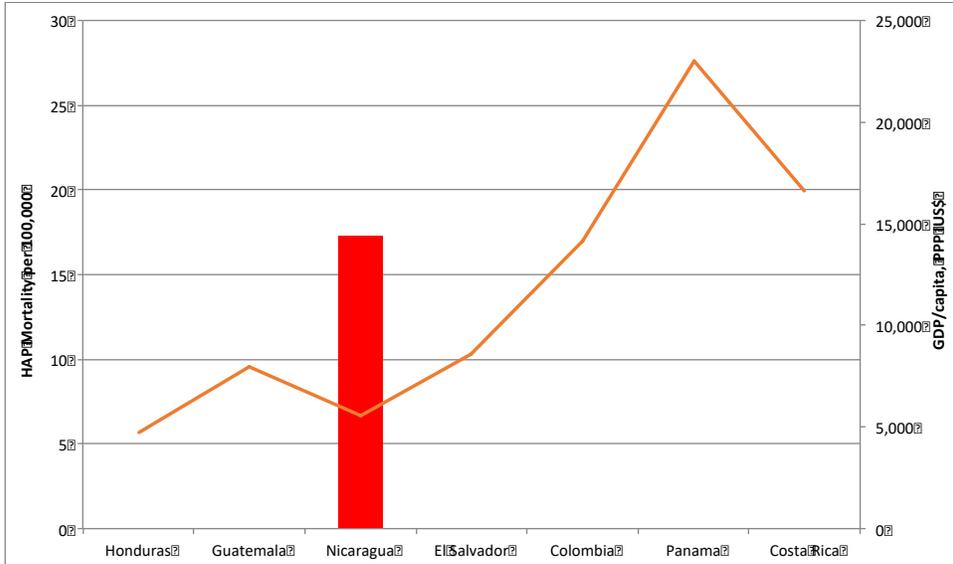
energy balance in Nicaragua in 2015 (IEA, <https://www.iea.org/statistics/statisticssearch/report/?country=Nicaragua&product=balances>). The majority of rural households also depend on wood and charcoal to cook. Fuel wood has been identified as the primary energy source for 54 percent of households (Pachauri et al, 2018).

Mortality and morbidity attributed to solid fuel use in households is an external deforestation cost that could be attributed to unsustainable natural resource use in Nicaragua, especially among poor who cannot afford other energy sources.

The positioning of Nicaragua among other Central America countries and the trends of the Household Air Pollution (HAP) reduction in the country are reflected in the Global Burden of Disease (GBD 2016) database.

Figure 9 presents the GBD estimates for the additional mortality attributed to HAP in the selected Central America countries. The countries are compared by the attributable deaths burden per 100,000. The GBD 2016 results suggest that health burden attributable to HAP risks in Nicaragua is at about 17 deaths per 100,000 that is 60-70 percent lower than in Honduras and Guatemala, but 35 percent higher than El Salvador and more than twice higher than Columbia, Panama and Costa Rica. Last three countries have significantly higher GDP per capita (measures in PPP) than Nicaragua.

Figure 9. Comparison of HAP mortality risk in the Central America countries



Source: Compiled by the author from GBD 2016

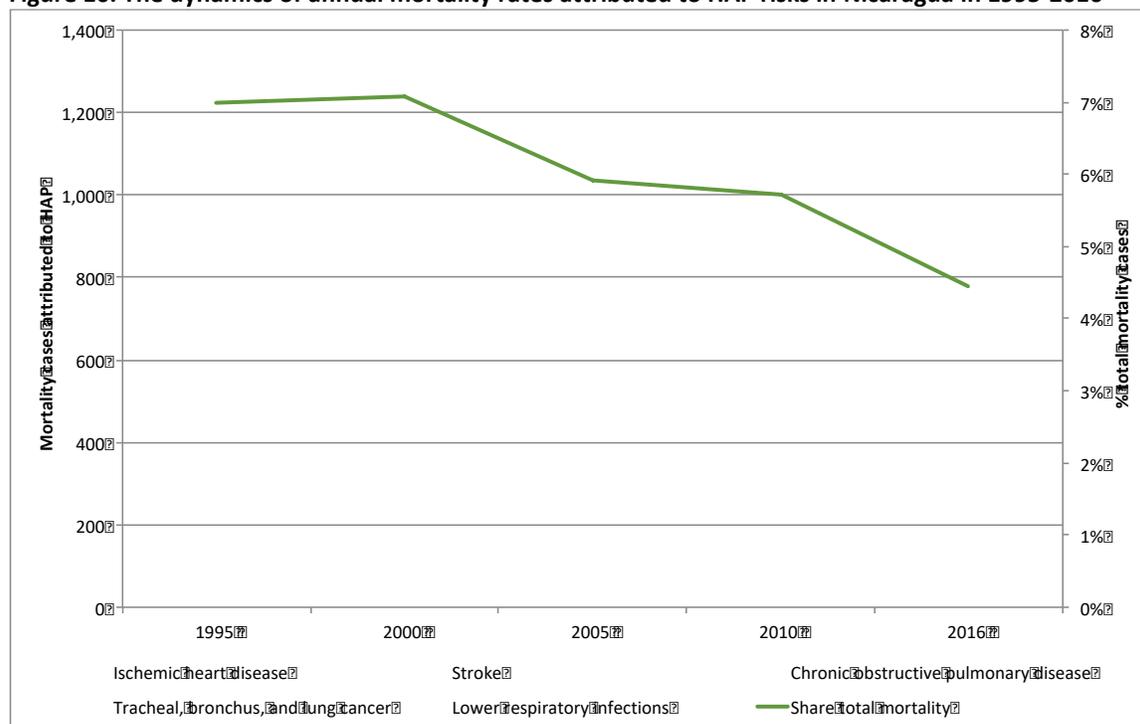
Nicaragua has been reducing health burden from HAP starting from 1995. Figure 10 presents the dynamics of health burden (additional annual mortality) attributed to HAP in Nicaragua in 1995-2016. In this time period HAP mortality rates reduced 20 percent. At the same time, this risk is at 4% of the total mortality, it is still the highest among the

selected Latin America countries in 2016 because of a significant share of biomass in the energy balance in Nicaragua.

Particulate matter (PM) is the household air pollutant that is associated with the largest health effects. The WHO recently reduced its guideline limits to an annual average ambient concentration of 10 microgram per cubic meter ($\mu\text{g}/\text{m}^3$) of PM_{2.5} and 20 $\mu\text{g}/\text{m}^3$ of PM₁₀ in response to increased evidence of health effects at very low concentrations of fine PM.

Fine particulate air pollution is associated with increased mortality and morbidity from cardiovascular disease, stroke, COPD, lung cancer (among adults) and lower respiratory illness mortality and morbidity (among children under 5 years of age and adults).

Figure 10. The dynamics of annual mortality rates attributed to HAP risks in Nicaragua in 1995-2016



Source: Compiled by the author from GBD 2016

The health burden attributed to household air pollution (HAP) in Nicaragua is estimated at 639-1489 additional mortality cases in GBD 2016. We use Hidden Dimension of Poverty (HDP) database that presents the latest estimates of the share of population who use solid fuel for cooking, and distribute this total estimate by the department in Nicaragua. Then annual health burden attributed to HAP in Nicaragua is presented in table 4.

Table 4. Health burden from HAP by department in Nicaragua

	Low mortality	High mortality

Pacific Zone	238	556
Chinandega	47	109
Leon	39	91
Managua	65	151
Masaya	34	80
Granada	13	30
Carazo	19	44
Rivas	18	41
Lago Nicaragua	4	10
Central and North Zone	270	628
Boaco	22	51
Chontales	16	38
Esteli	26	62
Jinotega	73	171
Madriz	23	54
Matagalpa	74	173
Nueva Segovia	35	81
Atlantic zone	131	305
Atlantico Sur	47	109
Atlantico Norte	66	153
Rio San Juan	19	43

Source: Estimated by the author using GBD 2016

The annual cost of mortality is calculated as Value of Statistical Life (VSL) multiplied by the estimated number of deaths associated with the HAP. Cost of morbidity is calculated as 10% of mortality cost. Table 5 presents the estimated annual cost of HAP in Nicaragua.

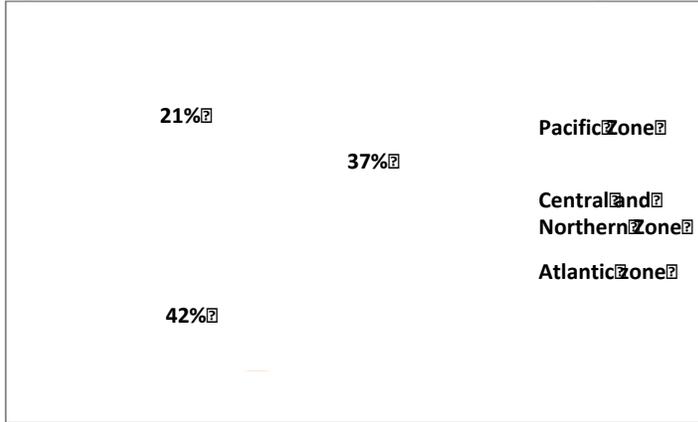
Table 5. The estimated annual cost of HAP in Nicaragua (Mn. US\$)

Zone	Pacific		Central and Northern		Atlantic	
	High	Low	High	Low	High	Low
Mortality	60	342	68	386	33	188
Morbidity	6	34	7	39	3	19
Total	66	376	75	245	36	206

Source: Estimated by the author

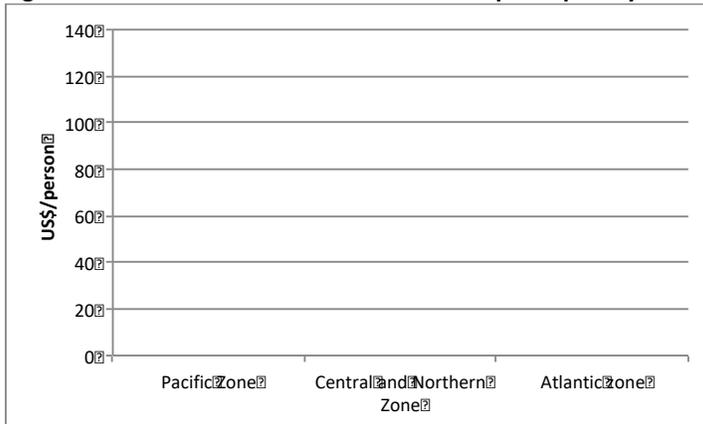
On average, the estimated annual cost of inadequate HAP in Nicaragua is US\$539 Mn. (4 percent of GDP in 2016), Central and Northern zone contributes 42 percent of the total, Pacific zone – 37 percent of the total, and Atlantic zone – 21 percent of the total.

Figure 11. The estimated annual cost of HAP in Nicaragua



Source: Estimated by the author

Figure 12. The estimated annual cost of HAP per capita by zone



Source: Estimated by the author

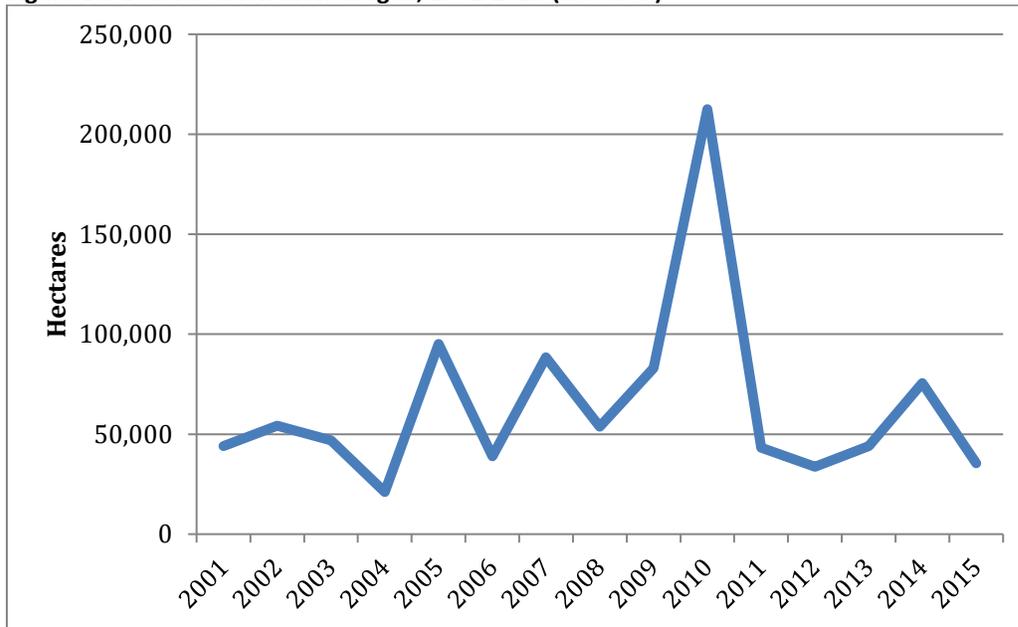
On per capita basis, the estimated costs are the highest in Central/Northern and Atlantic zones (about US\$120 per person), they are estimated at US\$72 per person in Pacific zone. This estimate presents an external effect of deforestation that negatively affects human capital in Nicaragua. This is the burden that affects the poor who predominantly use solid fuel for cooking.

4. Cost of deforestation

Nicaragua is in the top ten countries in the world with the highest deforestation rate. There was about 7.8 Mn. hectares of forest in 2000. Trees covered land reduced to 6.8 Mn. hectares in 2015. Deforestation rate is estimated at about 0.8% annually (globalforestwatch.com for the forests with tree canopy density more than 30%). In the Atlantic Lowlands covered with tropical wet forest that are rich in biodiversity, deforestation rate is the highest at 1.1% annually. In the Central Region and the Pacific Lowlands, lined with volcanoes and with mountain ranges, the rate of deforestation is 0.4-0.5% annually. The Pacific Lowlands have the highest population density in Nicaragua and are important agricultural areas.

Figure 13 presents deforestation trend in Nicaragua in 2001-2015.

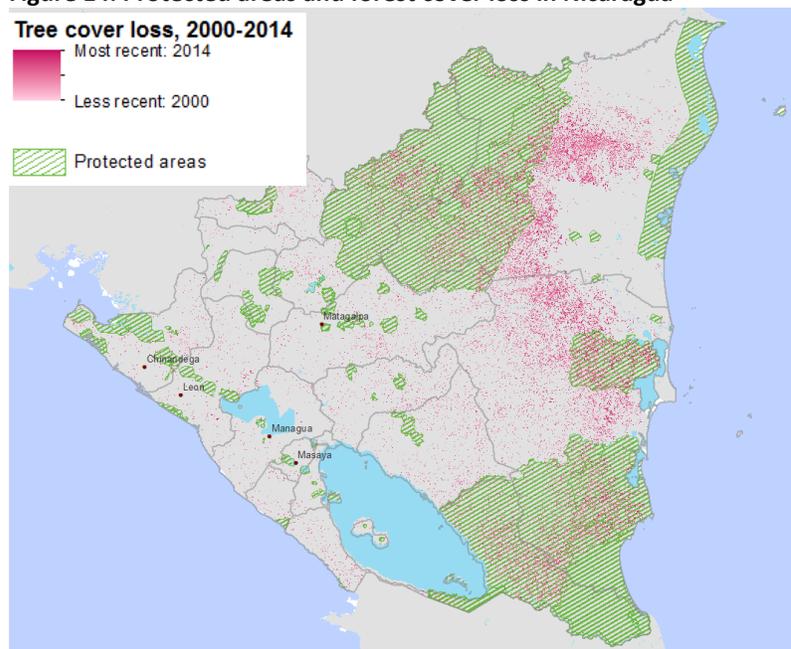
Figure 13. Deforestation in Nicaragua, 2001-2015 (hectares)



Source: globalforestwatch.org

Protected areas are being deforested also. Figure 14 presents the map with tree cover loss and protected areas in Nicaragua.

Figure 14. Protected areas and forest cover loss in Nicaragua



Source: Compiled by the World Bank staff from Globalforestwatch.org and IUCN Protected Areas database (2016)

Forest in Nicaragua provides essential ecosystem services that include provisional values (sustainable wood harvesting, non-timber values, including bush meat supply, etc.), regulation values (watershed protection, carbon storage) and cultural values (recreational values, existence values). Protection of forests in the Pacific Lowlands is vital for water conservation and soil erosion prevention. Drought risks are exacerbated by deforestation. They are of a particular concern in the central region - Dry Corridor, which covers about 28 percent of Nicaragua's territory and pose significant risks to water and food security. Also, deforestation contributes to devastating flood damage in highly populated areas. Besides total forest value loss, the impact of deforestation on indigenous population is important. Thus, deforestation is associated with a loss of ecosystem services generated by natural forest. Simultaneously, forest conservation may result in a wide range of benefits.

Deforestation and natural forest degradation exacerbated by climate change result in a substantial loss of ecosystem services values. However, substantial data, methodological, and other limitations make it difficult to calculate an estimate that captures and incorporates the full set of ecosystem services benefits. Only those benefits that are captured by recent studies or global ecosystem services analysis are included in the cost of deforestation estimate. For example, meta-analysis of the non-timber forest values presented in (Siikamäki et al, 2015) provides an estimated value of non-wood forest ecosystem services. The paper analyzed 139 studies to derive a function of ecosystem services based on location-specific ecological (for example, ecosystem type) and

socioeconomic factors (for example, income per capita or population density). The non-timber values of forest land estimated for Nicaragua are presented in table 6 below.

Table 6. The annual non-wood value of forestland in Nicaragua, (US\$/ha)

Ecosystem service provided by natural forest	2013 value, US\$/ha/year	2016 value, US\$/ha/year
Recreation	4.9	5.9
Habitat/Species Protection	0.1	0.1
NWFPS	23.1	27.7
Water Services	4.5	5.4
Total non-timber services	32.7	39.2

Note: Adjusted with GDP deflator to 2016.

Source: Siikamäki et al, 2015

Forest values from table 6 from the global study by Siikamaki et al (2015) are complemented by information from several sources that present values of forest in Nicaragua.

Watershed protection

The study by (Johnson and Baltodano, 2004) estimated WTP of local community in the highlands of Nicaragua to pay for watershed protection to restore local water supply. They are estimated at US\$3.2 per hectare of forest and agroforestry/year in 1998 or US\$17 per hectare/year in 2016. The estimate adjusted with GDP deflator and reduction of gallery forest extent by 8% in Matagalpa department of Nicaragua (as presented in Globalforestwatch.org). Coffee plantations areas are assumed to stay the same.

Carbon capturing and storage

Carbon storage is estimated at about 60tC/ha in the Atlantic Lowlands (MARENA, FCPF Carbon Fund, 2018), 43 60tC/ha in the Pacific Lowlands , and 24 tC/ha in the highlands of the Central Region (Gaitán et al, 2016). Annual carbon removal provided by forest reported at 3.4 tC/ha/year in (MARENA, FCPF Carbon Fund, 2018), and estimated for two other regions from the corresponding carbon storage differential. Then the cost of annual carbon capturing and storage is estimated at US\$5 per t of CO₂.

Then annual values of forest per hectare in each zone of Nicaragua is presented in Table 7.

Table 7. Forest values in Nicaragua, per hectare, US\$ 2016

	Atlantic	Pacific	Central and Northern
Annual			
Carbon removal	62	45	25
NTFP	28	28	28
Watershed Protection	17	17	17
Other	6	6	6
Total annual values	113	95	75

Accumulated			
The value of carbon storage	1104	788	440

Source: estimated by the author using the sources from the literature.

The total forest values are estimated as NPV (30 years, 6% discount rate) of the annual forest values separately by a natural zone in Nicaragua, taking into account a difference in the ecosystem values estimates in each zone. Then for estimation of the cost of deforestation per hectare, the value of carbon storage lost after forest cut is added to the NPV of the annual forest value. The resulting annual deforestation cost in Nicaragua is estimated as the product of deforestation cost per hectare and annual average deforestation rate (2000-2016) and presented in Table 8.

Table 8. The estimated annual deforestation cost in Nicaragua

	Atlantic	Pacific	Central and Northern	Total
Deforestation cost per hectare, US\$	2,548	2,005	1,405	
Annual average deforestation in 2001-2016, ha	54,794	3,053	11,708	69,554
Annual deforestation cost, US\$ Million	140	6	16	162

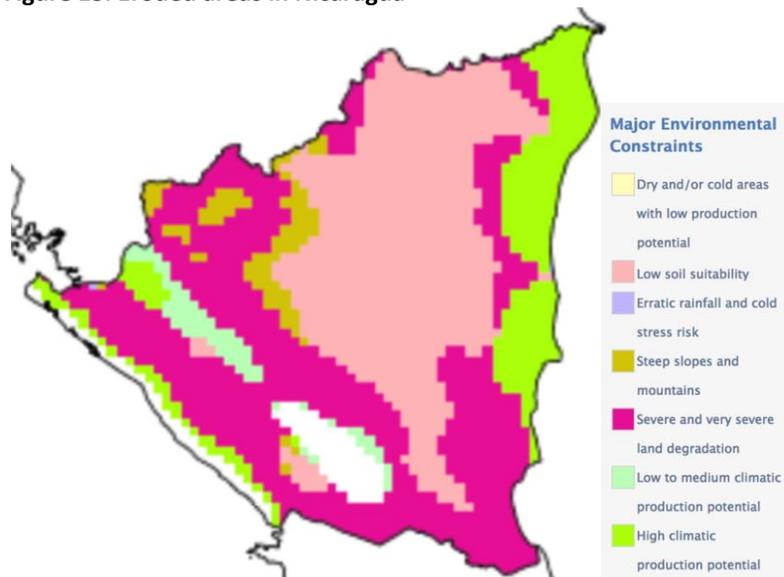
Source: estimated by the author

On average, the estimated annual cost of deforestation in Nicaragua is US\$162 Mn. (1.2 percent of GDP in 2016), Central and Northern zone contributes 10 percent of the total, Pacific zone – 4 percent of the total, and Atlantic zone – 86 percent of the total. Lack of studies on the forest values in Nicaragua is the reason behind dominance of the lost carbon value in the cost of deforestation. Productive forests in the Atlantic Lowlands have the highest annual average deforestation cost per hectare of remaining forest (US\$36 per hectare), while it is about 4 times less in two other zones.

5. Cost of soil erosion (Lake Nicaragua case)

Unsustainable agricultural practices that include rapid deforestation are aggravated by climate change in Nicaragua. Figure 15 presents the areas that suffered from soil erosion in Nicaragua.

Figure 15. Eroded areas in Nicaragua



Source: FAO, <http://www.fao.org/countryprofiles/maps/map/en/?iso3=NIC&mapID=604>

Currently, Nicaragua has about 140 000 ha under irrigation that is actually irrigated (11 percent of the total land under cultivation). The main crops benefitting from this are: sugarcane (45%), rice (30%), banana and plantain (24%), fruit, orchards and other grains (1%). The future potential for irrigation is very large as the Lake Nicaragua alone has an irrigation potential of 15,000million m³/year (World Bank, 2009) – enough to irrigate about half a million hectares (AQUASTAT, 2018).

According to a vulnerability study performed by the National Clean Development Office (ONDL, Spanish acronym) on adaptation options for water resources and agriculture, 75% of harvest losses were due to droughts and the rest of 25% due to floods. Besides, the lack of conservation practices in ranching and agriculture also promotes soil degradation. Cattle compact the soil and prevent rainwater absorption, increasing the volume of destructive runoff, while overgrazing increases erosion and decreases soil fertility. Vast expanses of a single crop such as cotton are particularly vulnerable to pests and erosion. Increased pesticide use further depletes natural fertility. Leaving cropland idle and bare between planting seasons invites wind and water erosion, as does planting on slopes without terraces or attention to contour lines. Inappropriate practices uphill make everyone downhill more vulnerable (<http://www.envio.org.ni/articulo/2852>).

In 2013 the World Bank completed a study on Lake Nicaragua pollution. Table 9 presents total mean annual sediment and nutrient flows to Lake Nicaragua that is an important social, economic and cultural resource in Nicaragua.

Box 1. Significance of Lake Nicaragua (Cocibolca)

Lake Nicaragua, also known as Lake Cocibolca, is a major freshwater resource in Central America and the second largest lake in Latin America after Lake Titicaca. With its surface area of 8,187 km², the lake covers nearly 15 percent of Nicaragua’s territory and is located entirely within Nicaraguan territory, although its watershed is shared between Nicaragua and Costa Rica. The lake’s watershed is very extensive, spanning 13,707 km² in Nicaragua (excluding the lake itself and its islands) and 2,577 km² in Costa Rica. With a population of around 750,000, the watershed is a major area for agricultural production, is one of the main tourist attractions in the country with its colonial city of Granada and Ometepe Island, and offers a habitat for many species. The watershed hosts three wetlands that were declared wetlands of global significance by the 1971 Ramsar Convention. Several fish varieties are endemic to the lake, and the watershed’s location within the Mesoamerican Biological Corridor has made it a meeting ground for fish, bird and mammal species from North and South America.

Source: The World Bank, 2013

The World Bank study (2013) estimates average annual pollution of the Lake Nicaragua, by estimating the sources and volume of the annual sediment production and nutrient pollution (Table 9, figure 16).

Table 9. The Estimated Mean Annual Nutrient Flows into Lake Nicaragua by Country

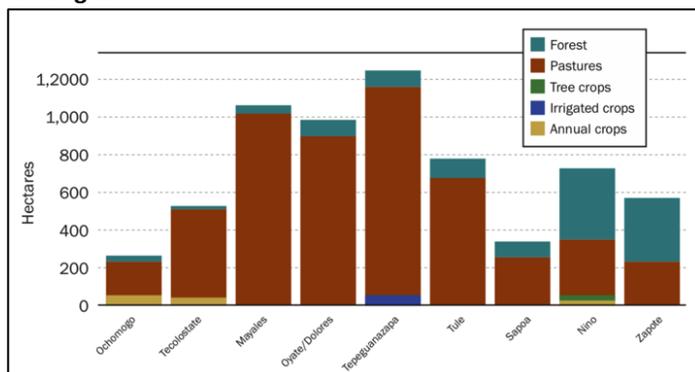
Item	Nicaragua (percent)	Costa Rica (percent)	Total
Watershed area (excludes the lake and islands)	77	23	13,365 km ²
Sediment load	16–26	84–74	10.3–25.3 million tons
Nitrogen load	59–64	41–36	5,288–9,551 tons
Phosphorus load	62–65	38–35	364–822 tons

Note: Sediment load is on average 13.3 tons/ha. Source: The World Bank. 2013

Sediment and nutrient loads from eroded soils in steep parts of the watershed are an order of magnitude higher than the other two sources, according to the results of this study. The estimates of nutrient loading discussed above clearly indicate that runoff and soil erosion contribute substantially more nutrients to Lake Nicaragua than wastewater or tilapia production, although tilapia production levels are growing fast.

We estimate cost of soil erosion in the Lake Nicaragua watershed by applying restoration cost method. It cost on average US\$3-4 to remove 1 t of sediments (ADB 2010; PNC ONU-REDD+/SEAM/INFONA/FAPI, 2016). Then annual cost of sediments removal from Lake Nicaragua is in the range US\$31-101 million with contribution of Nicaragua 16-26 percent. Watershed of Lake Nicaragua is at about 10% of the total area of Nicaragua. That explains potential high cost of soil erosion in the country.

Figure 16. Land Uses in the Watersheds that Contribute the Most Sediments and Nutrients to Lake Nicaragua



Source: The World Bank. 2013

Based on a vulnerability study of water resources using future climate scenarios in the three regions of the country (Pacific, Atlantic and Central), surface water proved to be highly vulnerable to climatic variability in the Pacific and Central regions by 2050 and 2100, while the Atlantic region proved to be not vulnerable at all, mainly due to flooding. Vulnerability is associated with impacts on agriculture in the Pacific and Central parts, due to intense use of water for irrigation. Regarding underground water, a sharp reduction of this will be noticed as of 2050 with the base water flow being four times smaller compared to the current one by 2050 and only 10% of the current one by 2100 (World Bank. 2009).

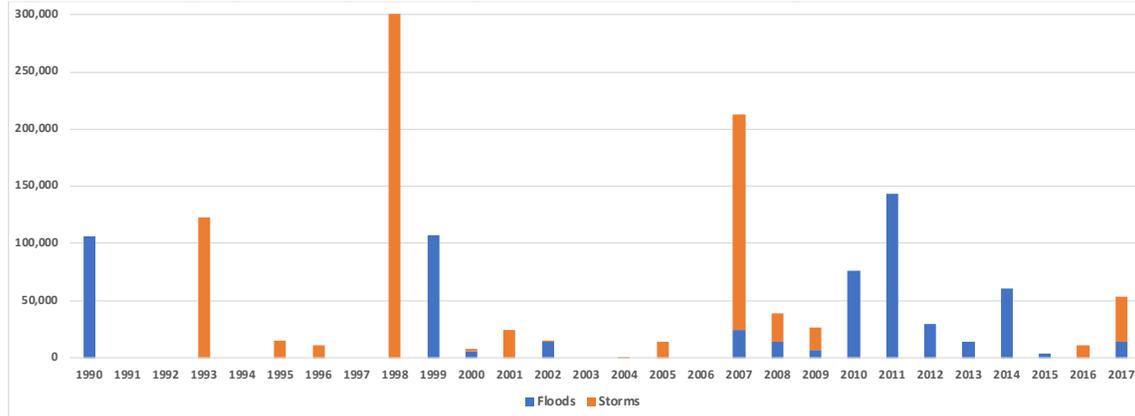
6. Cost of Natural Disasters

Nicaragua is prone to floods due to storms and hurricanes in summer and fall. The cities are flooded because of poor planning and bad drainage. Also, communities, which are sited along riverbanks, coastal settlements, and lowland areas affected by this natural disaster are affected.

The CEPAL presents a list of floods and storms (including hurricanes) that happened in Nicaragua since 1990. A major flood happens in the country every 10 years, and frequency of floods is increasing. Hurricane Mitch in 1998 was a unique meteorological disaster, that affected 0.9 billion people in Nicaragua. Figure 17 presents people affected by floods every year in Nicaragua (hurricane Mitch data is truncated).

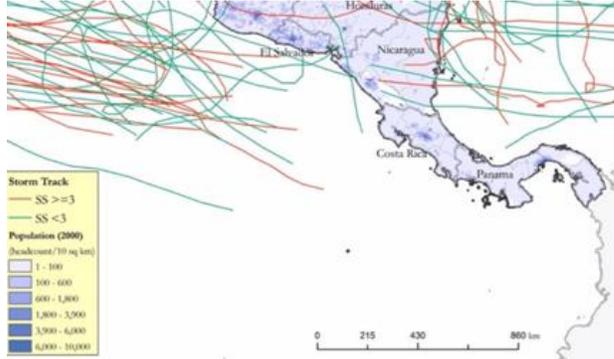
Nicaragua is one of the Central Latin America countries that is hit by hurricanes the most, especially in the Atlantic Zone (Ishizawa, O. and Miranda, J. 2016. Weathering Storms: Understanding the Impact of Natural Disasters on the Poor in Central America. Policy Research Working Paper 7692, The World Bank). Figure 18 presents Central America's storm tracks by intensity.

Figure 17. Total people directly affected by floods and storms in Nicaragua



Source: https://estadisticas.cepal.org/cepalstat/WEB_CEPALSTAT/estadisticasIndicadores.asp?idioma=i

Figure 18. Central America's Storm Tracks by Intensity

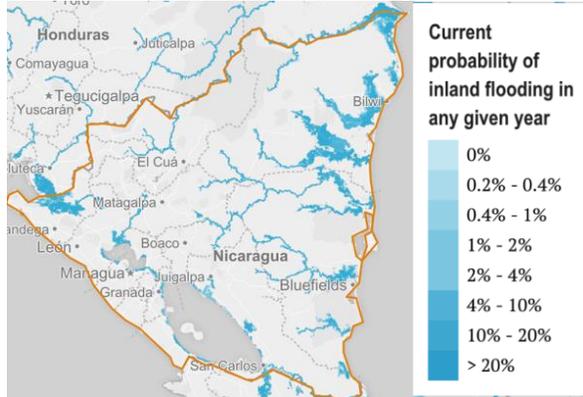


Note: SS is the Saffir-Simpson (SS) scale. The SS scale classifies events into five categories according to the sustained wind speed measurement, with one being of the lowest and five the highest wind speed. The wind speed is directly correlated with the intensity of the hurricane. The scales are as follow: 1 for hurricanes between 119 and 153 km/h, 2 for hurricanes between 154 and 177 km/h, 3 for hurricanes between 178 and 209 km/h, 4 for hurricanes between 210 and 249 km/h, and 5 for hurricanes above 250 km/h. Source: Ishizawa and Miranda, 2016

Nicaragua accounted for nearly half of the events (9 events in total) followed by Honduras (5 events in total) since 1983 (Ishizawa and Miranda, 2016). Storms under category SS 1 represented 63 percent of events (12 in total), while category SS 2 and SS 3 accounted equally for nearly 33 percent of total events. Ishizawa and Miranda (2016) further estimate that an increase of one standard deviation in the intensity of a hurricane leads to a decrease in total per capita GDP growth of between -0.9 and -1.6 percentage points. It was exactly the intensity of hurricane Mitch that was one in a century event in Nicaragua.

Hurricanes and storms are precursors of floods. Flood risk zones in Nicaragua are presented on Figure 19 as estimated by the Aqueduct model (Annex 2).

Figure 19. Flood risk zones in Nicaragua

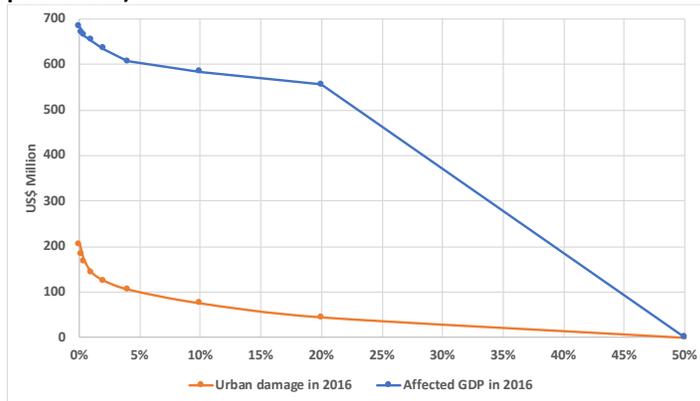


Source: <https://floods.wri.org>

The affected GDP for Nicaragua is calculated for floods of the following magnitudes: 2-year flood (50% probability of occurrence), 5-year-flood (20% probability of occurrence), 10 (10% probability of occurrence), 25 (4% probability of occurrence), 50 (2% probability of occurrence), 100 (1% probability of occurrence), 250 (0.4% probability of occurrence), 500 (0.2% probability of occurrence), and 1000-year flood (0.1% probability of occurrence). The impact of a 2-year-flood event is estimated at zero. Scattered plot of risks that corresponds to the event of each magnitude is a flood risk curve or exceedance probability-impact curve. Risk curve for Nicaragua fitted using Aqueduct model (<https://floods.wri.org>) is presented in Figure 20.

Annual expected affected GDP in Nicaragua depends on the level of flood protection. We assume that Nicaragua is protected from 2-year or 5-year flood events. Then we could utilize low and high values of annual exposed affected GDP and affected population due to floods that are estimated from the Aqueduct model (table 10).

Figure 20. Flood risk exceedance curve for Nicaragua (affected GDP and urban damage for zero flood protection)



Source: <http://floods.wri.org>

Table 10. Estimated annual expected cost of floods indicators in Nicaragua⁶

	High (with 2-year flood protection)	Low (with 5-year flood protection)
Annual Expected Urban Damage, US\$ million	23.2	16.7
Annual Expected Affected GDP, US\$ million	201.4	118.1
Annual Expected Affected population, thousand	53.4	31.3

Source: The Aqueduct Global Flood Analyzer modeling results, adjusted to 2016 GDP

The CoED study calculates annual cost that affects productive flows in the country. Thus, annual expected affected GDP that is actually lost reflects the economic cost associated with floods. Damage function used in this study is equal to 30-50% of the annual expected affected GDP to be lost due to floods. Then applying these losses to the annual expected affected GDP, we estimate that annual cost of floods in Nicaragua (with 2-5 years flood protection in place) is in the range US\$31-101 million (0.1-0.3 % of GDP in 2016). Note that the annual expected cost of floods depends on the effective flood protection in the country.

This estimate is close to the annual average loss for floods estimated by the UN Office for Disaster Risk Reduction (preventionweb.org) at US\$34.5 million, with the probable maximum loss from storm surge at US\$105 million. The World Bank in the Nicaragua Earthquakes and Hurricanes Risk Profile (2016), estimated annual average risk from hurricanes at US\$26.3 million, with the probable maximum loss at US\$748 million (2.2% equivalent of GDP in 2016). The latter estimate corresponds to the total destruction and complete affected GDP loss during 1 in a 1000 years event on figure 20.

⁶ Adjusted to 2016 with GDP deflator.

7. Conclusions

The COED to Nicaraguan society is estimated at about US\$0.9 billion, or 6.7 percent of the country's GDP in 2016 (table 11). Among the costs, it is important to note that:

- **Air pollution** stands out as the most important driver of degradation (3.8 percent of GDP). This is primarily due to the impacts caused by household air pollution (about 1,060 premature deaths).
- **Unsafe water supply, sanitation and hygiene** causes significant damage (1 percent of GDP) largely due to the effects of inadequate water supply, sanitation, and hygiene on health (about 260 deaths).
- Agricultural **land degradation, deforestation, and natural disasters** are also noteworthy, due to their negative effects on resource productivity and ecosystem services.
- In case of **devastating natural disaster scenario, cost of natural disasters** will be comparable to the average annual total national cost.
- **All zones in Nicaragua appear to have similar CoED**, but environmental health cost dominate in Pacific and Central zones, while natural resource degradation dominates in the Atlantic zone.

Table 11. Estimated annual COED in Nicaragua (US\$ million, 2016)

	Pacific Zone	Central Zone	Atlantic Zone	National average	% of GDP
Air	66-376	75-245	36-206	502	3.8%
Forests	6	16	140	162	1.2%
WASH	15-79	17-91	10-51	132	1.0%
Agricultural land	n/a	5-26	n/a	15.5	0.1%
Natural disasters	n/a	n/a	n/a	66	0.5%
Total average annual cost	273.5	245.5	291.5	877.5	6.7%

References

AQUASTAT, 2018

Asian Development Bank (ADB) 2010. Greater Mekong Subregion Biodiversity Conservation Corridors (RRP REG 40253). Supplementary Appendix B: Valuation of Ecosystem Services of Biodiversity Conservation Corridors in Cambodia, Lao PDR and Viet Nam. Asian Development Bank, Manila

Gaitán, L., Läderach, P., Graefe, S., Rao, I. and van der Hoek, R., 2016. Climate-smart livestock systems: an assessment of carbon stocks and GHG emissions in Nicaragua. *PLoS one*, 11(12), p.e0167949.

GBD results tool. <http://ghdx.healthdata.org/gbd-results-tool>

Globalforestwatch.org

IEA, <https://www.iea.org/statistics/statisticssearch/report/?country=Nicaragua&product=balances>

IUCN Protected Areas database (2016)

Johnson, N.L. and Baltodano, M.E., 2004. The economics of community watershed management: some evidence from Nicaragua. *Ecological Economics*, 49(1), pp.57-71

Lange, Glenn-Marie; Wodon, Quentin; Carey, Kevin. 2018. The Changing Wealth of Nations 2018: Building a Sustainable Future. Washington, DC: World Bank. © World Bank.
<https://openknowledge.worldbank.org/handle/10986/29001> License: CC BY 3.0 IGO.”

MARENA, FCPF Carbon Fund. 2018. Emissions Reduction Program to combat climate change and poverty in the Caribbean Coast, BOSAWAS Biosphere Reserve and Indio Maíz Biological Reserve.

Narain, U., and Sall, C. 2016. Methodology for Valuing the Health Impacts of Air Pollution: Discussion of Challenges and Proposed Solutions. World Bank, Washington DC.

Pachauri, S., Rao, N.D. and Cameron, C., 2018. Outlook for modern cooking energy access in Central America. *PLoS one*, 13(6), p.e0197974

PNC ONU-REDD+/SEAM/INFONA/FAPI. 2016a. Mapeo de los beneficios múltiples de REDD+ en Paraguay: análisis adicionales para informar la toma de decisiones sobre políticas y medidas REDD+. Asunción, Paraguay: FAO/PNUD/PNUMA

Pruss-Ustun, A., Bartram, J., Clasen, T., Colford, J., et al 2014. Burden of disease from inadequate water, sanitation and hygiene in low- and middle-income settings: a retrospective analysis of data from 145 countries. *Trop Med Int Health*, 19: 894-905.

Rojas E. Alternative Agriculture and Agroecology in Nicaragua E. Environmental Movement of Nicaragua, Managua, Nicaragua (not dated).

Siikamäki J., Santiago-Ávila, F., and Vail, P. 2015. Global Assessment of Non-Wood Forest Ecosystem Services: Spatially Explicit Meta-Analysis and Benefit Transfer to Improve the World Bank's Forest Wealth Database. RFF

The World Bank, World Development Indicators (WB WDI). 2018.

The World Bank. 2009. Nicaragua. Country Note on Climate Change Aspects in Agriculture

The World Bank. 2013. Policy and Investment Priorities to Reduce Environmental Degradation of the Lake Nicaragua Watershed (Cocibolca): Addressing Key Environmental Challenges

The World Bank. 2013a. Climate Change Impacts on Water Resources and Adaptation in the Rural Water Supply and Sanitation Sector in Nicaragua

Wolf, J., et al. 2014. Systematic Review. Assessing the impact of drinking water and sanitation on diarrhoeal disease in low- and middle-income settings: systematic review and meta-regression. Tropical Medicine and International Health doi:10.1111/tmi.12331, Volume 19 # 8, pp. 928–942

<http://www.fao.org/countryprofiles/maps/map/en/?iso3=NIC&mapID=604>

<http://www.envio.org.ni/articulo/2852>

WHO/UNICEF JMP (2017): <https://washdata.org/>

Annex 1. Estimation of Economic Value of the Health Burden of Pollution

In this report, we use lost welfare approach to estimate the economic cost of health burden attributed to pollution.

Welfare loss is calculated by multiplying the estimated number of premature deaths with the value of statistical life (VSL). VSL measures “represents an aggregate of individuals’ willingness to pay (WTP) for marginal reductions in their mortality risks. It is not the value of any single person’s life or death, nor does it represent a society’s judgment as to what that value should be (Narain and Sall, 2016). VSL is estimated using the stated preference approach, whereby surveyed individuals are asked how much they would hypothetically be willing to reduce their mortality risk marginally. As such, VSL is not limited to the value of output that would be lost in case of premature death but covers an array of other values that contribute to an individual’s and the society’s welfare. Therefore, this measure is not directly comparable with GDP.

VSL estimates are available for OECD countries. In this report, we transfer a range of VSL estimates from OECD countries to Nicaragua using the average GDP per capita differential and assumptions regarding the income elasticity of VSL, following the guidance in Narain and Sall (2016). The resulting low and high-end values, US\$ 0.25 million for the low VSL and US\$ 0.62 million for the high VSL are used in Nicaragua.

Specifically, we use the formula below for benefit transfer:

$$VSL_{N \text{ in } PPP} = VSL_{OECD \text{ in } PPP} \left(\frac{Y_{N \text{ in } PPP}}{Y_{OECD \text{ in } PPP}} \right)^\epsilon$$

$$VSL_N = \frac{VSL_{N \text{ in } PPP}}{PPP}$$

where

$VSL_{N \text{ in } PPP}$	=	VSL in Nicaragua in PPP terms
$VSL_{OECD \text{ in } PPP}$	=	VSL in OECD countries in PPP terms (2014)
$Y_{N \text{ in } PPP}$	=	Per capita GDP in Nicaragua in PPP terms
$Y_{OECD \text{ in } PPP}$	=	Per capita GDP in OECD in PPP terms (2014)
PPP	=	Purchasing power parity for Nicaragua
ϵ	=	Income elasticity of VSL

Table A1 presents the derivation of a range of VSL for Nicaragua from low-end and high-end VSL estimates in OECD countries (Narain and Sall, 2016), using the above formula. This range of adjusted VSL is used in welfare-based CoED estimates in this report.

Table A1. Benefit transfer of VSL for Nicaragua

	Low	High
Average VSL estimates from OECD (million US\$)	3.60	4.10
Country's GDP (US\$ billion) in 2016	13.23	13.23
Country's GDP PPP (US\$ billion) in 2016	34.13	34.13
Population (million) in 2016	6.15	6.15
GDP per capita (PPP US \$) in 2016	5,550	5,550
Average GDP/capita differential	0.15	0.15
Income elasticity of VSL	1.40	1.00
PPP	2.58	2.58
VSL transferred to Nicaragua (million US\$)	0.25	0.62

Source: estimated by the author

Annex 2. The Aqueduct Global Flood Analyzer

1. **Global hydrological and hydraulic modeling.** Daily river runoff and flood volumes ($0.5^{\circ} \times 0.5^{\circ}$) for the period 1960-1999 simulated using the global hydrological model PCR-GLOBWB and its extension for dynamic routing, DynRout. Daily precipitation, temperature, and radiation are used to estimate river runoff, and for each global $0.5^{\circ} \times 0.5^{\circ}$ cell, the resulting volume of water that ends up either in the river channel or on the adjacent floodplain (if flooding occurs) is estimated.
2. **Extreme value statistics.** From the daily flood volume time series for 1960-1999 annual maximum flood volumes for each $0.5^{\circ} \times 0.5^{\circ}$ cell on the map extracted and fitted to a Gumbel extreme value distribution curve. This allows to calculate flood volumes for floods of any magnitude (ranging from a 2-year flood event to a 1000-year flood event).
3. **Inundation modeling.** In this step, the relatively coarse resolution ($0.5^{\circ} \times 0.5^{\circ}$) flood volumes converted into high resolution ($30'' \times 30''$) flood hazard maps showing inundation depths for each cell on the map. This is done using the GLOFRIS downscaling module.
4. **Impact modeling.** Several types of “impacts” per $30'' \times 30''$ cell on the map for a variety of flood magnitudes (e.g. floods occurring once in 10 years, 100 years, 1000 years) are estimated. The impacts are then aggregated to user-selected geographic units (countries, states, basins). The impacts included in the Aqueduct Flood Analyzer are (1) population exposed to flooding, (2) GDP exposed to flooding, and (3) urban damage – in U.S. dollars – from flooding.
5. **Exposed population and GDP.** Exposed population and GDP estimated using downscaled population and GDP data for 2010. For each inundated cell on the map, the number of people and amount of GDP in the inundated cell counted and aggregated up to the country level.
6. **Urban damage.** Urban area per $5' \times 5'$ cell on the map is estimated and economic values to urban areas are assigned. Then a stage damage function used to estimate the percentage of flooded urban assets that would be damaged for different flood depths.
7. **Estimation of “annual expected impacts”.** Each impact – including exposed population, exposed GDP, and urban damage – was calculated for floods of the following magnitudes: 2-year flood, 5-year-flood, 10-, 25-, 50, 100-, 250-, 500-, and 1000-year flood. The impact of a 2-year-flood event was always deemed to be zero. Then “risk curves” or “exceedance probability-impact curves” are fitted. “Annual expected impact” is calculated as the area under the risk curve.

Source: <http://floods.wri.org>