



Vulnerability of Freshwater Resources in the Philippines and its Regions



ABSTRACT

Pressures on the freshwater resources of the Philippines continuously increase due to the intensifying demand of population and economic activities and the declining water supply due to watershed degradation and unsustainable abstraction. The vulnerability of freshwater resources is based on multi-dimensional factors of physical, social, environmental, and institutional features where assessments use composite proxy indicators to combine diversified issues in a simple and understandable form as adapted from the Freshwater Vulnerability Framework of UNEP. As the Philippine Government recently released a National Plan on Water Supply and Sanitation including regional-specific gaps and actions, this study uses Freshwater Vulnerability Index (FVI) to provide a holistic overview of the impacts of different threats and describe its contribution to the overall vulnerability of the water resource. The freshwater resources of the Philippines are moderately vulnerable based on the FVI index of 0.392 indicating that the freshwater resources are generally in good condition but must be ready to face major challenges, specifically on primary threats based on the component structure of the vulnerability. Management capacity contributes the most to the country's FVI, followed by the pressures of water development. Among the regions, freshwater resources experience high vulnerability in Central Visayas, CALABARZON (Cavite, Laguna, Batangas, Rizal and Quezon provinces), Bicol, Ilocos, Central Luzon, and Cagayan Valley. This study can provide insights on the prioritization of the national and regional interventions to reach water resources use and management sustainability.

Keywords: vulnerability, freshwater, supply, sanitation, climate

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INTRODUCTION

The availability of freshwater resources for human activities and ecosystem processes is becoming an increasingly significant global challenge. This is due to the quantitative and qualitative deterioration of water resources, driven by a combination of scarcity, competition for multiple uses, and the impacts of climate change (Aloj *et al.* 2012; USAID 2021; Bogardi *et al.* 2021). Changes in climate patterns and the corresponding alteration on the hydrological cycle can impact water availability and quality. These changes can result to having: too much water; too little water; and too much pollution (Grover 2015; Aloj *et al.* 2012). The 2022 Intergovernmental Panel on Climate Change Technical Summary (Pörtner *et al.* 2022) reported a projection that half of the global population will experience at least one-month of water insecurity annually, a situation that could be worsened by inadequate water governance. This projection is particularly alarming for countries already facing water insecurity and challenges.

In the Philippines, scarcity of water was not considered as an urgent concern with the perceived abundance of water resources. But through the years, simultaneous occurrence of increasing population and economic activities' water demand and the decreasing water supply due to watershed degradation and unsustainable groundwater abstraction resulted in an observed decrease in available per capita water (Rola *et al.* 2018). According to the Climate and Development of the Philippines report (World Bank Group 2022), the projected change in average precipitation may not significantly vary but annual and intra-annual distribution of precipitation may result to wetter northern and central parts while drier in southern parts of the country.

Vulnerability of a resource is generally defined as its "ability to get harmed" (Babel *et al.* 2011) but is always regarded as a context-based concept resulting to different vulnerability assessments especially with climate change (Fussler 2007). For water resources, the vulnerability

concept was based on risk factors from multi-dimensional assessments that include physical, social, environmental, and institutional features (*Gain 2012*). Using composite proxy indicators is an effective approach to combine these diverse features into a simple and understandable form (*Babel et al. 2011*). The use of freshwater vulnerability assessment is becoming more commonly conducted and integrated into management strategies for water resources (*Kanga Idé et al. 2019*) to evaluate the susceptibility and response capacity of a water system using contextually sensitive, holistic approaches for human and biophysical elements (*Plummer et al. 2012*).

One of these methods is a general framework proposed and used by the United Nations Environment Program (UNEP) to assess freshwater resource vulnerability that considers the water system's sensitivity to potential threats and its corresponding challenges including water resources' supply and demand accounting, supporting tenurial systems and governing policies on water management, and varying bio-physical and environmental factors (*Huang and Cai 2009*). This vulnerability assessment methodology has been adapted globally in various water resource management scales. Regional-level vulnerability assessments were conducted for countries belonging to Africa (*UNEP 2008*), Southeast Asia (*Babel and Wahid 2008*), West Asia (*UNEP 2012*), The Pacific Islands (*Duncan 2011*), and the Levant Region (*Al-Sibai et al. 2012*). Smaller scale applications for more localized assessments were conducted in the Hamlimba River Basin, Comoros, Southeast Africa (*El'Houyouun et al. 2019*) and the Al Jabal Al Akhdar of Sultanate of Oman (*Al-Kalbani 2015*), where local prioritization for efforts towards management were identified. The estimation of Freshwater Vulnerability Index (FVI) is based on two perspectives: the main threats to the development and utilization dynamics of water resources represented by resource stresses, development and use conflicts and ecological security; and the challenges of these systems to cope with these stresses measured by the region's water resource management capacity. The FVI can be represented by the function in Equation 1:

$$VI = f(RS, DP, EH, MC) \quad (1)$$

As the Philippines *National Economic and Development Authority (2021)* recently released a National Plan on Water Supply and Sanitation, including region-specific gaps and targets, a holistic analysis can provide an overview on the current impacts of different factors that affects water resources in the country. This study aims to estimate the vulnerability of the water resources of the Philippines based on the different

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parameters that threatens the resource and describe each factor's contributions to the overall vulnerability of the water resource. The vulnerability of water resources of each political region will also provide insights on the spatial variation of the water resource status within the country.

MATERIALS AND METHODS

Study Site

The study covers the vulnerability assessment of the freshwater resources of the Philippines and its 18 administrative regions (**Figure 1**). The country has an archipelagic land area of approximately 300,000 km between 4° 40' and 21° 10' N latitude and between 116° 40' and 126° 34' E longitude. Water resources in the country include inland freshwater, groundwater and marine bodies that includes 421 river basins and 79 natural lakes which were clustered in 12 Water Resource Regions (WRR) (*NEDA 2021*).

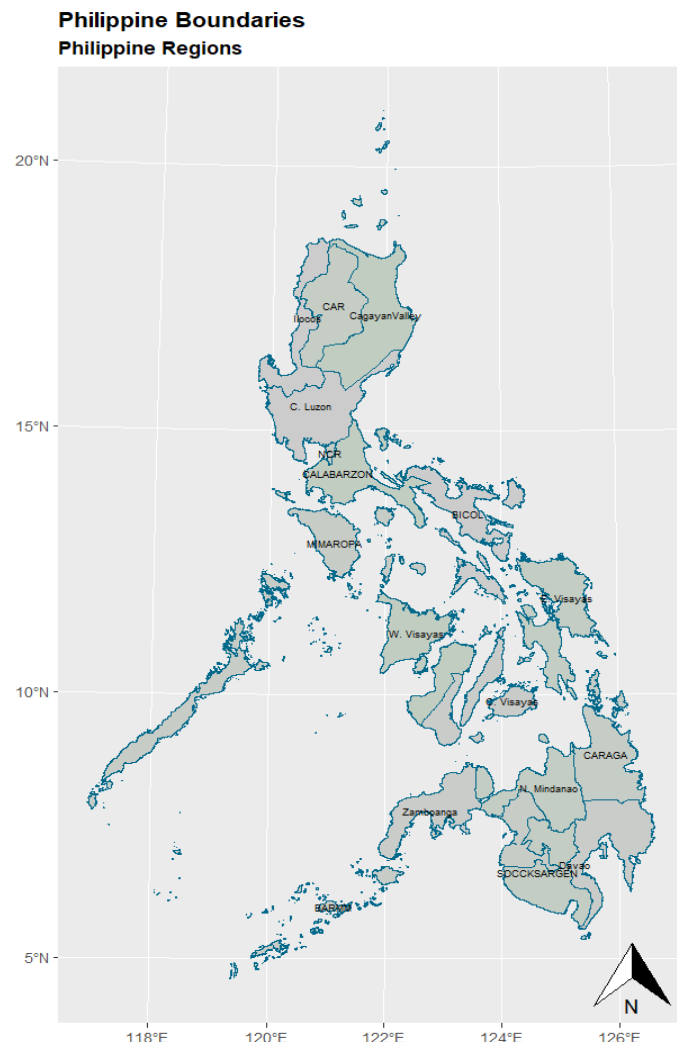


Figure 1. Map of the Philippines including boundaries of its 18 administrative regions.

Freshwater Vulnerability Index (FVI)

Freshwater Vulnerability Index (FVI) is a composite index of different parameters for a comprehensive analysis of the current state of freshwater management and use. The UNEP FVI framework includes Water Resource Stress (WRS), Management Capacity (MC), Water Development Parameter (WDP) and Ecological Health (EH) (**Figure 2**).

Total Water Resource involves components that only consider water resources and their hydrologic balance projecting future climate change effects climate change and the biophysical conditions presented by Equation 2 (each sub-parameter is detailed in **Table 1-a**):

$$RS=f(RSs,RSv) \quad (2)$$

Water Resource Development and Use involves analysis of components of water resource supply and demand, water resource development capacity and resource use presented by Equation 3 (each sub-parameter is detailed in **Table 1-b**):

$$DP=f(DPs,DPd) \quad (3)$$

Ecological Health involves the analysis of water resource post-development and use, as well as key issues including the water quality analysis presented by Equation 4 (each sub-parameter is detailed in **Table 1-c**):

$$EH=f(EHw,EHe) \quad (4)$$

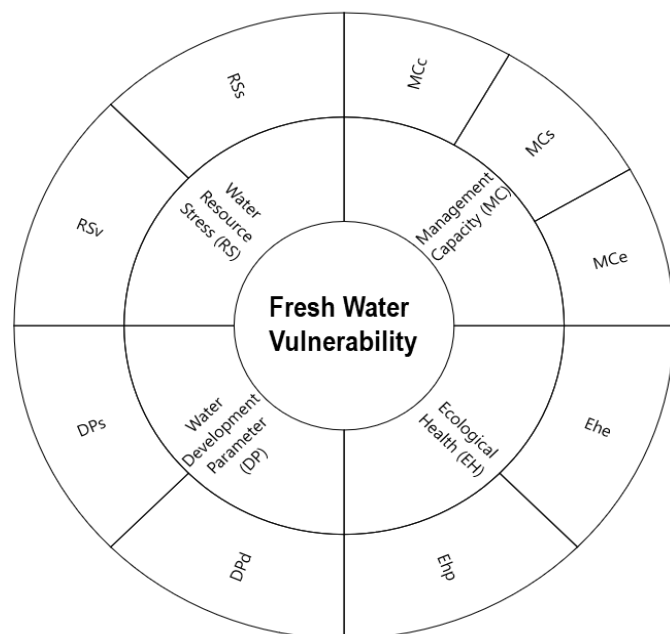


Figure 2. The United Nations Environment Programme Freshwater Vulnerability Index Framework.

Management involves components that assess the management capacity of the system together with its states and trends of arrangements, coordination, and other management factors presented by Equation 5 (each sub-parameter is detailed in **Table 1-d**):

$$MC=f(MCe,MCs,MCi) \quad (5)$$

The overall Vulnerability Index (VI) was estimated based on the categories using Equation 1 with values ranging from 0 representing no vulnerability to 1 representing high vulnerability. Equal weighing of sub-parameters within a main parameter and between parameters were adopted from *Al-Kalbani et al. (2015)* to reduce the bias of relative weights and to be able to analyze and compare final results.

Data Collection

Most recent relevant data were collected from publicly available national and regional reports, data books, statistical reports, and other documents considered as baseline data. Estimation of national data relevant to the vulnerability assessment includes 2022 National Water Resource Accounting (*PSA 2023*), 2022 Field Health Services Information System (*DOH 2022*), National Water Supply and Sanitation Databook and Roadmap (*NEDA 2021*), and land cover maps from *National Mapping and Resource Information Authority (NAMRIA) (2020)*.

Regional level available ground and surface water resource, water use, and demand estimation were collated from the Regional Water Supply and Sanitation Databook and Roadmap Reports (*NEDA 2021*). Updated values on the access to water supply and sanitation were collated from the recent 2022 Field Health Services Information System (*DOH 2022*), while the gross regional domestic product values were from the 2022 Regional Accounts of the Philippines (*PSA 2023*). For the bio-physical datasets, the maps used were from the 2020 Land Cover Map of *NAMRIA (2020)*, while the Modern-Era Retrospective Analysis for Research and Applications (MERRA-2) assimilation model obtained through the NASA POWER database was used to analyze precipitation variation for precipitation data from 1982 to 2022.

Resource Stress Parameter (RS). This parameter accounts for both the quality and quantity of water resources vis-à-vis the pressure brought about by sectoral demands and precipitation variation. Water stress parameter (RSs) evaluates the per capita water resource of each region compared to the minimum level per capita

water resource of 1700 m³ person⁻¹. National and regional per capita available water resource data were based on the estimated groundwater and surface water potential and the 2020 National and Regional Population Census.

Another water stress parameter is the water resources variation (RSv), an expression of the precipitation difference (coefficient of variation, cv) for the last 30

years. This parameter assesses the dependability of water resources based on the variation of their availability. According to *Huang and Cai (2009)*, a 30% variability can lead to high vulnerability of water resources. Daily rainfall data from 1982 to 2022 were accessed from MERRA-2. In calculating cv, the following conditions were observed (**Table 1**).

Table 1. Parameters used for Freshwater Vulnerability Index calculation.

Main Parameter	Sub-Parameter	Equation	Data Source
(a) Resource Stress Parameter	(a-1) Water Stress Parameter	$RS_s = \frac{1700 - R}{1700} ; \text{if } (R \leq 1700)$ $RS_s = 0 ; \text{if } (R > 1700)$	NEDA Water Supply and Sanitation Databook and Regional Roadmaps PSA 2020 housing and population census MERRA-2 global climatological data
	(a-2) Water Variation Parameter	$RS_v = \frac{cv}{0.3} ; \text{if } cv < 0.3$ $RS_v = 1 ; \text{if } cv \geq 0.3$	
(b) Development Pressure Parameter	(b-1) Water exploitation parameter (DPs)	$DP_s = \frac{WR_s}{WR}$	NEDA Water Supply and Sanitation Databook and Regional Roadmaps
	(b-2) Safe drinking water inaccessibility parameter	$DP_d = \frac{Pd}{P}$	
	(c-1) Water Pollution Parameter	$EH_p = \frac{WW}{WR} (WW < 0.10 * WR)$ $EH_p = 1 (WW \geq 0.10 * WR)$	Department of Health FHSIS 2022 NAMRIA land cover maps
(c) Ecological Health Parameter	(c-2) Ecosystem Deterioration parameter	$EHe = Ad/A$	
(d) Management Capacity Parameter	(d-1) Water Use Inefficiency Parameter	$MC_e = \frac{WE_{wm} - WE}{WE_{wm}} (WE < WE_{wm})$ $MC_e = 0 (WE \geq WE_{wm})$	PSA 2022 National Water Resource Accounting NEDA Water Supply and Sanitation Databook and Regional Roadmaps PSA OPENSTAT GRDP 2022
	(d-2) Improved sanitation inaccessibility parameter	$MC_s = \frac{Pd}{P}$	
	(d-3) Integrated Water Resource Management capacity parameter	$MC_i = \frac{1}{4} \sum_{i=1}^4 MC_i$	UN Water SDG 6.5.1 IWRM survey

Water Development Pressures (DP). This parameter estimates the exploitation of water resources across various sectors (eg. domestic and agricultural) and the capacity of management and technology systems for resource accessibility. The water exploitation parameter (DPs) defines the status of water resource development rate and its rate of disruption to the natural hydrological process through the withdrawal capacity while the safe drinking water inaccessibility parameter (DPd) presents the state of social adaptation for the water resource. To quantify the DPs, total water supply capacity of each region was evaluated with respect to the total water resource. Estimates of total water withdrawals were based on the withdrawal reported on the national and regional Water Supply and Sanitation Databook (*NEDA 2021*) based on National Water Resources Board (NWRB) water withdrawal permits. For the evaluation of the DPd parameter, population with access to basic safe water supply reported as safely managed drinking water source in 2022 national and regional field health services information system (FHSIS) database (*DOH 2023*).

Ecological Health (EH). The parameter that covers the overall health of the environment is measured by the contribution of wastewater generation to the vulnerability of the water resources and the level of ecosystem deterioration affecting the environmental flow. This parameter was based on two sub-parameters: the water pollution parameter (EHp) and the ecosystem deterioration parameter (EHe). The parameter EHp is evaluated based on the wastewater generation estimate of 80% of the projected national and regional water demands. The basis of the assumption is that over 80% of the wastewater generated in the Asia and Pacific are discharged untreated to waterbodies (*WWAP 2017*) with consideration the assumption in the adapted methodology of *Huang and Cai (2019)* that mixed sewage contains 10 times the quantity of clear water totally unusable due to NH_3 . The changes in natural landscapes due to urban and economic development are measured to determine the EHe, estimated based on the areas with landcover classification of Built-up, Open/Barren, and Annual crops from the 2020 NAMRIA land cover map.

Management Capacity (MC). The management capacity parameter evaluates the capacity of management systems to cope with the water issues related to water use efficiency, improvement of living conditions, and capacity to manage the resources in an integrated manner (*Huang and Cai 2009; Duncan 2011*). This parameter was based on three sub-parameters: water use inefficiency parameter (MCE), improved sanitation inaccessibility parameter (MCs), and IWRM capacity parameter (MCi).

The MCE parameter for the Philippines is based on the water use efficiency reported in the 2022 Philippine Water Accounts and the regional water use efficiencies were based on the 2022 Gross Regional Domestic Product and the estimated annual water withdrawals from the national and regional WSS Databook (*NEDA 2021*) based on NWRB water withdrawal permits. For the evaluation of the MCs parameter, population with access to improved sanitation facilities were based on the 2022 national and regional field health services information system (FHSIS) database (*DOH 2023*). The MCi parameter ratings were based on the results of SDG 6.5.1 Integrated Water Resource Management (IWRM) survey by *UN Water (2020a)* on the degree of integrated water resources management implementation as reported in their country survey in terms of enabling environment, financing, institutions and participations, and management instruments.

RESULTS AND DISCUSSIONS

Resource Stress Parameters

The vulnerability of freshwater resources based on Resource Stress (RS) is based on pressures posed by its scarcity and variation parameters (*Huang and Cai 2009*) (**Table 2**). The water stress parameter (RSs) is evaluated through the “water unit per population” Falkenmark Indicator provides guidance to categorize areas between water stress ($1000 - 1700 \text{ m}^3 \text{ capita}^{-1} \text{ yr}^{-1}$) water scarcity ($500 - 1000 \text{ m}^3 \text{ capita}^{-1} \text{ yr}^{-1}$), and absolute water scarcity ($<500 \text{ m}^3 \text{ capita}^{-1} \text{ yr}^{-1}$) classifications (*Rijsberman 2006*). Given the country’s total water resource potential of $145,990 \text{ MCM yr}^{-1}$, the country faces water stress conditions with a 2020 Falkenmark Indicator of $1338.92 \text{ m}^3 \text{ capita}^{-1} \text{ yr}^{-1}$ representing how the country experiences regular water stress with values lower than the accepted threshold of $1700 \text{ m}^3 \text{ capita}^{-1} \text{ yr}^{-1}$ (*Gleick and Cooley 2021*). The country’s 2020 Falkenmark Indicator also decreased by 7.39% compared to the 2015 value of $1445.71 \text{ m}^3 \text{ capita}^{-1} \text{ yr}^{-1}$ as reported by *NEDA (2021)* due to the 1.63% population growth rate between this five-year period. These values agree with *Pulhin et al. (2018)* that the water availability of the country is reaching critical limits due to increasing demand even with the abundance of the country’s water resources.

The estimated 2020 Falkenmark Indicators of the Philippine regions indicates that three regions are under absolute water scarcity conditions, three regions are under water scarce conditions, and one region under water stress conditions (**Table 2**). The regions of CALABARZON, NCR and Central Visayas have

Table 2. Resource stress vulnerability parameters for the Philippines and its regions.

Region	Resource Stress Sub-parameters			Resource stress index, RS	Vulnerability Rating
	Water Stress		Resource Variation Parameter, RSv		
	2020 Falkenmark Indicator (m³ capita⁻¹ yr⁻¹)*	Water Stress Parameter, RSs*			
NCR	7.34	0.996	0.200	0.598	High
Ilocos Region	847.18	0.502	0.161	0.331	Moderate
Cagayan Valley	2,134.98	0.000	0.227	0.114	Low
Central Luzon	639.50	0.624	0.124	0.374	Moderate
CALABARZON	161.22	0.905	0.195	0.550	High
MIMAROPA	1,419.83	0.165	0.118	0.141	Low
Bicol Region	681.50	0.599	0.173	0.386	Moderate
Western Visayas	1,928.92	0.000	0.151	0.076	Low
Central Visayas	363.65	0.786	0.174	0.480	High
Eastern Visayas	2,618.56	0.000	0.179	0.090	Low
Zamboanga Peninsula	2,110.40	0.000	0.240	0.120	Low
Northern Mindanao	3,356.52	0.000	0.177	0.089	Low
Davao Region	2,120.32	0.000	0.155	0.078	Low
SOCCSKSARGEN	1,906.36	0.000	0.192	0.096	Low
CAR	3,129.62	0.000	0.234	0.117	Low
BARMM	3,341.52	0.000	0.242	0.121	Low
CARAGA	6,493.90	0.000	0.217	0.109	Low
Philippines	1,338.92	0.212	0.433	0.323	Moderate

*Parameter values are based on the 2020 PSA national and regional population census

Falkenmark Indicators less than $500 \text{ m}^3 \text{capita}^{-1} \text{yr}^{-1}$ implying that water availability is becoming a major economic and human well-being constraint (Gleick and Cooley 2021). These regions are ranked to have the first, second and fourth highest populations on the 2020 population and housing census (PSA 2022). With Falkenmark Indicators less than $1000 \text{ m}^3 \text{capita}^{-1} \text{yr}^{-1}$ but more than $500 \text{ m}^3 \text{capita}^{-1} \text{yr}^{-1}$, the Ilocos, Central Luzon, and Bicol regions are experiencing water scarcity levels where water availability starts to affect health, economic development, and well-being (Gleick and Cooley 2021). Most of the regions have 2020 Falkenmark indicators that are above the water stress threshold.

Philippines' water stress parameter shows that the country is moderately vulnerable ($\text{RSs} = 0.212$) for water scarcity when considering the country level index. However, different levels of regional ratings show that, while most regions have low water stress vulnerabilities, some regions are experiencing severe and high vulnerabilities due to water scarcity, especially in highly populated regions (Figure 3).

For the water resource vulnerability posed by the variation of water availability, the country is rated to have a high vulnerability ($\text{RSv} = 0.433$) as the interannual precipitation received by the country for the past 50 years showed significant levels of variance with a 0.13 coefficient of variation (Figure 4). The country

annually receives an average rainfall of 2,400 mm, spatially varying across regions but mostly northern and southern regions. These are expected variations as the precipitation of the country is highly influenced by the changes in monsoon system during El Niño-Southern Oscillation (ENSO) events (Lyon et al. 2006). Drier or wetter conditions are highly amplified by ENSO events (Hilario et al. 2009), especially during the seasons close to the ENSO mature stage (Villafrute et al. 2014). ENSO events are highly related to the country's drought events with prominent effects on the decrease of water inflow to major multipurpose dams in Luzon and Mindanao (Jose et al. 1996; Tejada et al. 2024). The regional variation parameters show moderate vulnerabilities in the northern regions of Luzon Island and some regions of Mindanao Island. The northwestern part of the Luzon Island behaves differently from other regions during ENSO events as it is affected by the pressure changes in the West Philippine Sea (Kripalani and Kulkarni 1997).

Water Development Pressure

The development pressure (DP) parameter considers the status of water resource exploitation for utilization that alters the health of rivers, springs, and groundwater and system's level of development and adaptation to provide and meet society's well-being (Duncan 2011). This parameter reflects the supply and need balance of water resources posed

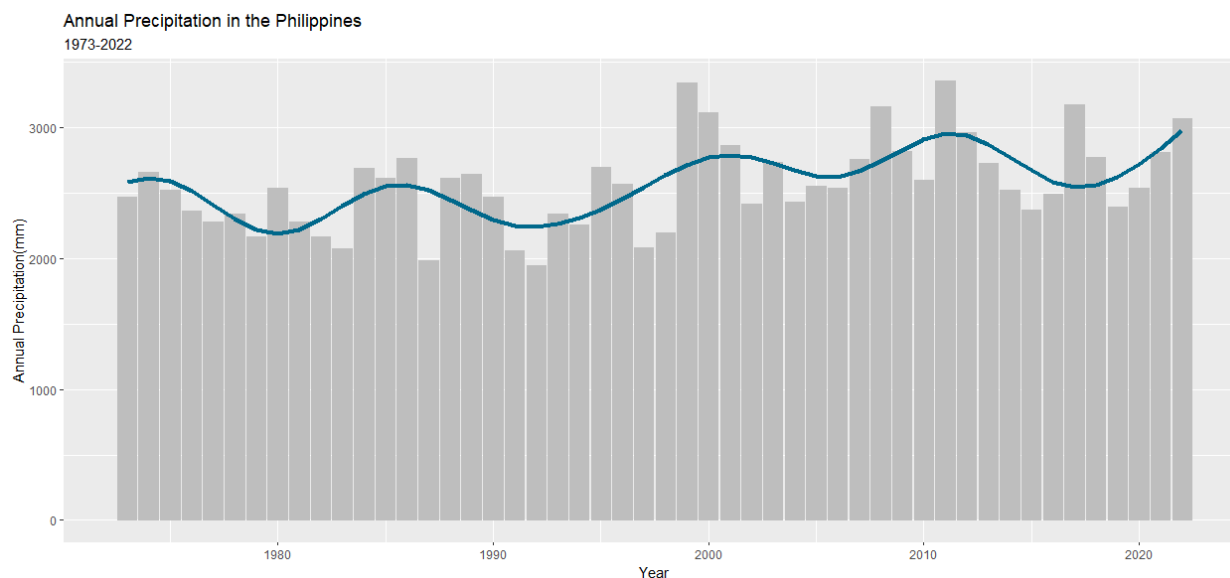


Figure 3. Fifty-year precipitation data of the Philippines (1973-2022).

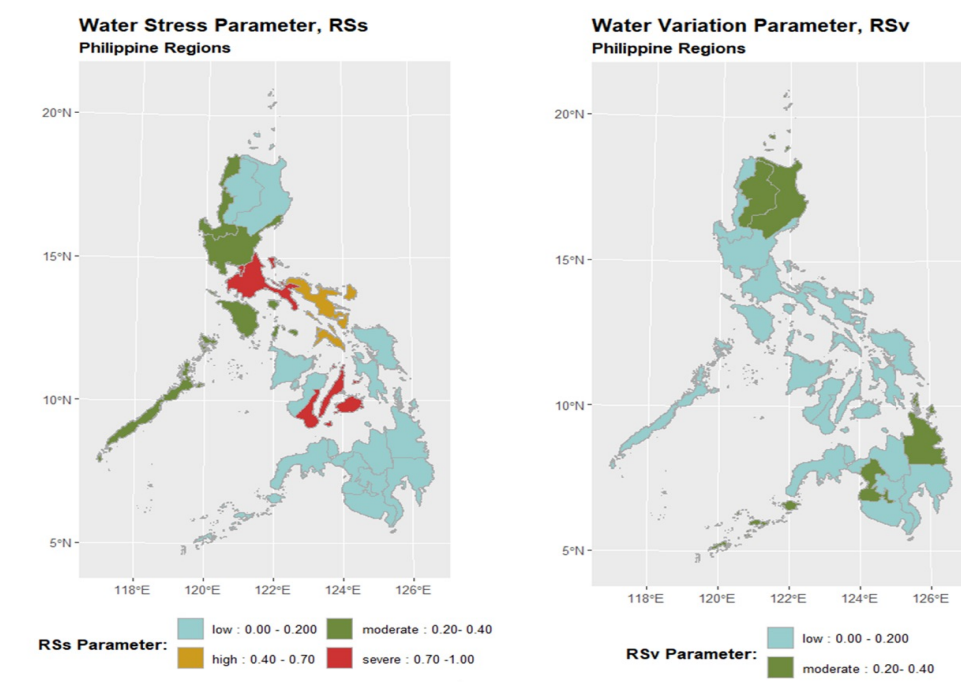


Figure 4. Resource stress vulnerability sub-parameters among Philippine Regions.

by pressures of use associated with urbanization and economic development demand (Huang and Cai 2009).

The water exploitation parameter (DPd) is expressed with withdrawal-to-availability ratio or WTA (also called water exploitation indicator or WEI) that presents the pressures posed by high volume water abstraction of freshwater resources for the identification of areas that faces water stress challenges (EEA 2003). The WTA can also be interpreted as the degree of water resource utilization needed to meet water demands and assess risks associated with over abstraction of water (UN Water 2009). The Philippines' WTA, based on the

estimated 2017 consumptive water use of 82 BCM yr⁻¹ is at 56.2% withdrawal from the country's potential water resource as reported by NEDA (2021). The agricultural sector, including irrigation, livestock, and fisheries, has the highest estimated water allocation mostly withdrawn from surface waters, while the groundwater resources are mostly allocated for industrial and domestic consumption (Rola et al. 2015). The 2040 WTA projections of Luo et al. (2015) predicted high degrees of the country's water shortage that will have high impacts on the agriculture sector but will also be experienced by industrial and domestic sectors (Pulhin et al. 2018). In addition, it is reported by the NWRB that actual water consumption

might be higher due to unpermitted extractions throughout the country compared to the reported NWRB granted withdrawal permits.

Exceeding the 40 % WTA threshold, the country's current WTA level is indicative of its high stress on water resources and severe water scarcity (*Hanasaki et al. 2018; Vanham et al. 2018*) interpreted with the presence of strong water use competition (*EEA 2003*). As both *EEA (2003)* and *Hanasaki et al. (2018)* signified the long-standing non-consensus on the WTA threshold, the country's WTA level may also be classified as "water stress" conditions under *UN Water (2009)* categories that provide a higher threshold of WTA at 60% when approaching physical water scarcity and 75% for water resources with physical water scarcity.

Even though the country generally has an abundance of water resources, geographic and climatic conditions cause significant variations in the distribution and availability of these resources across different regions (*Lapong and Fujihara 2008*). Another cause of regional variations of WTA is the different levels of pressures posed by degrees of population increase and creeping urbanization (*Rola et al. 2018*). Among the Philippine regions, Ilocos, Cagayan Valley, Central Luzon, CALABARZON, Bicol, and Central Visayas have WTA indicative of experiencing physical water scarcity. The results of regional WTA for Ilocos, Central Luzon, and CALABARZON regions are consistent with the findings of *Rola et al. (2018)*, where negative water balances occur for some regions due to the increasing demand for urbanizing, highly populated, and high-economic-growth areas.

Safe Drinking Water Inaccessibility Parameter (DPs) is an integrated parameter that represents the coping capacity of all stakeholders and the availability of technologies reflected by the proportion of population with access to improved drinking water sources (*Huang and Cai 2009*). As 35.2% of the population has no access to safe drinking water sources (**Figure 5**), the overall DPs parameter of the country has an index value of 0.352. The current value still contributes moderate vulnerability despite a 65.4% increase in value since 2019. Recent literature provided a contrast of the different levels of access to safe drinking water. Higher household income level, access to piped and bottled drinking water are directly related to how safe and clean the water is. (*Celeste 2023; Alfonso et al. 2022*). This has a impact on community health as higher rates of diseases spread and infection are evident in areas with reduced access to safe drinking water and sanitation (*Pulhin et al. 2018*).

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According to *Smets (2015)* report on water supply and sanitation in the country, the institutional and financial challenges hinder access to safe water supply. Most of the resources are allocated in the urban water supply sector but are still lacking due to low priority of water and sanitation in national development agenda resource allocation (*Smets 2015*). The rural areas are in a more distressed state as there is no nationally approved policy, investment program, or monitoring schemes for rural water supply. Based on the DPd index values, the regions with low vulnerabilities are focused on NCR, CALABARZON, and Central Luzon. The most vulnerable region is BARMM, with a severe DPd index rating, while the 10 other regions are still in a high vulnerability state.

Ecosystem Health Parameters

The terrestrial hydrologic cycle is influenced by anthropogenic activities (e.g. land use alterations and management, water withdrawal and use etc.) affecting future water availability (*Bosmans et al. 2017*). Vegetation significantly influences hydrological service provision (*Brauman et al. 2007*), such as the effect of anthropogenic water use (*Bosmans et al. 2017*). Vegetation type is an important factor that affects evapotranspiration (*Bosmans et al. 2017*), infiltration and runoff, both important hydrological processes contributing to the quantity and quality of water resources (*Har et al. 2021; Zabaleta et al. 2018*) as documented in several watershed-scale studies (*Santos et al. 2018; Boongaling et al. 2018; Caja et al. 2017*).

Looking at ecosystem deterioration (EHe) as a function of vegetation coverage is an important indicator in determining the capacity of the area to sustain its water resources. For this study, agricultural areas classified as annual crops were accounted as 'non-vegetated' due to their relative rate of change on vegetated cover across seasons. This frequency fluctuations alters the natural hydrologic process in an area that in turn, affects the expected water resource availability. This is supported by the study of *Chowdhury et al. (2022)*, where it was posited that environmental degradation is accelerated by agricultural activities in the long run. Based on the vegetation coverage of the country's 2020 landcover data, Philippines' EHe is rated as high (0.48), primarily attributed to most of the land use allotted for agricultural production (45.76%) and low forested area (23.56%). As reported by *Cruz (2018)*, the 75% decline in forest cover from 1575 to 2010 were observed due to forest harvesting and non-forest land conversions. At present, CAR, Cagayan Valley, and CARAGA have the highest forest coverage (46%, 41% and 38% coverage, respectively).

The water pollution parameter (Ehp) evaluates the influence of water pollution to the hydrological process expressed as the ratio of estimated wastewater discharge through the availability of total water resources with a dilution factor of 10 to raw wastewater (Duncan

2011). The estimated national wastewater generation of 3799.7 MCM year⁻¹ contributes moderate vulnerability (Ehp: 0.2082) to the country's overall vulnerability of freshwater resources. Untreated discharges from the water use of the domestic, industrial, agriculture and

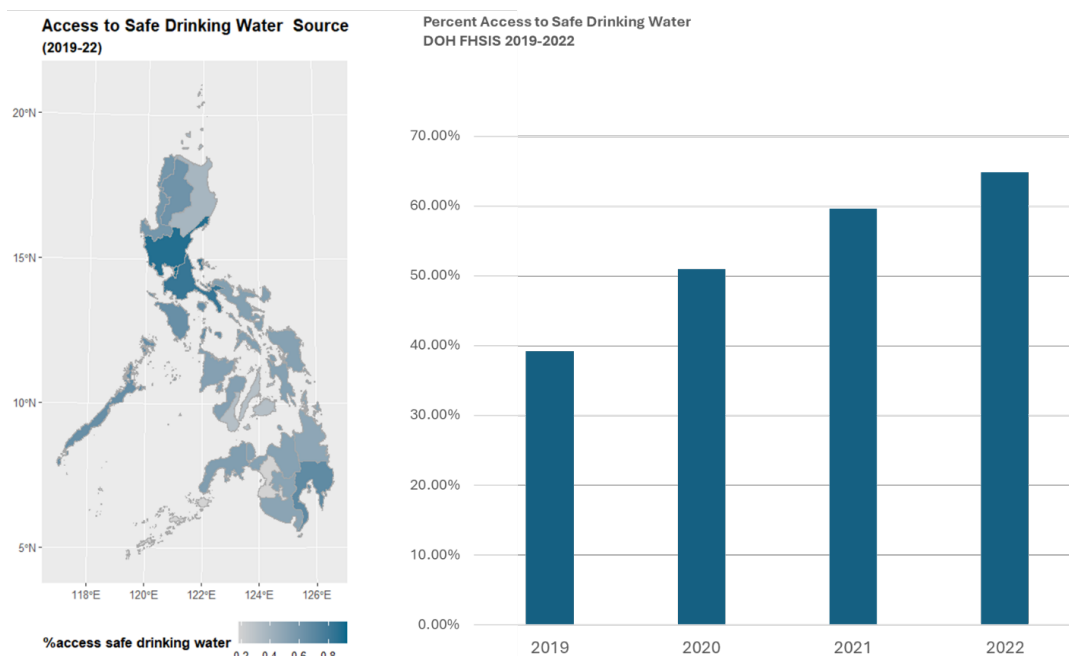


Figure 5. Percentage of population with access to safe drinking water sources in the Philippines and its regions.

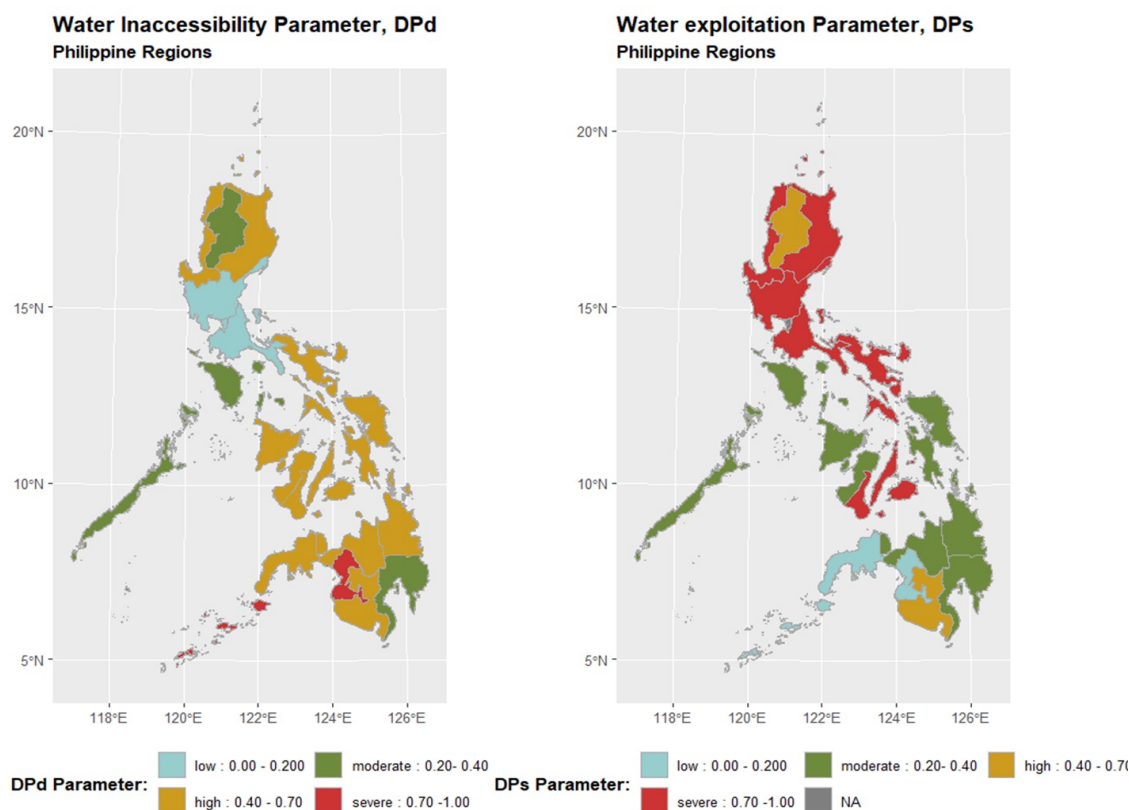


Figure 6. Development Pressure vulnerability sub-parameters in Philippine Regions.

Table 3. Development Pressure vulnerability parameters for the Philippines and its regions.

Region	Development Pressure Sub-Parameters		Development Pressure index, DP	Vulnerability Rating
	Water Exploitation Parameter, DPs	Drinking Water Inaccessibility Parameter, DPd		
NCR *	-	0.072	-	-
Ilocos Region	1.000	0.409	0.704	Severe
Cagayan Valley	0.874	0.625	0.750	Severe
Central Luzon	1.000	0.122	0.561	High
CALABARZON	1.000	0.176	0.588	High
MIMAROPA	0.396	0.356	0.376	Moderate
Bicol Region	0.764	0.472	0.618	High
Western Visayas	0.295	0.476	0.385	Moderate
Central Visayas	0.911	0.687	0.799	Severe
Eastern Visayas	0.239	0.480	0.360	Moderate
Zamboanga Peninsula	0.158	0.458	0.308	Moderate
Northern Mindanao	0.285	0.485	0.385	Moderate
Davao Region	0.346	0.324	0.335	Moderate
SOCCSKSARGEN	0.596	0.502	0.549	High
CAR	0.664	0.385	0.524	High
BARMM	0.082	0.818	0.450	High
CARAGA	0.212	0.516	0.364	Moderate
Philippines	0.562	0.352	0.457	High

*no provided data in the national and regional handbooks of *NEDA (2021)*

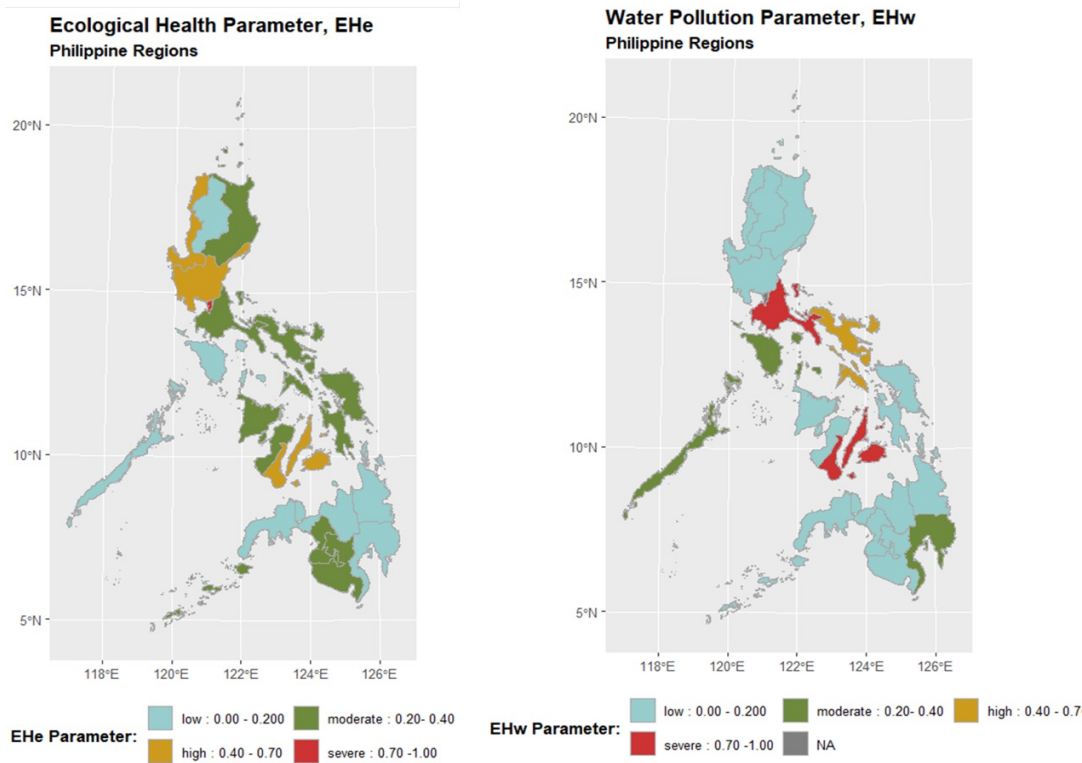


Figure 7. Ecological health vulnerability sub-parameters of Philippine Regions.

livestock sector significantly contribute to the pollution of Philippine waters (*ARCOWA 2018*) as the refuse normally ends up in tributaries and major waterways (*Domingo 2021*). Wastewater may also cause contamination of groundwater when leachates reach aquifers and water tables (*Rola et al. 2018*).

Water quality is poorest in urban areas with industrial and municipal wastewater as the major source of water pollution (*Pulhin et al. 2018*). Based on the water pollution parameter of the regions, both the CALABARZON and Central Visayas regions have severe vulnerability due to compounded effects of the estimated waste water volume

and their relatively lower natural resource potential compared to other regions. High vulnerability due to water pollution is posed in the Bicol Region while, moderate vulnerability is posed in Davao and MIMAROPA Regions.

Management Capacity Parameter

Improved and effective implementation of management practices are necessary for water sustainability and reduction in the vulnerability of freshwater resources (*El'Houyoum et al. 2020*). The management capacity parameter evaluates the capacity of management systems to cope with the water issues of water use efficiency, improvement of living conditions, and capacity to manage the resources in an integrated manner (*Huang and Cai 2009; Duncan 2011*).

The water use inefficiency parameter (MCE) integrates the capacity of policy and technology to water use efficiency evaluated through the economic returns per one cubic meter of water use compared to the average value of selected countries of 40 USD m⁻³ (*Huang and Cai 2009*). Based on the water flow accounts of *PSA (2023)*, the 2022 water use efficiency of the Philippines is 211.04 PhP m⁻³ (1 US\$ = 55 PhP). This registered a 42.3% increase between a 10-year period. Among the 2022 water use efficiencies of different economic sectors, the services sector has the highest water use efficiency of 1300.73 PhP m⁻³ followed by the industrial sector. On the

other hand, the agriculture sector is the most inefficient at 15.49 PhP m⁻³ even with a 14.0% increase since 2013. Challenges in agricultural water use efficiency are attributed to water losses due to institutional and technical deficiencies including the dilapidated structures of canal systems and lack of water pricing policies and structures (*Jose et al. 1996; Rola et al. 2018*).

The estimated 2022 MCE index of 0.904 contributes severe vulnerability to the freshwater resource of the country. All regions are also under severe vulnerability with MCE index ranging from 0.864-0.994. The highest vulnerability due to water use inefficiency is in Cagayan Valley followed by CAR and Northern Mindanao regions.

Improved sanitation inaccessibility parameter (MCs) measures the capacity of freshwater management systems to support the community's basic living conditions. The MCE parameter index for the country of 0.339 poses moderate vulnerability to the country's freshwater resources, even with a 102% improvement between 2022 and 2019 (*DOH 2023*). Among the regions, BARMM, Eastern Visayas, and Northern Mindanao are most severely vulnerable, while NCR is the least vulnerable among the regions. Despite the integration of septage treatment to the national development and programs, investments on wastewater management remains overlooked, underfunded, and fragmentally implemented due to the lack of a general and overarching framework and institutional body (*Domingo 2021*). Also,

Table 4. Ecological health vulnerability parameters for the Philippines and its regions.

Region	Ecological Health Sub-parameters		Ecological Health Index, EH	Vulnerability Rating
	Ecological Deterioration, EHe	Water Pollution Parameter, Ehw		
NCR *	0.912	-	-	-
Ilocos Region	0.409	0.034	0.221	Moderate
Cagayan Valley	0.375	0.137	0.256	Moderate
Central Luzon	0.410	0.121	0.265	Moderate
CALABARZON	0.217	1.000	0.609	High
MIMAROPA	0.172	0.218	0.195	Low
Bicol Region	0.217	0.484	0.351	Moderate
Western Visayas	0.217	0.192	0.204	Moderate
Central Visayas	0.456	1.000	0.728	Severe
Eastern Visayas	0.299	0.122	0.210	Moderate
Zamboanga Peninsula	0.132	0.184	0.158	Low
Northern Mindanao	0.112	0.122	0.117	Low
Davao Region	0.083	0.215	0.149	Low
SOCCSKSARGEN	0.325	0.194	0.260	Moderate
CAR	0.156	0.122	0.139	Low
BARMM	0.231	0.111	0.171	Low
CARAGA	0.113	0.054	0.084	Low
Philippines	0.248	0.208	0.228	Moderate

*no provided data in the national and regional handbooks of *NEDA (2021)*

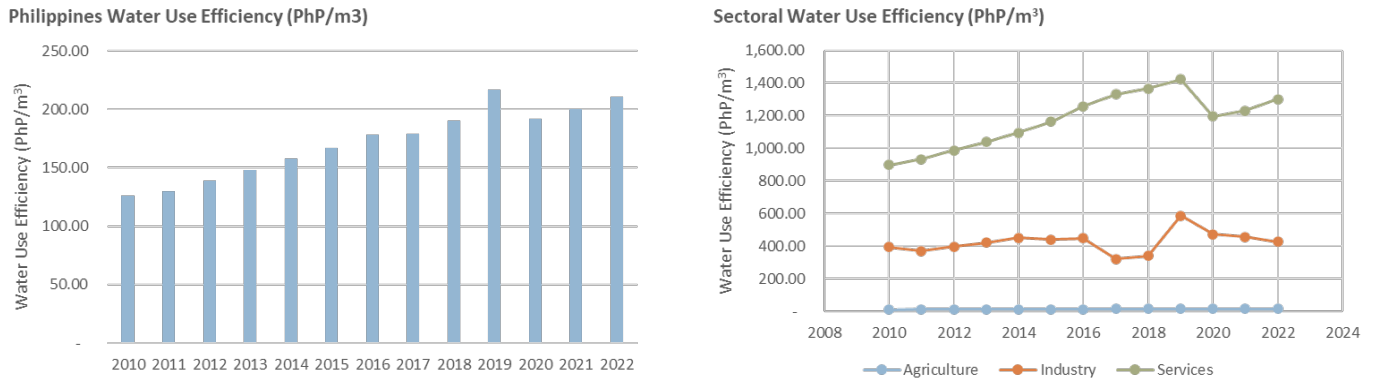


Figure 8. Water Use Efficiency of the Philippines and its sectors from 2008 to 2022.

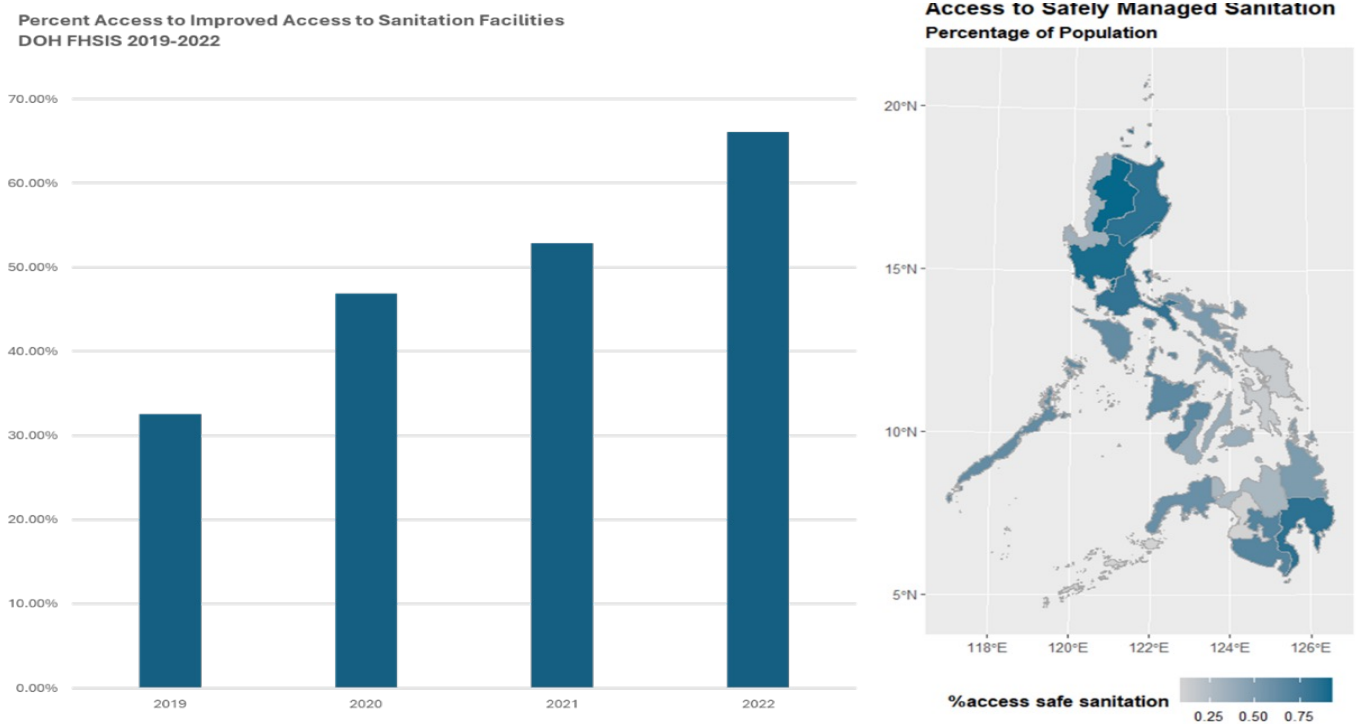


Figure 9. Percentage of population with access to safe sanitation facilities in the Philippines and its regions.

the country is still not meeting its targets due to gaps in monitoring that hinders local data generation for policy and service improvement and prioritization (Molina *et al.* 2021). A study by Celeste (2023) underscored that access to improved sanitation directly correlates to the level of income considering the need for aid provision for households with insufficient income. Impacts of the lack of sanitation in the country were evaluated by USAID (2008), wherein poor sanitation costed the country's economy significant losses mainly due to its impacts on health, followed by impacts on water resources.

The IWRM Capacity parameter (MCi) evaluates water management and its integrated implementation between different sectors and governance frameworks (Duncan 2011). The scores used in this parameter are

based on the national scale IWRM implementation scoring from *UN Water (2020b)* based on surveys and workshops conducted among the water actors. The Philippines is given a rating of 56 based on the country level implementation of the enabling policy environment, institutions and participations, management instruments and IWRM financing. To enable the policy environment in the country, national policies to support IWRM are already in place for different water management dimensions. However, there is a need to ensure alignment and harmonization, translation into actionable points, and tracking of progress. On the other hand, subnational implementation of IWRM is hindered by lack of technical personnel expertise and capacity, lack of coordination, and limited data collection. For institutions and participations, multiple agencies have water-related responsibilities

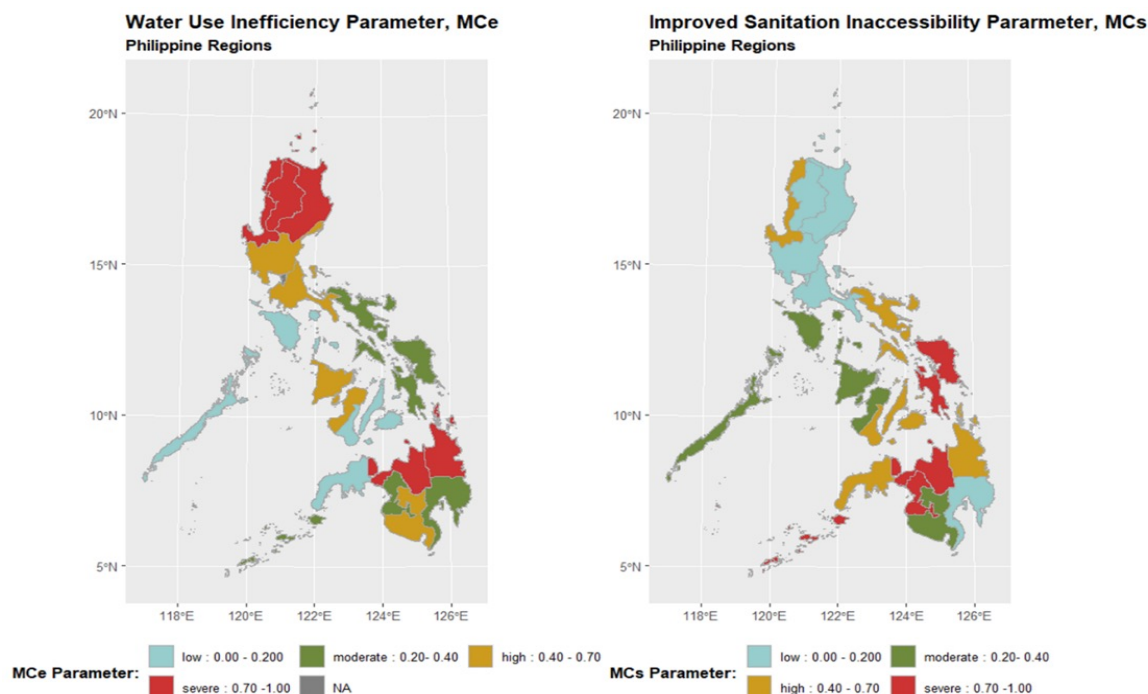


Figure 10. Management Capacity vulnerability sub-parameters of Philippine Regions.

leads to fragmentation that is slowly being addressed as responsibilities became clearer and engagements more defined. Public participation of actors was also institutionalized, especially at the sub-national level, but is impeded by lack of documentation and the need for more regular, active, and meaningful participation among stakeholders. For management instruments, there are programs dedicated for the long-term national monitoring of water quality and availability in all water management scales currently shared with the key policy implementors. However, the management is still increasing its scope in terms of geographical coverage and technological aspect. Financing IWRM has the lowest score among the IWRM components due to the competing development priorities in the national and subnational levels and insufficient funds for local government units that only allows them to deliver minimum investment expectation. Given the rating of the country, high vulnerability, MCi was rated with 0.44 for the overall IWRM capacity of the country.

Philippine Freshwater Vulnerability Index

The freshwater resources of the Philippines are moderately vulnerable based on the overall FVI parameter index of 0.392. This value indicates that the freshwater resources are in a generally good condition but must be ready in facing major challenges through technical or managerial capacity building based on the assessed vulnerability structure. Looking at the parameter values, the management capacity parameter has the highest contribution to the vulnerability

specifically the inefficiency of water uses and the implementation of an integrated management system for water resources. This is followed by the water development parameter specifically with 61.5% contribution from water exploitation and 38.5% contribution of drinking water inaccessibility. Resource Stress and Ecological Health parameters contributes 20.6% and 14.5% to the vulnerability, respectively.

Among the regions in the Philippines, except NCR that has incomplete parameter data, Central Visayas is the most vulnerable with a high vulnerability index value of 0.663. This is mostly due to the region's vulnerability due

IWRM Implementation rating
National 2020 Report for Philippines

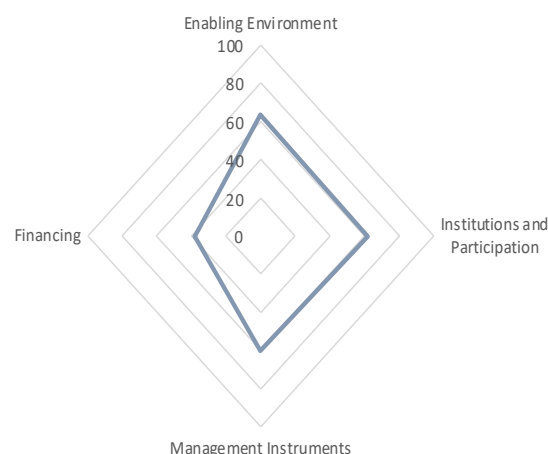


Figure 11. Philippines IWRM Instruments Rating for 2020 (UN Water 2020b).

Table 5. Management capacity vulnerability parameters for the Philippines and its regions.

Region	Management Capacity Parameter			Ecological Health Index, EH	Vulnerability Rating
	Water Use Efficiency Parameter, MCE	Sanitation Inaccessibility Parameter, MCs	IWRM Capacity Parameter		
NCR *	0.000	0.076	0.440	-	-
Region 1	0.984	0.660	0.440	0.694	High
Region 2	0.994	0.157	0.440	0.530	High
Region 3	0.947	0.114	0.440	0.500	High
Region 4a	0.952	0.177	0.440	0.523	High
Region 4b	0.886	0.376	0.440	0.568	High
Region 5	0.928	0.483	0.440	0.617	High
Region 6	0.942	0.343	0.440	0.575	High
Region 7	0.864	0.627	0.440	0.644	High
Region 8	0.921	0.852	0.440	0.738	Severe
Region 9	0.893	0.402	0.440	0.578	High
Region 10	0.987	0.704	0.440	0.710	Severe
Region 11	0.919	0.159	0.440	0.506	High
Region 12	0.959	0.311	0.440	0.570	High
CAR	0.993	0.083	0.440	0.505	High
BARMM	0.932	0.913	0.440	0.762	Severe
CARAGA	0.974	0.492	0.440	0.635	High
Philippines	0.904	0.339	0.440	0.561	High

*no provided data in the national and regional handbooks of *NEDA (2021)*

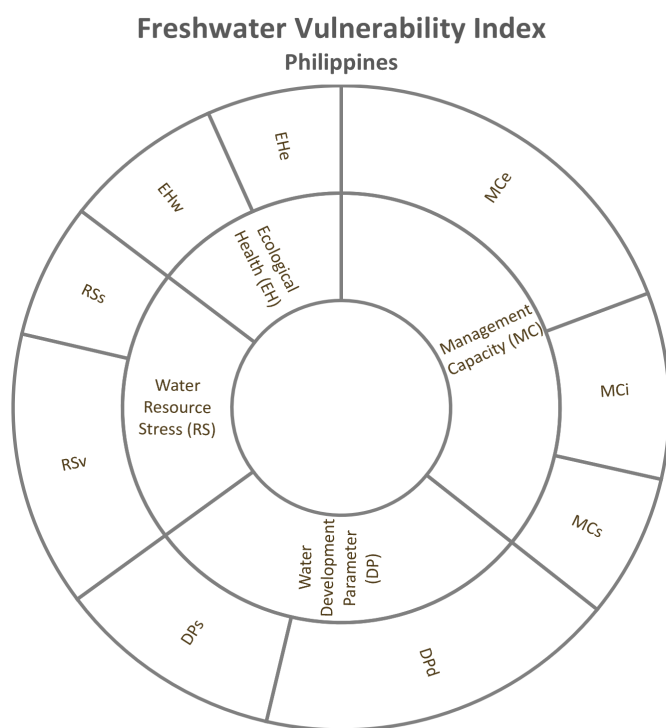


Figure 12. Distribution of parameter contribution to Philippines freshwater resource vulnerability.

to the development pressure and its ecological health. This is followed by regions with high vulnerability including the regions of CALABARZON, Bicol, Ilocos, Central Luzon and Cagayan Valley. The freshwater resources of all the remaining regions are moderately vulnerable with the Davao and Zamboanga Peninsula region having

the least values of 0.267 and 0.291, respectively. Both regions have low vulnerabilities due to acceptable index values for water resource stress and ecological health.

CONCLUSIONS AND RECOMMENDATIONS

Water scarcity in the Philippines has not been regarded as an urgent concern due to the perceived abundance of water resources. However, increasing pressures from the growing population, economic activities, and ecological degradation are intensifying resource stresses. The concept of water resource vulnerability was based on multidimensional factors, including physical, social, environmental, and institutional features. Vulnerability assessments are integrated into the formulation of management strategies to address susceptibility and response capacity.

As the Philippines is gearing toward a national plan on water supply and sanitation, this study attempted to provide a holistic analysis of the impacts of different factors that affect water resources in the country. This study adopted the UNEP freshwater vulnerability framework that uses a composite proxy indicator to combine diversified issues in a simple and understandable form. This includes analysis of parameters that includes water stress, development pressures, ecological health, and management capacity.

The Philippines' water stress parameter that accounts for both the quality and quantity of water

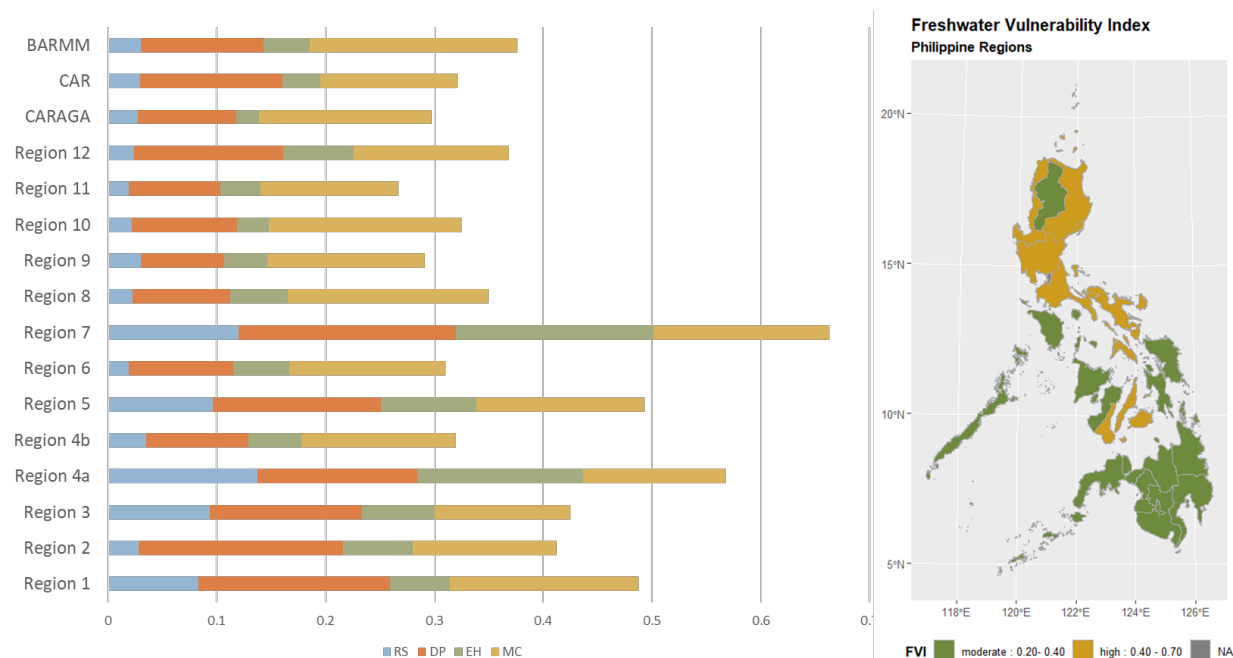


Figure 13. Regional Vulnerabilities and Distribution of parameter contribution to water resource vulnerability per region.

resources vis-à-vis the pressure brought about by sectoral demands and precipitation variation is 0.323 posing moderate vulnerability to its water resources. The sub-parameter indices of water stress and resource variation are moderately and highly vulnerable, respectively. Among the regions, Central Luzon and Ilocos Regions are highly vulnerable due to resource stress.

Based on the analysis of resource development parameter that accounts for both the status of water resource exploitation and the system's level of development and adaptation, the country's DP parameter index is 0.457 posing high vulnerability to its water resources. The sub-parameter indices of drinking water inaccessibility and resource exploitation parameter are moderately and highly vulnerable, respectively. Among the regions, Ilocos, Cagayan Valley, and Central Visayas are severely vulnerable due to resource development.

The analysis for ecological health parameter accounts for the overall health of freshwater resources measured by its water quality and the level of ecosystem deterioration affecting the environmental flow, the country's EH parameter index is 0.228 posing moderate vulnerability to its water resources. Both the sub-parameter indices of water pollution and ecological parameter pose moderate vulnerability to the water resources. Among the regions, high vulnerability is experienced in CALABARZON due to the ecological status of water resources.

Based on the analysis of the management capacity parameter, which includes the ability of management systems to address water use efficiency, improve living conditions, and manage resources in an integrated manner, the country's MC parameter index is 0.561. This indicates high vulnerability to its water resources. The sub-parameter indices of water use efficiency parameter pose severe vulnerability to the water resources while the IWRM Capacity and Sanitation inaccessibility poses high and low vulnerability, respectively. Severe vulnerability due to the management capacity is experienced in the regions of Western Visayas, Northern Mindanao and BARMM while all the remaining regions experience high vulnerability due to management capacity.

Overall, the freshwater resources of the Philippines are moderately vulnerable based on the FVI parameter index of 0.392, indicating a generally good condition of the water resources but facing major challenges in technical or managerial capacity building based on the assessed vulnerability structure. Management capacity contributes the most to this vulnerability value followed by the pressures of water development. Among the regions, freshwater resource experiences high vulnerability in the regions of Central Visayas, CALABARZON, Bicol, Ilocos, Central Luzon, and Cagayan Valley Region.

As the study provides baseline for the parameters that can affect the vulnerabilities of freshwater resources, studies and actions on specific components to reduce

the vulnerability of each region can be identified and focused on as priorities for a science-based water resource management. Additionally, the methodology provided can be used to project forecasted vulnerabilities of freshwater resources in the country in the future once datasets are available for long-term water resources planning.

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