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Mountainous City Landscape Water Supply System Potential Carbon Footprint: Case of the Philippines' Catbalogan Sky City Mega Project

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ABSTRACT

Catbalogan Sky City Mega Project (CSCMP) is a climate-change (CC) adaptation strategy proposed after Typhoon Haiyan devastated the Philippines in November 2013. It is currently being built on top of a hill about 120m from sea level to avoid the impact of storm surges, sea-level rise, and flooding. With the city's continued expansion, water demand further worsens the supply gap. This study focused on determining the carbon footprint of the proposed water supply scarcity solution. This solution includes the construction of a reservoir to receive runoff water from the watershed where the CSCMP is located. Results of the study show that the reservoir can supply the water requirement for the entire city. However, the carbon footprint of the recommended solution is between 123% and 557% due to water treatment of heavily contaminated runoff water and the power consumption in distributing water to higher elevations. There is a need for the city to design a harvesting system that will reduce the need for more intense water treatment (i.e., reducing exposure of runoff water to contaminants) and the use of renewable energy in powering pumps and other treatment activities.

INTRODUCTION

The global population has continuously grown by more than 80 million per year, and the rate expects to grow by 2 billion annually by 2050 (Population Matters 2018). The growth rate in urban areas continues to grow despite having low fertility attributed to migration. By 2050, the urban population share is expected to increase to 68% from 54% in 2018 (Bolay & Kern 2019, United Nations 2018). Some countries in Latin and North America, including the Caribbean, have their population share reaching about 80% in urban centers than in the countryside (Bolay & Kern 2019). Overall, Asian countries share about 54% of the global urban population, while Europe and Africa have 13% each (United Nations 2018).

Many urban areas are scarce with available land. Cities need to expand to accommodate people attracted to the urban centers. Cities either expand horizontally (new growth areas) or vertically through high-rise buildings (Al-Kodmany 2018, Wennersten 2018, Tosics 2015). Either way, both approaches have climate-change-related challenges. Going vertical makes cities denser and requires more energy, while the horizontal expansion will require changing land use and scarcity of land for some. Urban expansion (vertical or horizontal) will always increase population density. Densely populated urban areas are very vulnerable to the impacts of CC, especially those coming from low- and middle-income countries (Dodman 2009) like the Philippines.

Water resources are vital for any community's survival (Green Facts 2008); cities need this resource to be competitive; water is life (National Geographic nd). History explains that communities are established where water abounds, like coastal zones, nearby rivers, or the river mouth. Today, most of these communities' water resources are severely affected due to the intensifying CC phenomenon (Misra 2014, Talat 2021). Because of CC, some areas have more water during extreme hydrological events that lead to floods, while others experience water scarcity (Pingale et al. 2014, Steeneveld et al. 2018). Some cities in the world look for strategic approaches to address water scarcity. One good example is Singapore, which has four sources: runoff waters captured in catch basins, imported water from Malaysia, recycled water, and desalinated water (PUB nd.a, Hsien et al. 2019). Other water-scarce areas make use of rainwater as a viable resource. Rainwater harvesting is not new but remains one of the most influential alternative water supply options (Liu et al. 2020). In Singapore, runoff water is drained into canals, and those that exist in streams and rivers are treated before it is used for various purposes

(PUB nd.a, Hsien et al. 2019). The choice of water production process depends on many factors, the primary consideration is financial resources. While countries like Singapore can supply water to their population despite being water-scarce, other economically challenged countries face difficulty. In 2018, the water production cost in Singapore is pegged at $1.78 (PUB nd.c), while in the Philippines, it is US$0.21 per cubic meter for the first 40 cubic meters (MWSS 2017). The vast gap can be attributed to the cost of water production and the economic status of the countries.

The Philippines improving economy facilitated the growth of communities in major cities and those in the countryside. As it grows, the need for new areas for development is paramount. Equipped with information about disasters like Typhoon Haiyan, cities like the Catbalogan in the Eastern Visayas region embarked on an ambitious project dubbed the Catbalogan Sky City Mega Project (TAP nd., Orale & Novilla 2016, Hurtado 2019) or CSCMP. The project received positive reviews in the Philippines and abroad (Catbalogan LGU 2019, Meniano 2018, CDIA Asia 2016), but some questions remain, such as water supply requirements for the city to thrive.

This study aimed to present the likely water supply scenario if no suitable land use plan exists and a scientifically backed-runoff water collection system is incorporated. Information about the old city and the CSCMP, such as current and future water demand and the wastewater production profile, was determined to answer this. The water supply production and distribution cost were calculated based on the information gathered. Also, the potential contribution to CC was estimated.

MATERIALS AND METHODS

The paper focused on the characterization of the water supply for the Catbalogan Sky City project, specifically the runoff harvesting, treatment, distribution, and production cost, as well as the carbon footprint. The plans were based on secondary data; the current master plan for the Sky City and the drainage system collecting the runoff water and gray water are based on prevailing designs used by the LGU of Catbalogan and the indicative plans for the city. There is no active Comprehensive Land Use Plan (CLUP) in the City of Catbalogan.

Study Site Profile

The study site profile, specifically it is land utilization in the study site, was derived from secondary sources, mainly from unpublished Local Government of Catbalogan City reports. This information was validated through a physical survey using a drone to capture the current condition of the study sites, specifically land cover. Without an updated Comprehensive Land Use Plan (CLUP), the proposed Sky City Mega Project plans were based on the concept proposals submitted by the LGU of Catbalogan to various funding institutions. Population demographics are estimated based on the 2020 census population from the Philippine Statistics Authority. The researcher also referred to drone shots of the watershed and visited areas in the study sites for validation, especially along the groundcover parameters for the HEC-HMS-based modeling. The drone shots and other plans were georeferenced for QGIS analysis. Handheld GPS was used to locate specific areas seen in the drone images.

Water and Waste Water Production, Treatment and Distribution Profile

The current production, treatment, and distribution profile were extracted from the reports available at the Catbalogan Water District (CWD). From these reports, the proportion of production (PP) from each of the sources (PS_i) per month for n sources (e.g., Spring/groundwater; Caramayon, Masacpasac, Tomalistis, Executive, Lagundi; surface water Kulador and Sky City lagoon; and other minor sources) was calculated using equation (a);

$$PP = \frac{PS_i}{\sum PS_n} \quad \ldots(1)$$

The distribution according to the type of use (i.e., domestic use or DU, and non-domestic use or NDU) was also calculated based on the reports of CWD. Equations used for the PDU (proportion for DU) and PNDU (proportion of NDU) are (b) and (c) respectively;

$$PDU = \frac{DU}{(DU+NDU)}\ 100\% \quad \ldots(2)$$

$$PNDU = \frac{NDU}{(DU+NDU)}\ 100\% \quad \ldots(3)$$

The water system flow network was generally described based on inspections made to at least 20 households, 15 commercial establishments, and five institutional sectors. Documentary reviews and informal interviews with other sectors involved in the system and supplemented with technical reports by Gomba et al. (2007a, 2007b). The system's water supply network draws from water sources to collection and treatment facilities, then to domestic (households or DU) and non-domestic clients (i.e., industrial, commercial, institutional/government, others or NDU) utilization, then followed by wastewater production and disposal. The volume of wastewater is a function of water use. Information about wastewater production and disposal is unavailable in many parts of the Philippines (Claudio 2015, ADB 2013), including Catbalogan City. The UN Water estimates that around 80% of used water becomes wastewater. Most of the wastewater in Catbalogan City finds its way to waterbodies (Orale & Fabillar 2011); others seep into the grounds. Canals and waterways in Catbalogan are either concreted (with poor water tightness attributed to construction defects or poor maintenance/cracked) or unlined (like Antiao River and Antiao Creek). Seepage into the soil strata is governed by permeability, texture, bulk density, porosity, and others (Rai et al. 2017). The loss in water due to seepage and evaporation was estimated using a modified ponding method described by Rai et al. (2017). The modification includes creating a 1m x 1m x 1m pond filled with water until the soil is saturated to mimic an active drainage canal condition. After it is saturated, the pond is filled with canal water, and the drop in height is the loss estimate. The seepage and evaporation loss in the three sites was 16, 27, and 45, or an average of 29.33 or approximately 30%.

The future water supply network was based on the assumption that no specialized intervention exists. Here, the manner of production, treatment, and distribution of water and wastewater, including disposal, was analyzed similarly. The collection of runoff water as an additional water source was incorporated into the system.

Water Supply and Demand

Water demand and available water supply are based on a projected scenario of the future. This future is based on the plans such as the currently being updated Catbalogan Comprehensive Land Use Plan (CLUP) and the Sky City concept proposals, which were available during the study. Formulation and the implementation of planned developments like CLUP face many challenges (Lech & Leppert 2018, Salazar-Quitaleg & Orale 2016, Huang & Cantada 2019) that lead to the non-realization of the plan. For this paper, the realization rate of the planned future was set to only between 5% to 25% considering the low compliance of the city to zoning regulations and the variability of a future scenario affecting the implementation of the planned future. Available Water Supply (AWS) is from the CWD sources (CWS) and the extractable water at the planned lagoon (EWL). The subscript "t" stands for the time/year, specifically 2022 and 2040;

$$AWS_t = CWS_t + EWL_t \qquad \ldots(4)$$

The CWS is from at least three primary water sources and other groundwater wells (CWD 2018) and is assumed will not decrease or increase over time. The quantities were extracted from the monthly official reports of CWD (CWD 2015, CWD 2021, CWD 2022). The EWL, on the other hand, is the water collected from various drains to the lagoon. The quantity of EWL is estimated using the Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS) of the US Army of Engineers (USACE nd.). Equation (e) is for the water demand for 2022 and 2040.

$$WD_t = DD_t + CD_t + ID_t + GID_t + OD_t \qquad \ldots(5)$$

The WD was estimated from five groups of users; residential/domestic (DD), commercial (CD), industrial (ID), government offices/institutional (GID), and others (OD). These are estimated based on current and future scenarios. For example, the DD estimate considered the entire population and not only those who are serviced with CWD. Current water demand from the rest of the consumers was based on the 2020 monthly records of the CWD (CWD 2021).

Future water demand was based on the projected development scenario by 2040. The allocation of new residential, commercial and industrial zones will result in a higher population primarily through migration. The water demand by 2040 (WD_{2040}) under the 5% future development scenario is calculated as;

$$WD_{2040} = (LA_{2040})(5\%)(CR_{2022}) \qquad \ldots(6)$$

where LA is the land allocation for specific land use (e.g. residential/domestic, commercial, industrial, government/institutional, and others), and the term CR_{2022} is the base consumption rate for 2022 for the specific land use. For example, CR_{2022} for residential land use is calculated as;

$$CR_{2022(residential)} = \frac{LA_{2022(residential)}}{WD_{2022(residential)}} \qquad \ldots(7)$$

equation (f) and (g) is similar for other land uses. The consumption rate (CR_{2022}) for occupied residential, commercial, industrial, and institutional lands is estimated to be 2.45, 2.31, 0.14, and 1.0 cubic meters of water per square meter.

Wastewater Production Profile

Catbalogan wastewater production is unknown. Globally, it is estimated that around 80% of consumed water is transformed into wastewater, and the remaining 20% is a function of evaporation and unaccounted water (UN Water 2021a, UN Water 2021b, UNESCO nd.). In the Philippines, only 10% of all wastewater is treated, and only 5% of the total population is connected to a sewer network (Claudio 2015), Catbalogan City has almost none. Institutional/governmental, commercial, and Industrial wastewater production will be calculated similarly to domestic wastewater. The calculation of wastewater (WW) produced is 80% of water demand (WD). Formula (h) was used for all wastewater production per type of land use.

$$WW_{2040} = (WD_{2040})(80\% \qquad \ldots(8)$$

Runoff Water Estimation and Stormwater Collection System

Rainfall-runoff discharge estimation was through the HEC-HMS version 4.5 developed by the US Corps of Engineers – Institute for Water Resources Hydrologic Engineering Center. As shown in Table 1, the simulation data that were kept constant are the land allocation area and soil type, while the average monthly rainfall data was based on the 2021 reports from the Philippine Astronomical Geophysical and Astronomical Administration (PAGASA) for Catbalogan City. The impervious layer, lag time, and SCS-CN values were estimated based on the possible land utilization.

The stormwater collection system was assumed to be similar to what Catbalogan City currently uses. Runoff water enters the canal bringing in sediments, solid waste, and contaminants. The runoff waters, including those drained from roofs of buildings/houses, roads, lawns, and other pavements, including those from vegetated grounds, are most often heavily contaminated with chemical and biological matters. Without a detailed plan of the Sky City, it is assumed in this paper that roadsides have a drainage system leading to the impounding dam.

Carbon Footprint of Water Supply Production and Distribution

Carbon Footprint is estimated using CO_2-e or the Carbon Dioxide Equivalent; several metric tons of CO_2 emissions with the same global warming potential as one metric ton of another greenhouse gas (EPA 2022). The entire operation of the CSCMP will generate a Carbon Footprint designated as Carbon Dioxide equivalent or CO_2-e; one of which is the production, treatment, and distribution of water supply. In this paper, only the carbon footprint due to pumping water from the source to treatment plants and clients, as well as chemicals (i.e., chlorimide) was considered. Based on CWD reports for 2021, about 0.632 kWh of energy was used to pump out water from the source to the treatment facility and distribution. About 78% of the energy used was used for production and 22% for distribution. The exact value will be used to pump out water from the lagoon to households. Therefore, the carbon footprint in water production (CFWP) and distribution (CFWD), considering the type of energy used (CFET) in Catbalogan City, is based on current practice is;

$$CFWP = WD[(0.632)(78\%)](\%EM_{nr})(CFET) \quad \ldots(9)$$

$$CFWP = WD[(0.632)(78\%)](\%EM_{nr})(CFET) \quad \ldots(10)$$

The $\%EM_{(nr)}$ is the percent of the energy used that is non-renewable. Energy production from renewable sources like geothermal energy has a very low carbon footprint (Pehl et al. 2017, EIA nd.), thus was not considered. The value used for this study is 43% extracted from the 2020 and 2021 energy mix used by the local power supplier, the Samar II Electric Cooperative (SAMELCO II 2020, SAMELCO II 2021). The CFET for energy from coal-powered electrical plants is about 0.79 kg of CO_2e per kWh of energy produced (Richie 2020, Scherer & Pfister 2016). The distribution cost for the case of the CSCMP is 0.632 kWh of energy per cubic meter.

The current treatment process includes sedimentation, rapid and slow sand filtration, and finally, chlorination

Table 1: Parameters used in the HEC-HMS simulation.

Land Allocation	HEC Parameters	Year (Development Scenario)		
		2022	2040 (5%)	2040 (25%)
Sky City Area: 0.909 km2	SCS-CN	77	85	92
	Impervious Layer [%]	5	50	80
	Lag Time [min]	30	20	15
Outside Area: 1.55 km2	SCS-CN	77	80	90
	Impervious Layer [%]	5	10	25
	Lag Time [min]	30	25	18
Green Area: 0.616 km2	SCS-CN	77	77	77
	Impervious Layer [%]	1	1	1
	Lag Time [min]	45	45	45
Lagoon Area: 0.309 km2	SCS-CN	77	77	77
	Impervious Layer [%]	1	5	5
	Lag Time [min]	5	5	5

(CWD nd.). For this study, the current carbon footprint is based solely on the chlorination process, while by 2040, it is assumed that it will become more advanced. The carbon footprint to produce potable water from groundwater/spring water, and surface water from the river in 2022 is 0.02 and 0.08 kg CO_2e per cubic meter, respectively. By 2040, the carbon footprint for groundwater/spring water, surface water (i.e Antiao River or other imported water from rivers of other nearby towns), and runoff water are estimated at 0.05, 0.10 (Biswas & Yek 2016), 0.39 kg of CO_2e (Hsien et al. 2019) per cubic meter of water respectively.

The SCMP will harvest runoff water and store it in a lagoon as a reservoir. There is no available runoff water harvesting design making it potentially heavily contaminated. The current runoff collection system for the City of Catbalogan also receives wastewater from all sources, the reason for it being treated as gray water.

RESULTS AND DISCUSSION

All cities are called upon to respond to the challenges posed by global warming. However, the responses of every city vary; most often than not, these actions lack evaluation of whether it is a solution or contributing to the problem they aimed to address. The foregoing will present the CC adaptation of a small city in the Philippines and examine the carbon footprint of the approach. The study delimits its scope to water supply, one of the challenges the new project will face.

Catbalogan Sky City Profile

Catbalogan is a coastal component city and the capital of the province of Samar Philippines (PhilAtlas nd.a) The 106,440 population as of the 2020 census is distributed to its 57 barangays or villages (PhilAtlas nd.b), most of which is concentrated in the city center, which is only about 2% of the total land area (Orale 2006). With a 2.47% growth rate, the city will reach 173,396 thousand by 2040. The actual population density in the city center will likely reach around 10,000 people per square kilometer (Orale 2006), one of the highest in the Eastern Visayas Region. These numbers do not include the transient workers coming to the city for work and other purposes but returning to nearby municipalities/

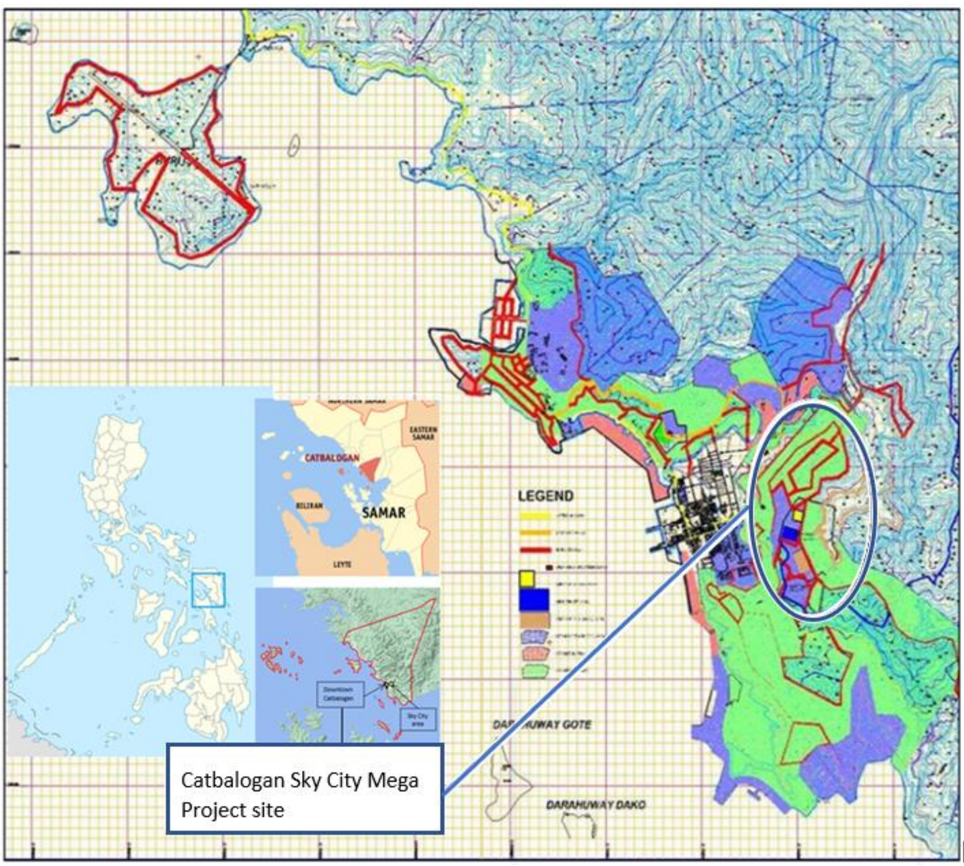

Fig. 1: Comprehensive development map of the entire Catbalogan; inset is the Sky City Mega Project.

cities at night. The City of Catbalogan has an economic activity among others that is among the highest based on the Competitiveness Index report since 2016 (DTI nd.), further attracting investors to the city. There is, however, minimal land area for the growing demand for expansion as the city has only about 15% flat to gently sloping land surface. Fig. 1 shows the Comprehensive Development Plan (CDP) of the City of Catbalogan and the site of the proposed CSCMP. This CDP is expected to be part of the currently formulated Comprehensive Land Use Plan (CLUP) of the City of Catbalogan.

The 2013 impact of the tropical super typhoon Haiyan resulted in the birth of the CSCMP (Hurtado 2019); a new township located 120m above sea level (Skyscraper City 2015) found northeast of the old Catbalogan City downtown area. The project aims to be an example of localizing the Sustainable Development Goals (SDGs), the Sendai Framework, and the New Urban Agenda to create a resilient, safe, and sustainable city (Hurtado 2019). The project area covers about 440 hectares, and the first phase of initiatives is on its way (CDIA Asia 2016). The new city will utilize 50% open space and 50% buildable space for hotels, resorts, health and wellness center, education and training hubs, and multi-purpose complexes (Skyscraper City 2015). The plan was praised in many venues here and abroad; in 2015, the project was among the few proposals promoted by Urban-Low Emission Development Strategies cities out of 150 submissions (Meniano 2018). The estimated and proposed Catbalogan land use distribution is mentioned in Table 2.

Water & Wastewater Production and Distribution Profile

The main source of water for Catbalogan use is springs supplemented with groundwater pumping. The main sources are heavily influenced by precipitation. This water supply, distribution, and consumption as well as water loss are shown in Figs. 3 and 4.

As of 2022, the water supply system network: As of March 2022, Catbalogan City, through its Catbalogan Water District (CWD), supplies water from at least six sources, as shown in Fig. 2. About 10% is from surface water (river), and the rest is from groundwater. Around 86% are extracted at the mouth of springs, and around 4% are pumped from deep wells. The said waters are post-processed differently; the surface water

Table 2: Estimated current (2022) and proposed (2040) Catbalogan land use distribution.

Land use with buildings*	Land Area [m^2]			
	2022		2040	
	Old City	Sky City	Old City	Sky City
Residential	144,804	0	6,452,091	185,833
Commercial	10,478	0	466,854	378,896
Industrial	44,204	0	1,969,635	218,319
Others	39,709	0	1,769,333	89,507
Reservoir	0	0	0	387,875
Remaining lands without buildings	1,730,001,203	0	165,054,663	0

*Values were estimated from Google Map Image and Drone Shots (2022) and Fig. 1 (2040).

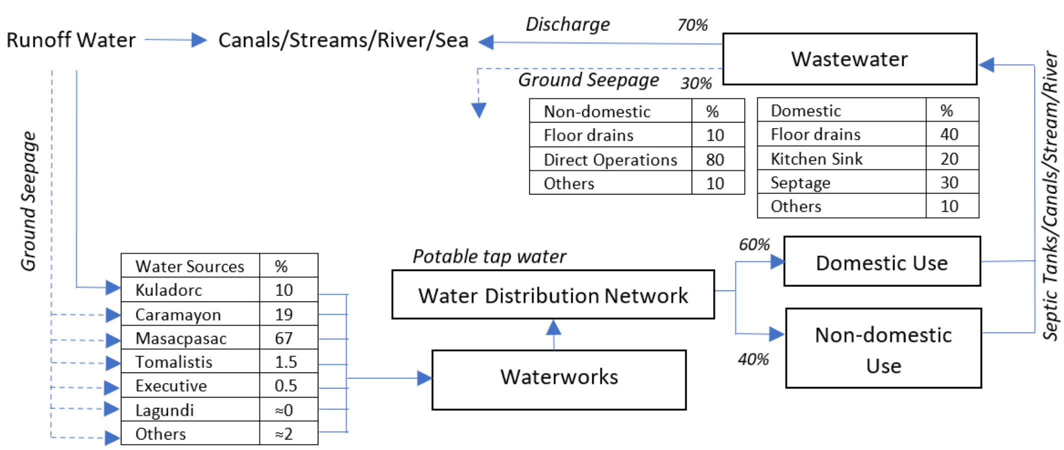

Fig. 2: Current Catbalogan city water and wastewater production and distribution.

undergoes several steps to remove sediments and passes through a rapid and slow sand filtration system (CWD nd.), while other sources are not subjected to it. All sources, however, are treated with chlorine compound to eliminate any pathogenic bacteria present. After water treatment, it is distributed to at least 26 of the 57 barangays of the City of Catbalogan. As of the study period, there are about 8,144 households serviced by the CWD, 153 government offices/units, and 924 commercial/industrial service connections (CWD 2021). Approximately there will be around 39,740 individuals, or 37.3% of the Catbalogan populace, served by CWD. The remaining population secures their water from public and private artesian wells, open wells, and boxed spring water like those houses near the CSCMP site.

More than three-quarters of the water produced by the CWD is used for domestic purposes, and the rest is for commercial/industrial and institutional uses. Waste water produced, therefore, is mostly coming from households. The volume of waste is about 80% of the water consumed. At household levels, about 40% exit from floor drains, 20% from kitchens, 30 % disposed of in septic tanks, and about 10% from other domestic activities like watering plants, cleaning lawns, swimming pool, and other minor uses. Except for wastewater deposited in septic tanks, other wastewater is disposed of directly in drainage systems, canals, streams, rivers, or the sea. Even wastewater from septic tank leaching chambers finds its way to the drainage canals. Some of this wastewater seeps into the ground, risking contamination of groundwater aquifers. The manner of wastewater disposal deteriorated waters of the only river in Catbalogan (Antiao River) to a level comparable to sewage water (Amascual et al. 2020). Antiao River is the receiver of the majority of drainage waters in the City of Catbalogan.

Plausible scenario of water supply system network by 2040: If the LGU of Catbalogan observes the same manner of runoff management, the water collected in the catchment basin (lagoon as shown in Fig. 3-Right) will be very contaminated, and cleaning it will be very expensive for the people of Catbalogan. Shown in Fig. 4 is the likely water supply network cycle from the source of water, treatment, distribution, utilization, disposal of wastewater, and back to the source. There is also a possibility that if the watershed

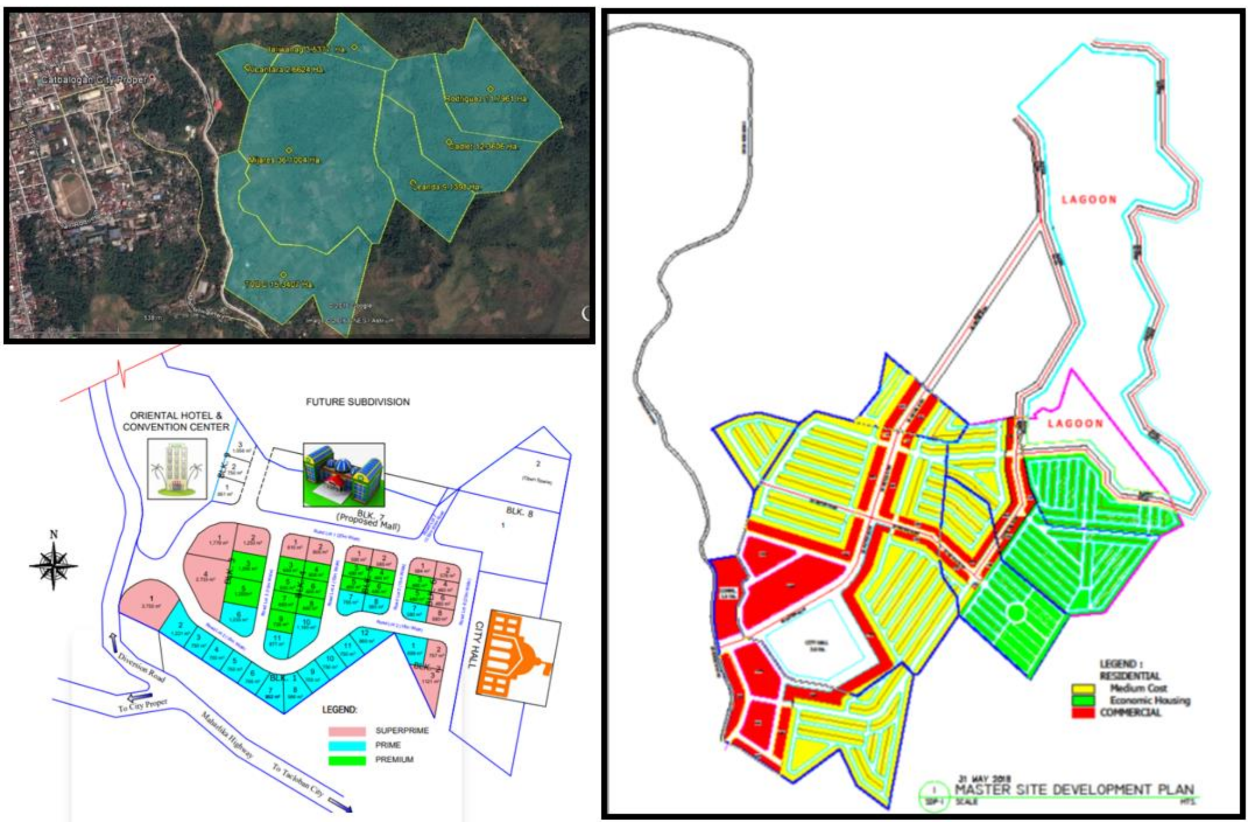

Fig. 3: The Sky City mega project; (Right) Master site development plan, (Upper-Left) Site for Phase 1, (Lower-Left) Lot allocation for Phase 1.

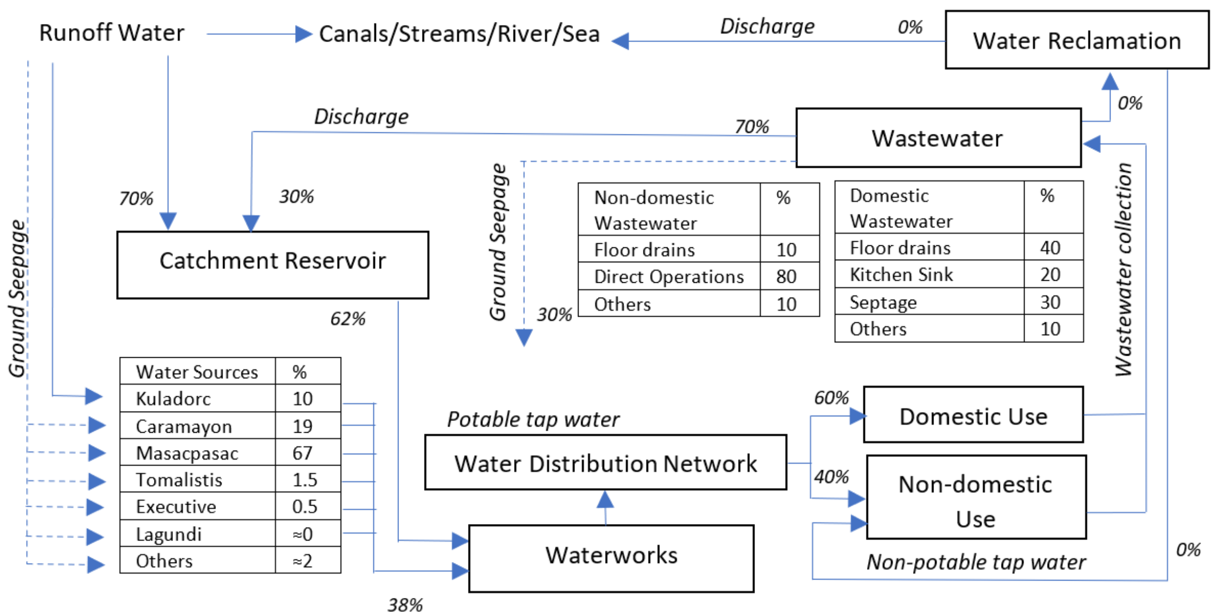

Fig. 4: Projected Catbalogan city water and wastewater production and distribution.

is not improved, the 38% share of the water supply may be further reduced. Satellite images and ocular inspection of the watershed reveal continuing degradation of ground cover due to various illegal ground cover-changing activities, including increasing agricultural activity in the area. The area's transformation into the CSCMP alone will change the land use from vegetated lands to urban centers.

With improved commercial and institutional activities, the water demand will be more than the capacity of the current water supply source. Commercial buildings require a substantial volume of water depending on the size. The Catbalogan Sky City Mega Project will house hotels, resorts, a health and wellness center, education and training hubs, and a multi-purpose complex, to name a few (Skyscraper City 2015). These facilities will require water in their operation. For example, every square meter of an educational facility may need around 1.62 cubic meters of water per day ($m^3.d^{-1}$). Every type of facility will have different demands; a healthcare facility will need 5.17 $m^3.d^{-1}$, lodging/hotels about 4.64 $m^3.d^{-1}$, a mall will need 1.40 $m^3.d^{-1}$, and public assembly centers will require 2.86 $m^3.d^{-1}$ (2017).

Plans often are not realized as it is expected due to many factors. Complicated processes govern the development phase, and events like COVID-19 or a disastrous typhoon like Yolanda change government priorities, often halting planned developments. In some cities abroad, they found that land use conformity to master plans is less than 50% and significantly varies depending on the location within the city (Huang & Cantada 2019). Conformance to planned land use is more challenging in the Philippines due to conflicting policies, influential land owners, overlapping mandates between government authorities, and political interference (Lech & Leppert 2018). In Samar, even the formulation of CLUPs alone is a severe challenge, many do not have, and others have inactive plans (Salazar-Quitalig & Orale, 2016). This situation is true in the case of Catbalogan City; based on its old (inactive) land use plan, a small portion of the plans became a reality. Considering a more complicated case for the Philippines and the observations made to CLUP implementation in Catbalogan, a conservative 5%, and 25% realization was considered for rainfall-runoff simulation purposes.

A 5% development scenario will result in a water demand of about 71,572 cubic meters per month for the CSCMP alone and another 552,030 cubic meters for the old city, or a total of about 623,602 cubic meters per month. The published production capacity of the CWD is pegged at 387,474 cubic meters per month (CWD 2021). Incorporating losses from extraction, treatment, to distribution will make the current capacity of CWD not even enough for the current demand of about 398,167 cubic meters per month. In higher development scenarios (e.g 25%), the gap between available water resources and the demand will increase by 980,001 or about 253%. The development planners must therefore look for additional water sources to supply the water demand of the near future like what Singapore did (WWF 2012, Hsien et al. 2019, PUB nd.b), securing water elsewhere while developing systems to make self-sufficient in the very near future (IWA nd.).

Table 3: Catbalogan city water requirements.

Land use with buildings	Monthly Water Demand (m^3)					
	2022		2040 (05%)		2040 (25%)	
	Old City*	Sky City	Old City	Sky City	Old City	Sky City
Residential**	355,996	0	459,848	22,843	563,699	114,216
Commercial	24,167	0	53,839	43,696	269,196	218,478
Industrial	6,041	0	13,460	1,492	67,302	7,460
Institutional	10,462	0	23,308	1,179	116,540	5,896
Others	1,500	0	1,575	2,362	1,875	2,812
Sub Total	398,167	0	552,030	71,572	1,015,613	348,862
Total	398,167		623,603		1,367,475	

*based on CWD records
**estimated demand for the entire population

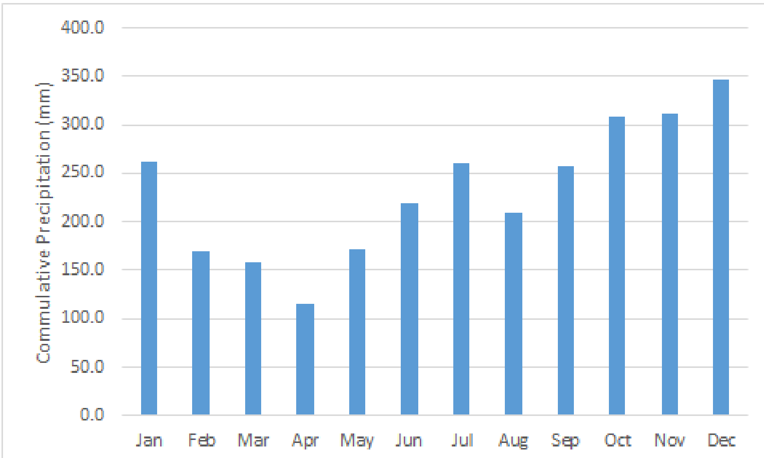

Fig. 5: Average monthly precipitation per month (1948-2021; PAGASA).

Runoff Water Production

Catbalogan City has an average precipitation rate of 180 mm per month. The highest recorded monthly precipitation is about 1,140 mm, and the largest single-day rain was more than 350 mm (Orale 2015). With the degraded ground cover in the area, most of this rainwater will run off the surface and exit into the Antiao River. It was predicted that the construction and development of the CSCMP would result in a larger volume of runoff water which may swell the river and flood the old city (Orale & Novilla 2016). Collecting the runoff water from the CSCMP and storing it in a reservoir will reduce this risk.

The Local Government of Catbalogan allocated around 387,875 square meters as the catchment basin for the lagoon. In the absence of engineering plans for the said reservoir, it is assumed that the lagoon will have an average depth of one meter resulting in a capacity of 387,875 cubic meters of water on any given day if enough precipitation is available. Fig. 5 shows 73-year average monthly precipitation characteristics in Catbalogan from the database of the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA) Catbalogan City Office. The rain will be the primary source of water for the water reservoir.

Fig. 5 shows that April and December receive the least and the most rain, respectively. Low-rain months include February, March, and May. On the other hand, October and November are considered high-rain months. There are also occasions when one month rain is poured in few hours which often chokes waterways resulting into floods.

Fig. 6 shows the amount of runoff water the lagoon receives during December and April, the driest and wettest months in Catbalogan. These values were derived from the HEC-HMS modeling using the parameters given in Table 1. For the April and December 2021 rain, the total volume of water harvested during low-rain months like April is about

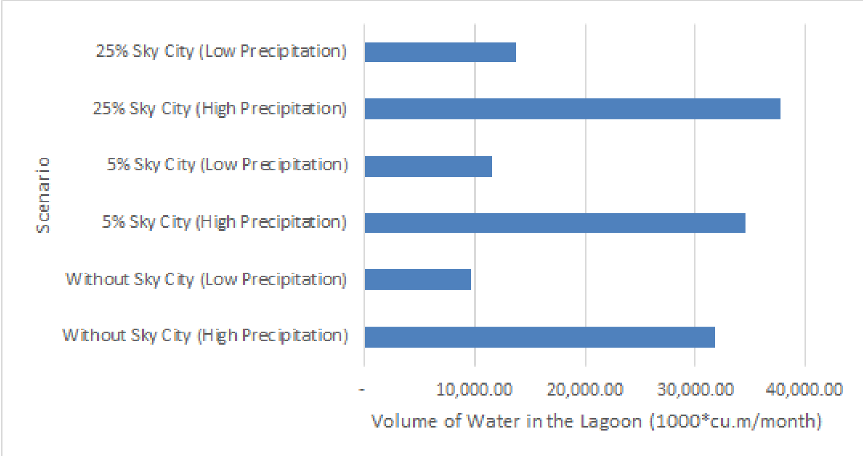

Fig. 6: Volume of harvested runoff water at the lagoon.

9,715,000 cubic meters in current condition, and it will reach 13,698,300 by 2040 in a 25% development scenario. The volume of runoff water collected is higher by 175% to 228% during peak rain months like December. This means that the lagoon can supply water demand not only for the CSCMP but for the entire City of Catbalogan. There will be a surplus of about 12,330,825 cubic meters per month, even in low-rain months.

Therefore, the lagoon's designed capacity must be greater than the city's water demand for any future scenario. As given in Table 3, in a 25% development scenario by 2040, the city needs about 1.4 million cubic meters of water per month or about 46,000 cubic meters per day. The lagoon can provide much-needed water every day. While abundant water is available for Catbalogan City, treating it is another challenge.

Runoff Collection Treatment and Distribution System

The CSCMP has no plans for how the runoff water will be collected, treated, and distributed. It is assumed in this paper that construction methods for roads, drainage systems, building designs and execution, and wastewater management will be similar to what exists in the old city. There will be canals that will receive runoff water from roads, lawns, paved and unpaved grounds, stormwater from buildings, and even wastewater from the kitchen, toilet drains, and excess water from septic tanks of buildings. According to the Environmental Protection Agency of the USA (EPA 2003), urban runoff is exposed to a variety of pollutants such as sediments, wastes from motor vehicles like oil, excess fuels, grease, and other chemical compounds, most of which are toxic. Agricultural activities also contribute to wastewater from pesticides and excess nutrients from fertilizers. Runoff waters may contain viruses and bacteria from the effluents of toilets. It may also contain heavy metals from various sources. These canals will drain the wastewater to the catchment basin or the lagoon. The water in the reservoir will be treated separately from other CWD water sources. Since the water collected is heavily contaminated, the treatment required will also be more complex, like the reclamation of blackwater. The treatment of similar wastewater in Singapore requires filtration, reverse osmosis, and disinfection (PUB nd.e, Thompson & Powell 2003) instead of the usual surface water treatment which includes coagulation, sedimentation, filtration, disinfection, biological activated carbon, and mineralization (PUB nd. d). Currently, the CWD only uses coagulation, filtration, and disinfection to treat surface water from Kulador and only disinfection for groundwater and spring water sources.

A strategic approach to minimizing the contamination of rainwater to other runoff water (i.e from lawns, roads, etc) must be explored. Rainwater harvesting at the building level will reduce exposure of this excess water to contamination. This harvesting will reduce the energy required to pump water from the treatment facility to the users. Less contaminated water means a reduced need for chemicals to make the water potable or safe for domestic and other uses.

Catbalogan Sky City Water Supply Carbon Footprint

Current water supply production and distribution. The CWD uses power extensively to pump water from various sources and to its clients. Most of the carbon footprint comes from water production and distribution. Depending on the water supply condition, the CWD spends up to 334,267 kWh per month, especially during dry seasons. SAMELCO II, the energy distributor, has varied sources; most are from the nearby geothermal power, and the rest are from fossilbased power plants. Considering the energy mixes of the power distributor, the CO_2e equivalent for the collection and distribution is shown in Table 4. The CO_2e equivalent for water treatment is also shown in Table 4.

The carbon footprint for the current water supply production, treatment, and distribution reaches 2,222 kgCO_2.e.day^{-1}, 627 kgCO_2.e.day e.day^{-1}, and 627 kgCO_2.e.day^{-1}, respectively, or a total of about 3,194 kg CO_2-e/day. The collection of water from the source is a heavy contributor to the carbon footprint profile sharing about 69% compared to 11% for treatment and 20 for distribution. This is because water extraction from CWD sources relies heavily on pumps. Using renewable resources in powering pumps that extract water can significantly reduce the carbon footprint.

The current treatment process used by CWD only covers simple steps; sedimentation, slow and fast sand, and chlorination. The carbon footprint estimates come primarily from the chemicals and minimal energy used in making the water potable. CWD uses a chloramine (e.g. monochloramine) compound totaling about 326 kg per month. With CWD water extracted mainly from groundwater sources, the treatment is minimal. The carbon footprint for groundwater and surface water sources is estimated at only 0.02 and 0.08 kg of CO_2-e per cubic meter of water produced (Biswas & Yek 2016). As shown in Fig. 3, the water supply comes from 10% surface (Kulador) and 90% different groundwater/spring sources. This means that water treatment for 398,162 cubic meters per month water is about 10,352 kilograms of CO_2-e per month.

Runoff water-based water supply production and distribution carbon footprint. The CSCMP proposes a runoff water harvesting feature. This feature is both a flood mitigation measure for the old city and, at the same time, provide the much-needed water not only for the CSCMP but for the old city as well. As shown in Table 3, the current theoretical available volume of water supply according to CWD estimates cannot accommodate even the current water demand. No engineering details are yet available on how runoff water will be collected and drained to the lagoon. Runoff water in the City of Catbalogan mixes with wastewater dumped into existing drainage systems. This will make the runoff water collected contaminated and

Table 4: Carbon footprint of water supply production and distribution.

Processes	CO_2-e [kg.month^{-1}]				
	2022	2040**			
	Old City*	Old City (5%)	Sky City (5%)	Old City (25%)	Sky City (25%)
Treatment	10,352	72,554	27,054	248,923	131,870
Collection	66,676	74,449	0.00	96,486	0.00
Distribution	18,806	26,578	15,366	48,616	74,897
Total	95,835	173,582	42,420	394,025	206,767

*estimate if 100% of the population is served
**conservative estimates assuming 5% or 25% of planned development is attained

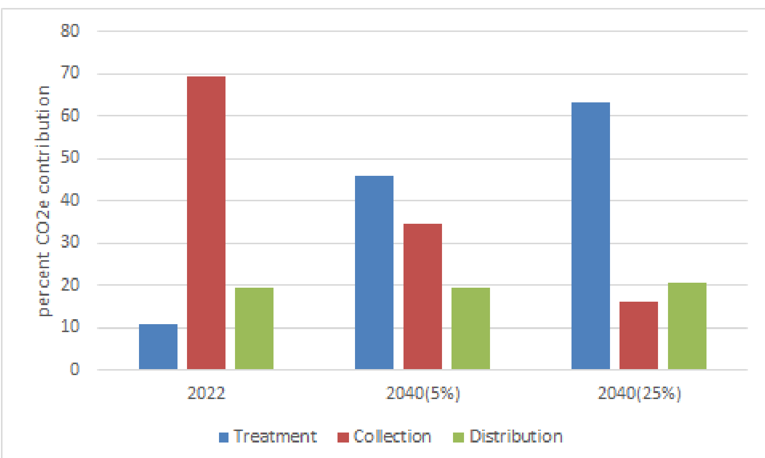

Fig. 7. Per cent CO_2e contribution in the production, treatment, and distribution of water supply.

require specialized water treatment far beyond the current processes.

The carbon footprint increases by about 125% and 526% for a 5% and 25% development scenario by 2040 compared to the 2022 condition. As shown in Fig. 7, the treatment required will increase by about 862% and 3,578% for the 5% and 25% development scenarios by 2040. The decrease in the carbon footprint contribution from the water collection processes cannot compensate for the increase from water treatment processes. The carbon footprint of the proposed water system for the CSCMP is 123% and 557% for the same scenario in 2040, respectively.

Overall, the CSCMP will result in a significantly higher carbon footprint because of increased water demand for Catbalogan City. The lagoon at the CSCMP will provide much-needed water for the new and the old city. The effort to reduce the contamination of runoff water and use renewable energy to extract, treat and distribute water must be continuously explored. The introduction of better rainwater harvesting technology may be explored to minimize at least the treatment requirements. Rainwater harvesting at a lot owner's building or lawn level may be considered for investigation.

CONCLUSIONS AND RECOMMENDATIONS

Catbalogan City lacks both water and area for expansion. In light of the global impact of CC, it proposed to inhabit higher elevated land away from the threats of lowland flooding for unusually heavy rains and sea level rise in the future. The CSCMP was packaged as a CC adaptation; however, if not properly designed, it can contribute more to CC than help address it. While the local government unit of Catbalogan implements the Sky City, the old city is also poised to receive additional development activities, further widening the gap between the available water and the water demand. It is estimated that in a 5% development success scenario, about 623,603 cubic meters of water per month is needed, or about 60% deficient. The lagoon at the CSCMP can supply the needed water for the city even at a 25% development scenario by 2040. If the rainwater harvesting is not properly engineered, the treatment alone is estimated to produce more than 8 to 36 folds of CO_2-e. Therefore, the local government unit of Catbalogan must legislate and implement green-engineering building standards to ensure any development like the CSCMP will be low-impact. A well-engineered runoff water collection and distribution system can be formulated and implemented to minimize carbon footprint and make CSCMP a successful climate adaptation strategy for mountainous city landscapes.

REFERENCES

ADB. 2013. Philippines: Water Supply and Sanitation Sector Assessment Strategy, and Road Map. Asian Development Bank, Mandaluyong City, Philippines

Al-Kodmany, K. 2018. The Vertical City: A Sustainable Development Model. WIT Press, England.

Amascual, R., Panganoron, H., Gamba, A., Irene, E. and Amparado, M.L. 2020. Water Quality Assessment of Antiao River in Samar, Philippines. Samar State University, Catbalogan City, Samar.

Biswas, W. and Yek, P. 2016. Improving the carbon footprint of water treatment with renewable energy: A Western Australian case study. Renew. Wind, Water Solar, 3(14): 45.

Bolay, J. and Kern, A. 2019. Intermediate cities. Blackwell, London.

Catbalogan LGU. 2019. Catbalogan Sky City Mega Project Gets the Nod from Tourism. (Catbalogan LGU) Retrieved March 5, 2022, from http://www.catbalogan.gov.ph/catbalogan-sky-city-mega-project-gets-the-nod-from-tourism-investors/

Catbalogan LGU. nd. Local Heritage. Retrieved September 12, 2020, from The Official Website of the City Government of Catbalogan: http://www.catbalogan.gov.ph/for-visitors/local-heritage/

CDIA Asia. 2016. From CIIPP, Catbalogan's Sky City Project Gets Funding from the Private Sector. Retrieved March 4, 2022, from https://cdia.asia/2016/09/13/from-ciipp-catbalogans-sky-city-project-gets-funding-from-the-private-sector/

Claudio, L. 2015. Wastewater Management in the Philippines. Retrieved March 3, 2022, from https://www.wipo.int/edocs/mdocs/mdocs/en/wipo_ip_mnl_15/wipo_ip_mnl_15_t4.pdf

CWD. 2015. 2015 Monthly Data Sheet. Retrieved 2022 1, 2015, from https://catbaloganwd.gov.ph/files/MDS%202015.pdf

CWD. 2018. About Us. Retrieved March 1, 2022, from https://www.catbaloganwd.gov.ph/about%20us.html

CWD. 2020. Water Production Graph Per Source. Retrieved October 15, 2020, from Catbalogan Water District: https://www.catbaloganwd.gov.ph/

CWD. 2021. Catbalogan Water District. Retrieved March 1, 2022, from https://catbaloganwd.gov.ph/files/MDS%20Jan-Dec%202020.pdf

CWD. 2022. Transparency Seal - Catbalogan Water District. Retrieved 1 2022, 2022, from https://catbaloganwd.gov.ph/transparency%20seal.html

CWD. nd. Kulador Treatment Plant. Retrieved March 3, 2022, from http://catbaloganwd.gov.ph/Kulador.html

Dodman, D. 2009. Urban Density and Climate Change. United Nations Population Fund (UNFPA), NY.

DTI. nd. Rankings of Cities and Municipalities. Retrieved October 5, 2020, from Cities & Municipalities Competitiveness Index: https://cmci.dti.gov.ph/pages/rankings/

EIA. 2017. 2012 Commercial Buildings Energy Consumption Survey: Water Consumption in Large Buildings Summary. Retrieved October 8, 2020, from Commercial Buildings Energy Consumption Survey (CBECS): https://www.eia.gov/consumption/commercial/reports/2012/water/

EIA. nd. Geothermal Explained - Geothermal Energy and the Environment. Retrieved March 2, 2022, from https://www.eia.gov/energyexplained/geothermal/geothermal-energy-and-the-environment.php

EPA. 2003. Protecting Water Quality from Urban Runoff. Retrieved February 14, 2022, from https://www3.epa.gov/npdes/pubs/nps_urban-facts_final.pdf

EPA. 2022. Convert emissions or energy data into concrete terms you can understand - such as the annual CO_2 emissions of cars, households, and power plants. Retrieved July 10, 2022, from https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Gomba, F.E., Orale, R.L. and Uy, R.S. 2007a. Stochastic Process Applied to Catbalogan Supply Resource Planning. 10th National Convention on Statistics (NCS), Catbalogan City.

Gomba, F., Orale, R. and Uy, R. 2007b. Assessment of Masacpasac Water Supply: A Technical Study. Catbalogan Water District, Catbalogan City.

Green Facts. 2008. Water Resources. Retrieved March 2, 2022, from https://www.greenfacts.org/en/water-resources/index.htm

Hsien, C., Low, J.S., Fuchen, S.C. and Han, T.W. 2019. Life cycle assessment of water supply in Singapore: A water-scarce urban city with multiple water sources. Resour. Conserv. Recycl., 6: 151.

Huang, C. and Cantada, I. 2019. Challenges to Implementing Urban Master Plans - What Are We Missing? Retrieved July 24, 2022, from World Bank Blogs: https://blogs.worldbank.org/sustainablecities/challenges-implementing-urban-master-plans-what-are-we-missing

Hurtado, A. 2019. Catbalogan Sky City Mega Project Gets the Nod from Tourism Investors. Retrieved October 7, 2020, from The Official Website of the City Government of Catbalogan: http://www.catbalogan.gov.ph/catbalogan-sky-city-mega-project-gets-the-nod-from-tourism-investors/

IWA. nd. City Water Stories: Singapore. Retrieved February 28, 2022, from https://iwa-network.org/wp-content/uploads/2016/12/IWA_City_Stories_Singapore.pdf

Lech, M. and Leppert, G. 2018. Current Issues of the Philippine Land Use Planning and Management System. German Institute for Development Evaluation, Bonn, Germany.

Liu, Y., Wang, M., Webber, M., Zhou, C. and Zhang, W. 2020. Alternative water supply solutions: China's South-to-North-water-diversion in Jinan. J. Environ. Manag., 16: 276.

Meniano, S. 2018. Catbalogan's Mega Project Attracts Big Companies. Retrieved October 10, 2020, from Philippine News Agency: https://www.pna.gov.ph/articles/1040995

Misra, A.K. 2014. Climate change and challenges of water and food security. Int. J. Sustain. Built Environ., 3(1): 153-165.

MWSS. 2017. MWSS Approves New Rates Effective January 1, 2018. Retrieved February 3, 2022, from https://www.manilawater.com/customer/agos/2017-12-15/mwss-approves-new-rates-effective-january-1--2018#:~:text=Once%20the%20new%20rates%20take,increase%20from%20P305%20to%20P306.

National Geographic. nd. Freshwater Crises. Retrieved March 1, 2022, from https://www.nationalgeographic.com/environment/article/freshwater-crisis

Orale, R. 2006a. Land Use Zoning for industrial use based on geohazard assessment. Eng. Pebble, 12:135-165.

Orale, R. 2006b. Landslide Suceptibility Assessment in Catbalogan, Samar: Proposed Hazard Control Program. International Civil Engineering Congress 2006 (ICEEC 2006) and the 7th National Civil Engineering Education Congress 2006 (7th NCEEC). Angeles City, Pampanga Philippines.

Orale, R. 2015. Flood risk assessment in post-Antiao river control project in Catbalogan City, Philippines. Country. Dev. Res. J., 3(2): 39-52.

Orale, R. and Fabillar, L.A. 2011. Coastal waste transport in Catbalogan City, Philippines, and nearby towns. Iran. J. Energy Environ., 1(2): 56.

Orale, R. and Novilla, R. 2016. Flood risk at various stages of Catbalogan Sky City project development. Country. Dev. Res. J., 4(1): 82-94.

Pehl, M., Arvesesn, A., Humpenoder, F., Popp, A., Hertwich, E. and Luderer, G. 2017. Understanding future emissions from low-carbon power systems by integration of life cycle assessment and integrated energy modeling. Nat. Energy, 2: 939-945.

PhilAtlas. nd.a. Catbalogan, Province of Samar. Retrieved February 5, 2022. from https://www.philatlas.com/visayas/r08/samar/catbalogan.html#sectionEconomy

PhilAtlas. nd.b. Catbalogan, Province of Samar. Retrieved September 18, 2020. from Philippine Atlas: https://www.philatlas.com/visayas/r08/samar/catbalogan.html

Pingale, S.M., Jat, M.K. and Khare, D. 2014. Integrated urban water management modeling under climate change scenarios. Resour. Conserv. Recycl., 83: 176-189.

Population Matters. 2018. Climate Change. Retrieved October 10, 2020, from Population Matters: https://populationmatters.org/the-facts/climate-change

PUB. nd.a. Four National Tap. Retrieved March 31, 2021, from https://www.pub.gov.sg/watersupply/fournationaltaps

PUB. nd.b. Singapore Water Story. Retrieved March 3, 2022, from https://www.pub.gov.sg/watersupply/singaporewaterstory

PUB. nd.c. Water Price. Retrieved January 31, 2022, from https://www.pub.gov.sg/watersupply/waterprice

PUB. nd.d. Water Treatment. Retrieved March 1, 2022, from https://www.pub.gov.sg/watersupply/watertreatment

PUBb. nd.e. Domestic & Non Domestic. Retrieved March 1, 2022, from https://www.pub.gov.sg/usedwater/treatment/usedwatertreatmentprocess

Rai, R.K. Singh, V.P. and Upadhyay, A. 2017. Planning and Evaluation of Irrigation Projects. Methods and Implementation. Elseiver, Netherlands

Richie, H. 2020. What are the Safest and Cleanest Sources of Energy? Retrieved February 20, 2022, from https://ourworldindata.org/safest-sources-of-energy

Salazar-Quitalig, R. and Orale, R.L. 2016. Comprehensive land use planning capacity of local government units in Samar Philippines. Country. Dev. Res. J., 4(1): 36-52

SAMELCO II. 2020. Generation Mix Rate. Retrieved March 1, 2022, from https://samelcodos.com/generation-mix-rate/

SAMELCO II. 2021. Generation Mix Rate 2021. Retrieved March 1, 2022, from https://samelcodos.com/generaiion-mix-rate-2021/

Scherer, L. and Pfister, S. 2016. Hydropower's biogenic carbon footprint. PLoS One, 11(9): 548.

Skyscraper City. 2015. Catbalogan Sky City. Retrieved September 12, 2020, from Skyscraper City: https://www.skyscrapercity.com/threads/catbalogan-catbalogan-sky-city-mix.1813878/

Steeneveld, G., Klompmaker, J.O., Groen, R.J. and Holtslag, A.A. 2018. An urban climate assessment and management tool for combined heat and air quality judgments at neighborhood scales. Resour. Conserv. Recycl., 132, 204-217.

Talat, N. 2021. Urban water-supply management: indirect issues of climate change leading to water scarcity scenarios in developing and underdeveloped nations. In Thokshorn, B., Qiu, P. and Iyer, P.K. (eds), Water Conservation in the Era of Global Climate Change. Elsevier, The Netherlands, pp. 47-71.

TAP. nd. Catbalogan Sky City Mega Project. Retrieved March 3, 2022, from https://tap-potential.org/projects/catbalogan-sky-city-mega-project/

Thompson, M. and Powell, D. 2003. Case Study-Kranji High-Grade Water Reclamation Plant, Singapore. Proceedings of IMSTEC 3.

Tosics, I. 2015. Growing Cities: How to Expand in a Sustainable and Integrated Way? Retrieved October 1, 2020, from URBACT: https://urbact.eu/growing-cities-how-expand-sustainable-and-integrated-way

UN Water. 2021a. Water Quality and Wastewater. Retrieved March 1, 2022, from https://www.unwater.org/water-facts/quality-and-wastewater/

UN Water. 2021b. Summary Progress Update 2021: SDG 6 - Water and Sanitation for All. UN Water, Geneva, Switzerland.

UNESCO. nd. The United Nations World Water Development Report. Retrieved March 1, 2022, from http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/

United Nations. 2018. 68% of the World Population is Projected to Live in Urban Areas By 2050, says UN. Retrieved October 1, 2020, from United Nations - Department of Economics and Social Affairs: https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html

USACE. nd. HEC-HMS - Hydrologic Engineering Center - US Army Corps of Engineers Retrieved January 11, 2022, from https://www.hec.usace.army.mil/software/hec-hms/

Wennersten, R. 2018. Chapter 6. Development of New Sustainable Urban Areas: Horizontal or Vertical Planning Systems for Resource Efficient Cities. In Y. Ergen, An Overview of Urban and Regional Planning (pp. 103-120). IntechOpen.

WWF. 2012. Singapore Water Management. Retrieved March 20, 2022, from https://wwf.panda.org/wwf_news/?204587/Singapore-water-management