ASSESSMENT OF CATCHMENT CONDITIONS AFFECTING WATER-RELATED ECOSYSTEM

Phanith Kruy[1] and Piyatida Ruangrassamee[1,*]
[1]Department of Water Resources Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand
[*]Corresponding author email address: Piyatida.H@chula.ac.th

ABSTRACT

Sustainable Development Goal 6 (SDG 6) is developed to ensure the availability and sustainable development of water sanitation for all by 2030. SDG 6 includes monitoring changes in the extent of water-related ecosystems over time. Water-related ecosystems provide ecological functions and biodiversity for nature and humans, however, they are at risk from human activities. Asian Water Development Outlook (AWDO) also considers environmental water security as one of the key dimensions. It is reported in AWDO 2020 that an effective assessment of aquatic ecosystem health is vital to understanding this key dimension. The environmental water security in AWDO 2020 assessed the health of rivers, wetlands, and groundwater systems and measures the progress in restoring aquatic ecosystems to health on a national and regional scale which is divided into two main indicators which are catchment and aquatic system condition and environmental governance. This study focuses on catchment conditions, including change in riparian land cover and groundwater depletion that affects water-related ecosystems on a basin scale. The objective of this study is to analyze changes over 10 years during 2009-2018 of riparian land cover, groundwater depletion, riverine connectivity, and water quality in Chao Phraya, Tha Chin, and East Coast Gulf River Basins and the year 2000 is selected as a baseline. The results show that the central region has relatively high pressures from riparian land cover change particularly tree cover loss, low riverine connectivity, and the water quality index has remained in poor condition. The impacts from agricultural, livestock, and industrial activities, as well as urbanization in the three river basins, are prominent. Restoring the ecological system and proper management of water resources to support livelihood and economic development is very important.

Keywords*: water-related ecosystem, environmental water security, land cover, riverine connectivity, groundwater depletion*

1. INTRODUCTION

Water-related ecosystems provide ecological functions and biodiversity for nature and humans, however, they are at risk from human activities. Understanding the linkages between ecosystem and socio-economic development is crucial for sustainable development pathways. SDG 6 includes monitoring changes in the extent of water-related ecosystems over time. Asian Water Development Outlook (AWDO) also considers environmental water security as one of the key dimensions. It was reported in AWDO 2020 [1] that an effective assessment of aquatic ecosystem health is vital to understanding this key dimension. The key dimension of environmental water security assesses pressures on the health of rivers, wetlands, and groundwater systems and measures progress in restoring aquatic ecosystems to health on a national and regional scale.

This study focuses on pressures that affect the water-related ecosystem and its states based on AWDO 2020 framework. The objective of this study is to analyze changes over 10 years during 2009-2018 of riparian land cover, groundwater depletion, riverine connectivity, and water quality in Chao Phraya, Tha Chin, and East Coast Gulf River Basins and the year 2000 is selected as a baseline. The socio-economic development in the three selected river basins is high. As a result, the health of the ecosystem has been compromised and potentially diminish ecosystem services.

2. DATA AND METHODOLOGY

AWDO 2020 [1] proposed a framework to quantitatively evaluate environmental water security by assessing pressures on the health of rivers, wetlands, and groundwater systems. The indicators proposed in AWDO 2020 [1] consist of Catchment and Aquatic System Condition Index (CASCI), which includes land cover, hydrology alteration, groundwater, connectivity, and water quality, and Environmental Governance Index (EGI), which includes sustainable nitrogen management, wastewater treatment, and terrestrial protection by utilizing available database and satellite data at a national and regional scale.

The methodology used in this study is based on the Catchment and Aquatic System Condition Index (CASCI) proposed by AWDO 2020 [1] to assess the catchment conditions affecting the water-related ecosystem but this study investigates only four indicators, namely riparian land cover change, groundwater depletion, water quality, and riverine connectivity during 2009 - 2018 as a preliminary analysis. In addition to local observations, regional scale data and satellite data are examined to evaluate the potential applications on a basin scale.

2.1. RIPARIAN LAND COVER CHANGE

The United States Department of Agriculture (USDA) defines a riparian zone as an area adjacent to a stream, lake, or wetland consisting of a mixture of trees, shrubs, and/or grass planting. The Copernicus (the European Union's Earth observation programme) considers the riparian zone as transitional areas occurring along the watercourse and freshwater ecosystems [2]. Naiman and Décamps [3] and Naiman et al. [4] define the riparian zone as the area in between the stream channel and maximum water extent or the terrestrial landscape toward the uplands where vegetation may be influenced from the water table or flood or soil’s ability to retain water.

The land cover in the riparian zone provides multi-function for the water quality, biodiversity, productive soils, economic opportunities, etc. It reduces erosion and runoff of sediment, nutrients, and removes potential pollutants from water runoff, increases habitat area, and as well as shades the stream to maintain temperature [5]-[7]. Losses of riparian land cover indicate conditions of increasing pressure on the river's health, which have a negative impact on aquatic ecosystem health. The consequence of the changes is various, like physical, thermal, and chemical, relating to nutrient dynamics [8]. Thus, quantifying land cover changes in the riparian zone is an alternative way to assess pressure on aquatic ecosystem health.

The potential riparian zone is defined by using stream network and surface water extension. The river network in the Chao Phraya, Tha Chin, and East Coast Gulf river basin is delineated by using digital elevation models (DEM) with a resolution of 90 m provided by the Greater Mekong Subregion (GMS) information portal [9] and Hydrology Tools in ArcGIS 10.5. The sub-catchment with the upstream area greater than 100 ha was delineated, and the Strahler’s stream order, which is greater than or equal to the 3rd order, was filtered to be stream networks for this study.

The global surface water extension from Pekel et al. [10] is used in this study. Pekel et al. [10] quantified changes in global surface water monthly, seasonally, and annually with a spatial resolution of 30 m and time spanning from 1984 to 2019. The dataset comprises occurrence change, seasonality, recurrence, transitions, and maximum water extent.

The potential riparian zone in this study is defined as a buffer of 100 m width along the stream network and seasonal water extension. The seasonal water extension is an overlayed dataset between 2009 to 2018, excluding 2011 when severe floods occurred in Thailand. The land cover in the potential riparian zone of the Tha Chin River Basin in 2018 is shown in Figure 1 as an example.

Three classes of landcover, including shrublands, grassland, and forest, are selected to assess the riparian landcover change in the potential riparian zone based on AWDO 2020 in the Chao Phraya, Tha Chin, and East Coast Gulf River Basins. The shrublands and grassland are obtained from the Regional Land Cover Monitoring System (RLCMS), which SERVIR-Mekong developed with the U.S. Forest Service, NASA Applied Science Program, Google, the University of Maryland, and governments of countries in the Mekong region (Cambodia, Myanmar, Thailand, and Vietnam). The land cover from the SERVIR-Mekong has a spatial resolution of 30 m from 1987 to 2018, and it is available through SERVIR-Mekong [11].

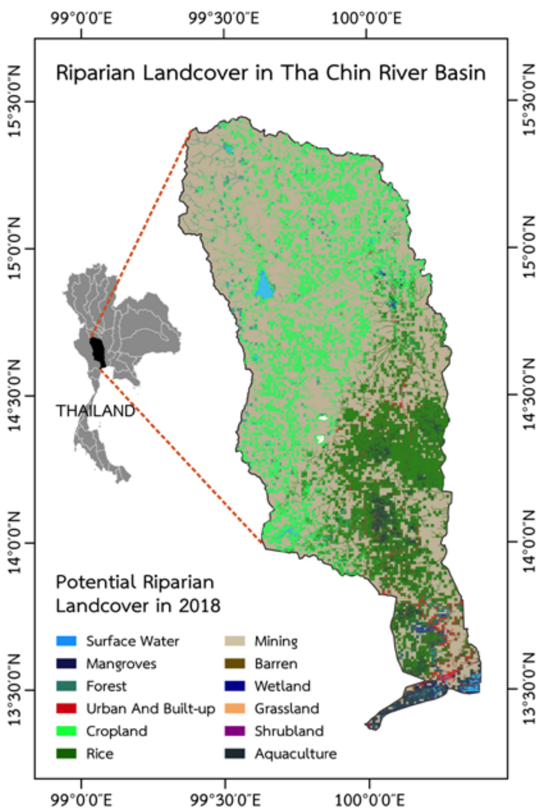


Figure 1 Land cover in the potential riparian zone of Tha Chin river basin

The forest cover is available and obtained from Hansen et al. [12]. Hansen et al. [12] identified tree cover removal across the globe by using remote sensing dataset from Landsat 5, 7, and 8. The tree cover was defined as all vegetation greater than 5m in height and may take the form of natural forest or plantations across canopy densities. The global forest extent and change had been characterized from 2001 through 2019 using the forest cover in 2000 as a baseline.

In this study, the riparian land cover of grassland, shrubland, and forest is analyzed for changes between 2009-2018 from the baseline of the year 2000.

2.2. GROUNDWATER

Groundwater is an alternative water source for use, especially during the dry period. Unsustainable groundwater use resulting long term depletion occurs when groundwater consumptions exceed replenishment rates. This can be significant impacts on surface water and consequently aquatic ecosystem health, as well as other groundwater-dependent ecosystems [13]-. In AWDO 2020, groundwater depletion is a sub-indicators for CASCI. For groundwater depletion assessed by AWDO 2020, the Gravity Recovery and Climate Experiment (GRACE) satellite data [14] and latest NoAh Land Surface Model datasets were used along with the models [1]. GRACE is a joint mission between NASA and the German Aerospace Center (DLR) launched to capture the variability in the earth's gravity field near the earth's surface such as oceanic and atmospheric circulations, as well as terrestrial water cycling [14]-[15]. Mass changes cause gravity changes. The mass variations can be explained as changes in the layer of water thickness near the earth's surface [16]. Combining GRACE data and the latest NoAh Land Surface Model datasets obtained from land data assimilation systems (LDAS), the groundwater depletion was estimated for AWDO 2020.

Li et al. [17] used the Catchment Land Surface Model (CLSM) to investigate variations in global groundwater storage. The CLSM does not specifically model variations in the water table, and groundwater storage can be calculated by subtracting root zone water storage from total soil profile storage. This groundwater storage was confirmed as shallow groundwater [18].

The Global Land Data Assimilation System version 2.2 (GLDAS-2.2) includes a main product from CLSM-F2.5 with Data Assimilation for the Gravity Recovery and Climate Experiment (GRACE-DA) from February 2003 to present [19]. The data assimilation techniques are used to estimate optimal fields of land surface states (e.g. soil moisture, snow, surface temperature) and fluxes (e.g. evapotranspiration, ground heat flux) [20]. The product of GLDAS-2.2 contains 24 land surface fields (e.g., surface soil moisture, groundwater storage, terrestrial water storage, etc.) with the daily temporal resolution and a spatial resolution of 0.25° which available from GES-DISC [21].

In this study, the daily groundwater storage data used are from the GLDAS-2.2 dataset between 2009 to 2018 with a spatial resolution of 0.25°. The long-term monthly average was removed from monthly groundwater storage before performing regression analysis during 2009-2018 for the three river basins. Figure 2 shows the groundwater storage in mm in the Tha Chin River Basin in June 2018 using data from GLDAS 2.2.

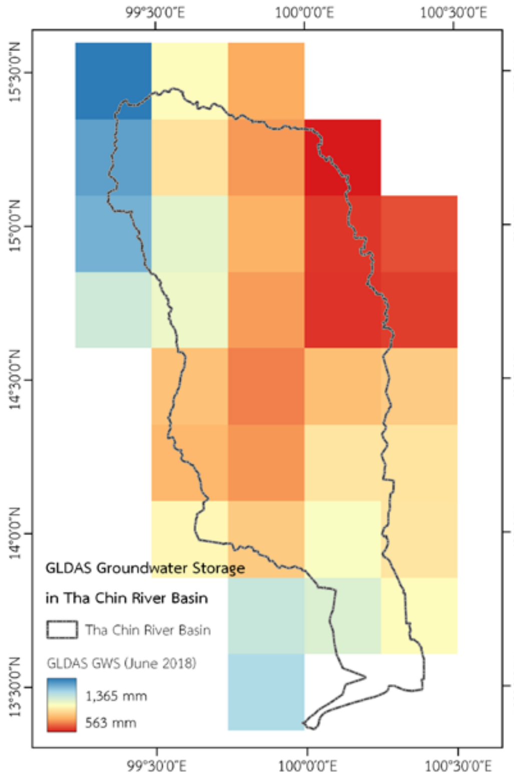


Figure 2 Groundwater storage detection from GLDAS 2.2

2.3. RIVERINE CONNECTIVITIES

Free-Flow Rivers (FFRs) status from Grill et al. [22] was used to define the connectivity status of the rivers in AWDO 2020. Grill et al. [22] defined FFRs as a river where ecosystem functions and services are largely unaffected by changes to the fluvial connectivity, allowing unobstructed movement and exchange of water, energy, material, and species within the river system and with surrounding landscapes.

The FFRs status is determined based on the Connectivity Status Index (CSI) of the river from five pressure factors on the river including river fragmentation (longitudinal), flow regulation (lateral and temporal), sediment trapping (longitudinal, lateral, and vertical), water consumption (lateral, temporal, lateral and temporal), and infrastructure development in riparian areas and floodplains (lateral and longitudinal)**.** Rivers with high levels of connectivity (CSI ≥ 95%) throughout the entire length are considered FFRs. The value for the CSI, the dominant pressure factors, and the FFRs status are available from Günther and Bernhard [23].

This study uses the CSI from Grill et al. [22] for the three River Basins to determine the state of the ecosystem.

2.4. SURFACE WATER QUALITY

Surface water quality in Thailand is mainly monitored by Pollution Control Department (PCD), Ministry of National Resources and Environment. Thailand categorizes surface water quality and its sources into five classes according to the usage. The water quality status is assessed by Water Quality Index (WQI). There are five parameters used to calculate WQI, including DO, BOD, TCB, FCB, and NH_3. The WQI is calculated as a score that varies from 0–100. The WQI's classification is Excellent (91-100), Good (71-90), Fair (61-70), Poor (31-60), and very poor (0-30) [24]. PCD reported that the main causes of deterioration of surface water are wastes from communities, industries, agriculture, and livestock.

3. RESULTS AND DISCUSSION

The preliminary results using the available local observations, large scale data and satellite information are presented and discussed in this section.

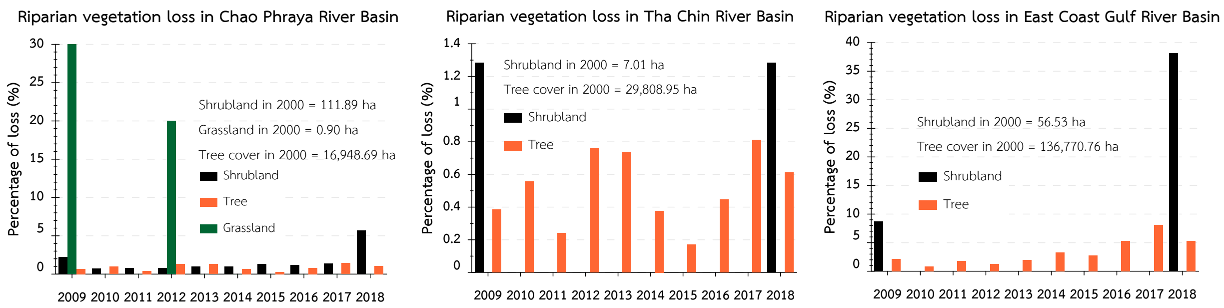
3.1. RIPARIAN LAND COVER CHANGE

The loss of vegetation presents changes in the riparian zone and potentially affect water quality, biodiversity, productive soils, economic opportunities and reduces erosion and runoff of sediment and nutrient. The riparian land cover of grassland, shrubland, and forest is analyzed for changes between 2009 - 2018 from the baseline of the year 2000. Figure 3 (a) shows the percentage of riparian vegetation loss in the Chao Phraya River Basin. The tree cover in 2000 was 16,949 ha, and the total tree cover loss from 2009 - 2018 was 1,519 ha. The major vegetation loss in Chao Phraya River Basin is tree cover loss, but in terms of percentage loss, grassland has the highest percentage change. For Tha Chin River Basin, there was no grassland detected from the SERVIR-Mekong land cover products.

The tree cover in 2000 was 29,809 ha and the total tree cover loss from 2009 - 2018 was 2,085 ha. For East Coast Gulf River Basin, there is no grassland detected. The tree cover in 2000 was 136,771 ha and the total tree cover loss from 2009 - 2018 was 44,784 ha.

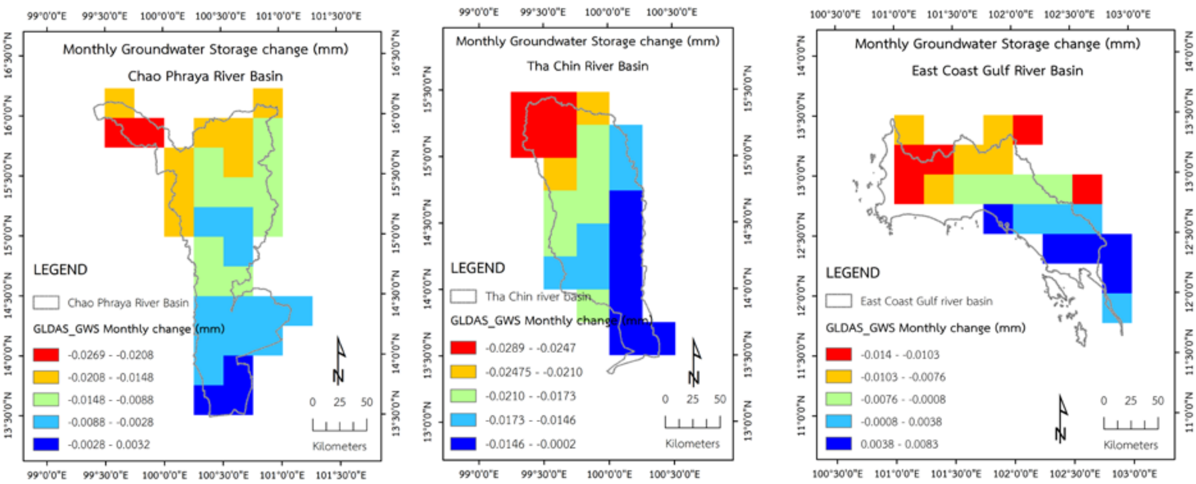
3.1. GROUNDWATER

The daily data of groundwater storage from GLDAS 2.2 was used in this study, and it represents groundwater storage in the shallow aquifer [18]. The spatial analysis was conducted to define the rate of change of groundwater storage. Figure 4 shows the rate of change in monthly groundwater storage in the three river basins. Overall, shallow groundwater storage does not show a significant trend. For the upper part of Chao Phraya River Basin, shallow groundwater has a relatively more decreasing trend than the lower part of the basin as well as Tha Chin River Basin. For East Coast Gulf River Basin, the spatial distribution of groundwater storage trend is highest decreasing trend at the western part and lower decreasing trend from the west to the east. However, the data presented here need to be further validated with available data from observation wells.



(a) (b) (c)

Figure 3 Riparian vegetation loss in (a) Chao Phraya, (b) Tha Chin, (c) East Coast Gulf river basin



(a) (b) (c)

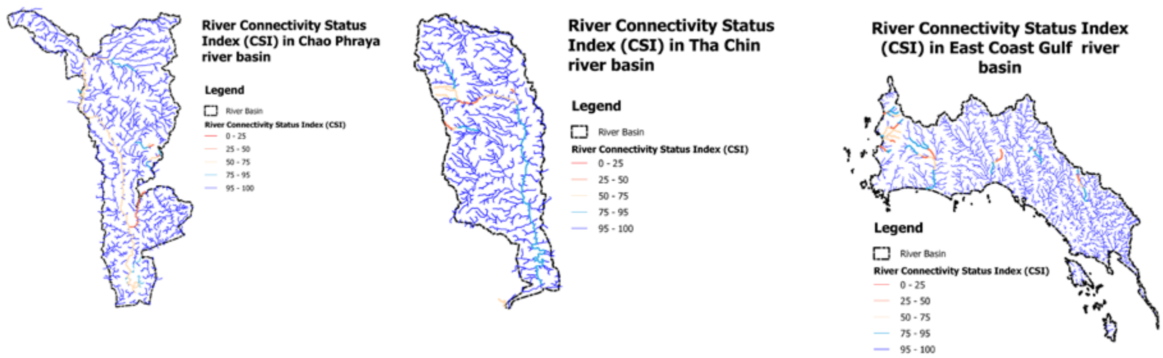
Figure 4 the rate of change in monthly groundwater storage in (a) Chao Phraya, (b) Tha Chin, (c) East Coast Gulf River Basin

3.2. RIVERINE CONNECTIVITIES

Riverine connectivity indicates a state of a water-related ecosystem. The river connectivity status index for each river reach in the three river basins is shown in Figure 5. The data presented here are from Grill et al. [22]. River reach with CSI higher than 95% is considered to have good connectivity status otherwise, it is considered impacted. If the river's entire length has good connectivity (CSI ≥ 95%), it is defined to be free-flowing rivers. The main river of Chao Phraya River Basin, the upper reach of Tha Chin River, and Rayong River have CSI at a low level.

3.3. SURFACE WATER QUALITY

The WQI on a provincial scale from Thailand State of Pollution Reports (PDC) in each river basin during 2009 - 2018 is shown in Figure 6 and Figure 7. In the Chao Phraya and Tha Chin river basins, the provincial WQI has a higher score at the upstream and lower score at the downstream (poor condition) before it flows to the Gulf of Thailand. Figure 7 (b) shows the WQI of the three provinces in East Coast Gulf River Basin. The WQI in Rayong is in fair condition while Chanthaburi and Trat are in good condition.



(a) (b) (c)

Figure 5 The river connectivity Status Index (CSI) in (a) Chao Phraya, (b) Tha Chin, (c) East Coast Gulf river basin

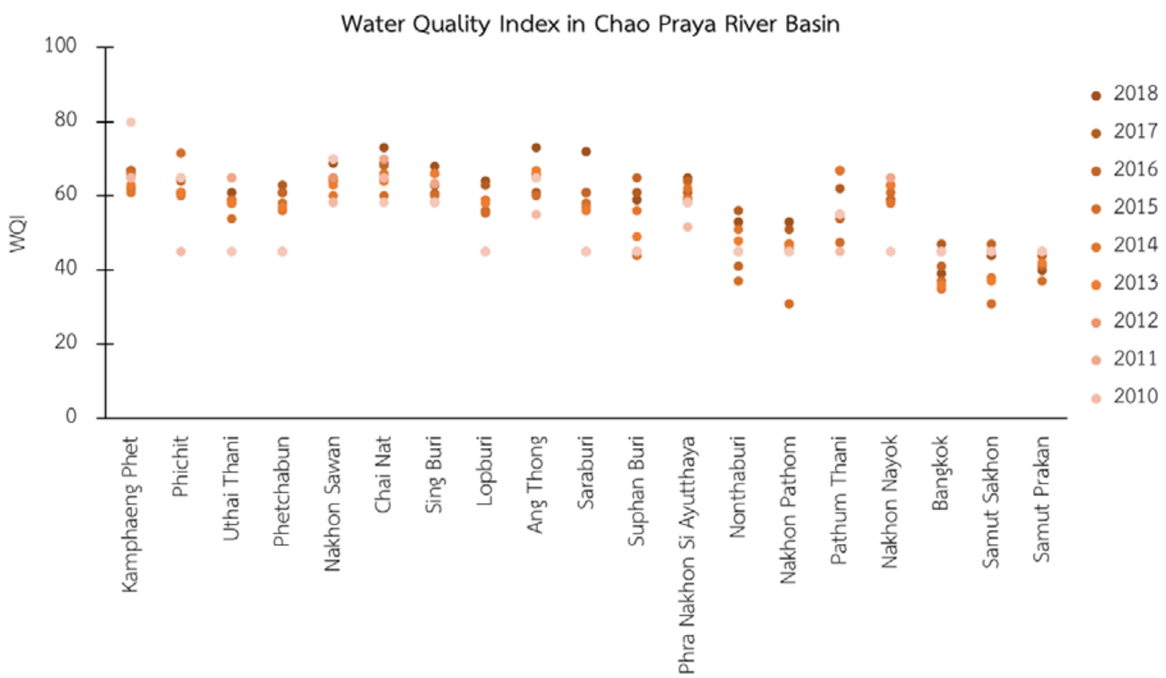
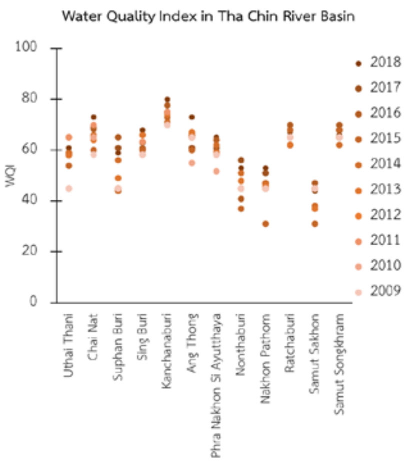


Figure 6 The Provincial WQI in Chao Phraya River Basin

(a)



(b)

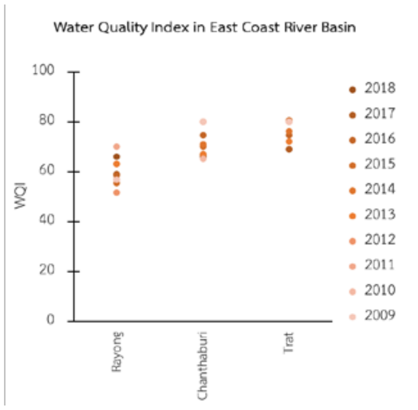


Figure 7 The Provincial WQI in (a) Tha Chin, (b) East Coast Gulf river basin

4. CONCLUSIONS

This study assesses the catchment conditions affecting the water-related ecosystem based on the Catchment and Aquatic System Condition Index (CASCI) proposed by AWDO 2020 but investigates only four indicators, namely riparian land cover change, groundwater depletion, water quality, and riverine connectivity during 2009 – 2018 as a preliminary analysis. In addition to local observations, regional scale data and satellite data are examined to evaluate the potential applications on a basin scale.

It is found that the major riparian land cover change in the three river basins is tree cover loss. The shallow groundwater storage does not show a significant trend. For the state of the water-related ecosystem based on connectivity status index, it shows that the Chao Phraya River, the upper reach of Tha Chin River, and Rayong River have low connectivity status index. The water quality index (WQI) in the lower parts of Chao Phraya River Basin and Tha Chin River Basin are in poor condition and the water quality index in Rayong is in fair condition. The four indicators investigated in this study can be used with other related indicators, for example, density of cropland, livestock, residential, industries, pollution loading, and biotic factors, to identify hotspots and pressures affecting the water-related ecosystem. The results signify the restoration of the ecological system and proper management of water resources to support livelihood and economic development in these three river basins.

5. ACKNOWLEDGMENTS

The authors are grateful for the guidance from Dr. Ben Stewart-Koster and Mr. Jeremy Hauw, Griffith University, and the scholarship from Chulalongkorn University's Graduate Scholarship Programme for ASEAN or Non-ASEAN Countries for Mr. Phanith Kruy.

6. REFERENCES

[1] ADB, Asian Water Development Outlook 2020: Advancing water security across Asia and the Pacific. Asian Development Bank, 2020.

[2] C. J. Weissteiner et al., "Europe's Green Arteries—A Continental Dataset of Riparian Zones," Remote Sens-Basel, vol. 8, no. 11, p. 925, 2016.

[3] R. J. Naiman and H. Décamps, "The Ecology of Interfaces: Riparian Zones," Annual Review of Ecology and Systematics, vol. 28, no. 1, pp. 621-658, 1997, doi: 10.1146/annurev.ecolsys.28.1.621.

[4] R. J. Naiman, K. L. Fetherston, S. J. McKay, and J. Chen, "Riparian forests," River ecology and management: lessons from the Pacific Coastal Ecoregion, pp. 289-323, 1998.

[5] J. D. Allan, "Landscapes and Riverscapes: The Influence of Land Use on Stream Ecosystems," Annual Review of Ecology, Evolution, and Systematics, vol. 35, no. 1, pp. 257-284, 2004, doi: 10.1146/annurev.ecolsys.35.120202.110122.

[6] E. Tabacchi, L. Lambs, H. Guilloy, A.-M. Planty-Tabacchi, E. Muller, and H. Décamps, "Impacts of riparian vegetation on hydrological processes," Hydrol Process, vol. 14, no. 16 - 17, pp. 2959-2976, 2000.

[7] G. Bentrup, "Conservation Buffers—Design guidelines for buffers, corridors, and greenways," Gen. Tech. Rep. SRS–109. Asheville, NC: US Department of Agriculture, Forest Service, Southern Research Station. 110 p., vol. 109, 2008.

[8] B. J. Pusey and A. H. Arthington, "Importance of the riparian zone to the conservation and management of freshwater fish: a review," Mar Freshwater Res, vol. 54, no. 1, pp. 1-16, 2003.

[9] GMS. "Digital Elevation Model for Thailand." https://portal.gms-eoc.org/maps?cmbIndicator MapType=data&cmbIndicatorTheme=6&cmbIndicatorMap=17 (accessed March 27, 2021).

[10] J.-F. Pekel, A. Cottam, N. Gorelick, and A. S. J. N. Belward, "High-resolution mapping of global surface water and its long-term changes," Nature, vol. 540, no. 7633, pp. 418-422, 2016, doi: (doi:10.1038/nature20584).

[11] SERVIR-Mekong. "Regional Land Cover Monitoring System." https://servir.adpc.net/tools/regional-land-cover-monitoring-system (accessed December 28, 2020).

[12] M. C. Hansen et al., "High-resolution global maps of 21st-century forest cover change," Science, vol. 342, no. 6160, pp. 850-853, 2013. [Online]. Available: https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.7.html.

[13] J. Kath, A. J. Boulton, E. T. Harrison, and F. J. Dyer, "A conceptual framework for ecological responses to groundwater regime alteration (FERGRA)," Ecohydrology, vol. 11, no. 7, p. e2010, 2018, doi: https://doi.org/10.1002/eco.2010.

[14] M. Rodell, J. Chen, H. Kato, J. S. Famiglietti, J. Nigro, and C. R. Wilson, "Estimating groundwater storage changes in the Mississippi River basin (USA) using GRACE," Hydrogeol J, vol. 15, no. 1, pp. 159-166, 2007/02/01 2007, doi: 10.1007/s10040-006-0103-7.

[15] B. D. Tapley, S. Bettadpur, J. C. Ries, P. F. Thompson, and M. M. Watkins, "GRACE measurements of mass variability in the Earth system," Science, vol. 305, no. 5683, pp. 503-505, 2004.

[16] Z. Rzepecka and M. Birylo, "Groundwater Storage Changes Derived from GRACE and GLDAS on Smaller River Basins—A Case Study in Poland," Geosciences, vol. 10, no. 4, p. 124, 2020.

[17] B. Li, M. Rodell, J. Sheffield, E. Wood, and E. Sutanudjaja, "Long-term, non-anthropogenic groundwater storage changes simulated by three global-scale hydrological models," Sci Rep-Uk, vol. 9, no. 1, p. 10746, 2019/07/24 2019, doi: 10.1038/s41598-019-47219-z.

[18] H. Rui, H. Beaudoing, and C. Loeser, "README document for NASA GLDAS version 2 data products," Goddart Earth Sciences Data and Information Services Center (GES DISC): Greenbelt, MD, USA, 2018.

[19] B. Li, H. Beaudoing, and M. Rodell, "GLDAS Catchment Land Surface Model L4 daily 0.25× 0.25 degree GRACE-DA1 V2. 2, Goddard Earth Sciences Data and Information Services Center (GES DISC), Greenbelt, Maryland, USA," ed, 2020.

[20] M. Rodell et al., "The global land data assimilation system," Bulletin of the American Meteorological Society, vol. 85, no. 3, pp. 381-394, 2004. [Online]. Available: https://ldas.gsfc.nasa.gov/gldas/#.

[21] GES-DISC. "GLDAS Catchment Land Surface Model L4 daily 0.25 x 0.25 degree GRACE-DA1 Early Product V2.2." EARTHDATA. https://disc.gsfc.nasa.gov/datasets/GLDAS_CLSM025_DA1_D_EP_2.2/summary?keywords=GLDAS%20_CLSM (accessed March 14, 2021).

[22] G. Grill et al., "Mapping the world's free-flowing rivers," Nature, vol. 569, no. 7755, pp. 215-221, 2019/05/01 2019, doi: 10.1038/s41586-019-1111-9.

[23] G. Günther and L. Bernhard, Mapping the world's free-flowing rivers: data set and technical documentation. 2019.

[24] PCD, Booklet on Thailand State of Pollution 2018. Pollution Control Department, Ministry of Natural Resources and Environment, 2019.