Low-Emission Food Systems

Unveiling Water Resources of the Vietnamese Mekong Delta

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The Research Institute for Climate Change (DRAGON-Mekong) at Can Tho University serves as the central hub for organizing training, conducting scientific research, facilitating technology transfer, and exchanging knowledge with national and international institutions. It collaborates with universities, governmental and non-governmental organizations, businesses, and local communities to contribute to climate change adaptation and mitigation efforts. The DRAGON acronym represents the Delta Research And Global Observation Network, with the goal of establishing a worldwide information network, fostering collaboration, and sharing extensive experiences across various deltas globally.

Disclaimer

Summary

The Vietnamese Mekong Delta is responsible for half of the country's rice production. This is possible due to abundant freshwater resources available for agriculture. This report provides a general overview of water resources in the region, presents unique water-related challenges using earth observation data, and description of measures to address them. Structurally, section one provides a general introduction followed by description of surface water resources, its uses and dynamics. Section three contains information on water infrastructure in the region. Section four covers water extent dynamics of small reservoirs followed by section five that focuses on groundwater pumping. Section six presents information about the Google Earth Engine – based tool developed to visualize surface waters and water infrastructure of the region for different time ranges using different satellites. Section seven focuses on institutional arrangements related to water management in the Vietnamese Mekong Delta. Finally, section eight provides concluding remarks and recommendations to overcome identified challenges.

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1. Introduction

The Vietnamese Mekong Delta (VMD), consisting of 13 provinces, is often referred to as the "rice bowl" of Vietnam, contributing 50% of the country's rice production and 27% of its Gross Domestic Product (GDP). The region benefits from abundant freshwater resources, receiving 90% of the annual runoff from upstream regions, making most areas suitable for agriculture. Other than agriculture, VMD contributes 70% of total aquaculture production. In total, one-third of the country's GDP is completed by the VMD (Behr, 2019). The primary water usage demand is for rice irrigation, which accounts for over 70% of the region's water demand. However, water is also used for perennial and annual plants, fruit trees, and aquaculture. The total potential flow of the Mekong Delta each year is approximately 400 - 500 billion m^3, with variations in the dry season due to saltwater intrusion (ICEM, 2012). River transportation stands as a crucial node in the region, thanks to its dense network of rivers and canals, including the Tien and Hau rivers, with a total canal length of 28,000km. The current transportation system of VMD consists of 15,000km of primary canals, 27,000km of secondary canals, and over 50,000km of tertiary canals. There are 13,000km of dikes, and 7,000km of them are designed for flood protection for summer rice fields (Marchand et al., 2011).

On the other hand, groundwater is crucial, especially in coastal regions facing water shortages during the dry season. There are more than one million wells in VMD to address all purposes, including domestic, agricultural, and other industrial usage (UNDP, 2020). Groundwater in the VMD is categorized into eight different aquifer levels, each at varying depths (Nguyen et al., 2019). These aquifers play a vital role in supporting agriculture and community needs. The region faces various challenges related to water resources due to its geographical settings and seasonal climate variations. During the rainy season, the region experiences flooding, while the dry season brings salinity intrusion (Trung & Tri, 2014), impacting both surface and groundwater quality (although the delta has not been flooded since 2011 due to climate change and hydropower 'dams' operation in the upstream of the Mekong). Aquaculture, particularly shrimp farming, has grown in the VMD. The implications of land use changes, including the intensification of agriculture, which has both positive and negative consequences, and the expansion of shrimp farming that can lead to mangrove degradation, must be scrutinized. Rising sea levels and salinity intrusion threaten freshwater-based agriculture and change the aquatic environment, which then leads to threats to existing ecosystems and agriculture. The potential hazards due to climate change, such as land submersion, coastal floods, erosion, increased soil salinity, and drainage issues, emphasize the need for adaptation measures and context-specific responses to address these challenges (Tri et al., 2023). For instance, improving water control, enhancing drainage systems, managing saline intrusion, and organizing rural water supply would be impactful solutions for the key challenges (MARD, 2016).

Climate change further exacerbates these challenges, with rising sea levels and changing seasonal flows affecting croplands. Additionally, caution should be taken on the sudden changes in the flow due to operational changes in the hydropower dams located upstream due to potential flood inundation. Usually, the Northern region of VMD experiences deep inundation and nearly overbank flooding of two rivers, Tien, and Hau. Central VMD is moderately influenced by the flood from the upstream and the impact of the tidal dynamics and sea level rise. The lower region, or the coastal zone, is influenced by marine hydrology. Infrastructure management of the region has specific targets to cover based on the region's nature. According to the "Towards a Mekong Delta Plan" edited by Marchand et al. in 2011, taking measures for flood protection in cities and residential

areas, controlling the acidity of soils to be used in agriculture and aquaculture production, collaborating existing flood control measures with the water storage and traffic management measures, improving the irrigation capacity by dredging the canals and creating links between existing canals and improving the capacity of drainage pumping for the areas with issues in gravity (Marchand et al., 2011). The present work focuses on understanding the significance of water resources in the VMD and the measures required to address the region's unique water-related challenges using earth observation (EO) data and other resources. Researchers are increasingly relying on EO data to gauge parameters such as cultivated area, crop yield, and phenology. The widespread availability of EO data, featuring enhanced spatial and temporal resolution, provides a valuable resource for examining diverse facets of rice cultivation, spanning from phenological aspects to evaluating crop yields (Chowdhury et al., 2023). The work in this report includes mapping water resources, identifying major problems, and assessing current regulations towards achieving SDGs (specifically SDG 2 and SDG 13) in the VMD.

2. Surface Water Resources

Both climate change and anthropogenic interventions impact water resources in the region (Liu et al., 2022). Seasonality and transition of surface water over the past years provide an overview of the availability and changes of surface water resources over time. JRC Global Surface Water Mapping Layers, v1.4, available in Google Earth Engine (GEE), has the location and temporal distribution of water for the past 37 years, from 1984 to 2021, with 30m resolution. The dataset includes monthly maps of surface water generated using Landsat scenes since 1984. In addition to the locations of the surface water bodies, the dataset consists of information about the frequency of water occurrence, maximum water extent, water seasonality and transition (Li et al., 2023). Figure 1 represents a historical water occurrence map of VMD. The extreme values were discarded using percentile analysis. When interpreting the occurrence of water, it becomes evident that areas with aquaculture and similar land use classes have high water occurrence, while it is the other way around when it comes to areas with rice cultivation.

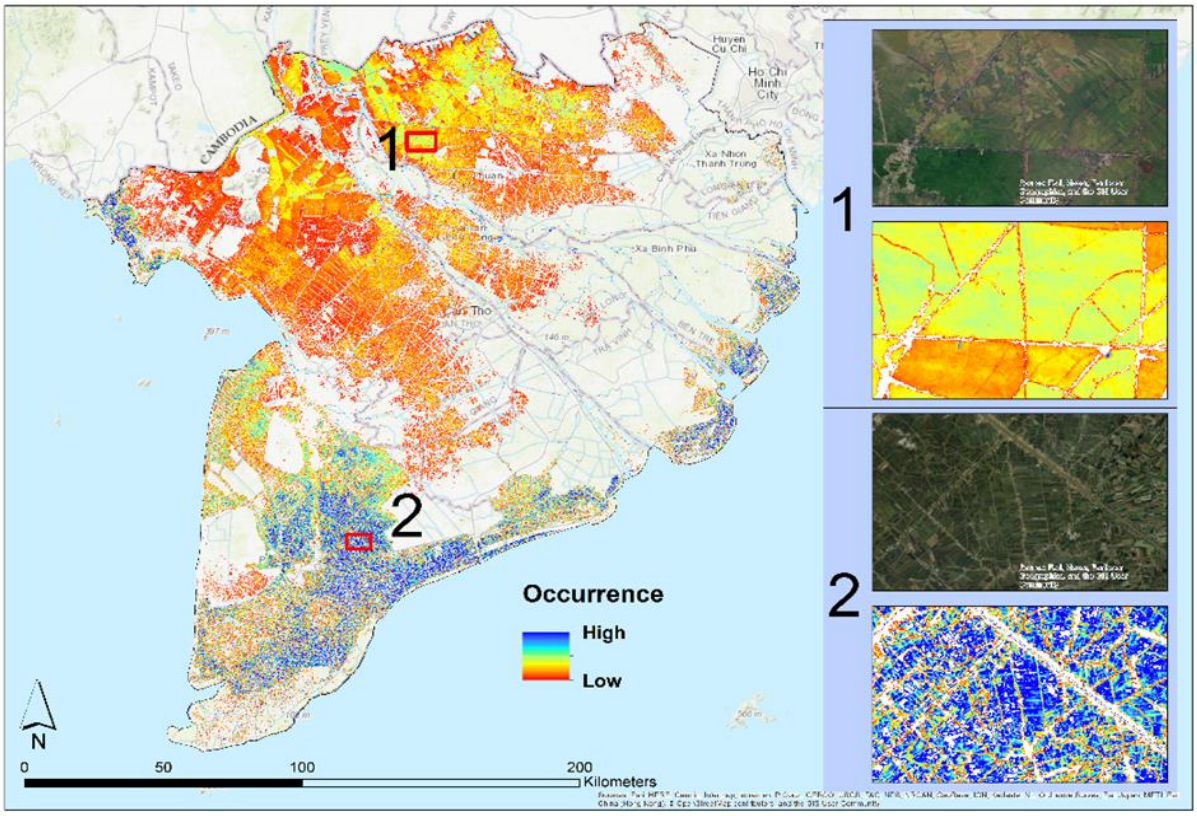

Figure 1. Water Occurrence. (1) represents a zoomed view of rice cultivated area where the water occurrence is low, while (2) shows the zoomed view of aquaculture area where the water occurrence is higher.

Similarly, an overview of the seasonality of surface water is presented in Figure 2, where the extreme values are removed using percentile analysis and classified only into three classes based on the months. From the regions identified as having water for 1-3 months, the temporal water, especially the rice cultivated areas, can be detected. The areas coming under the second and third classes, where the water is available for 3 – 9 months, are the areas with water most of the year and

can be identified as aquaculture regions. From the last class, with 9 – 12 seasonality, the permanent water is identified.

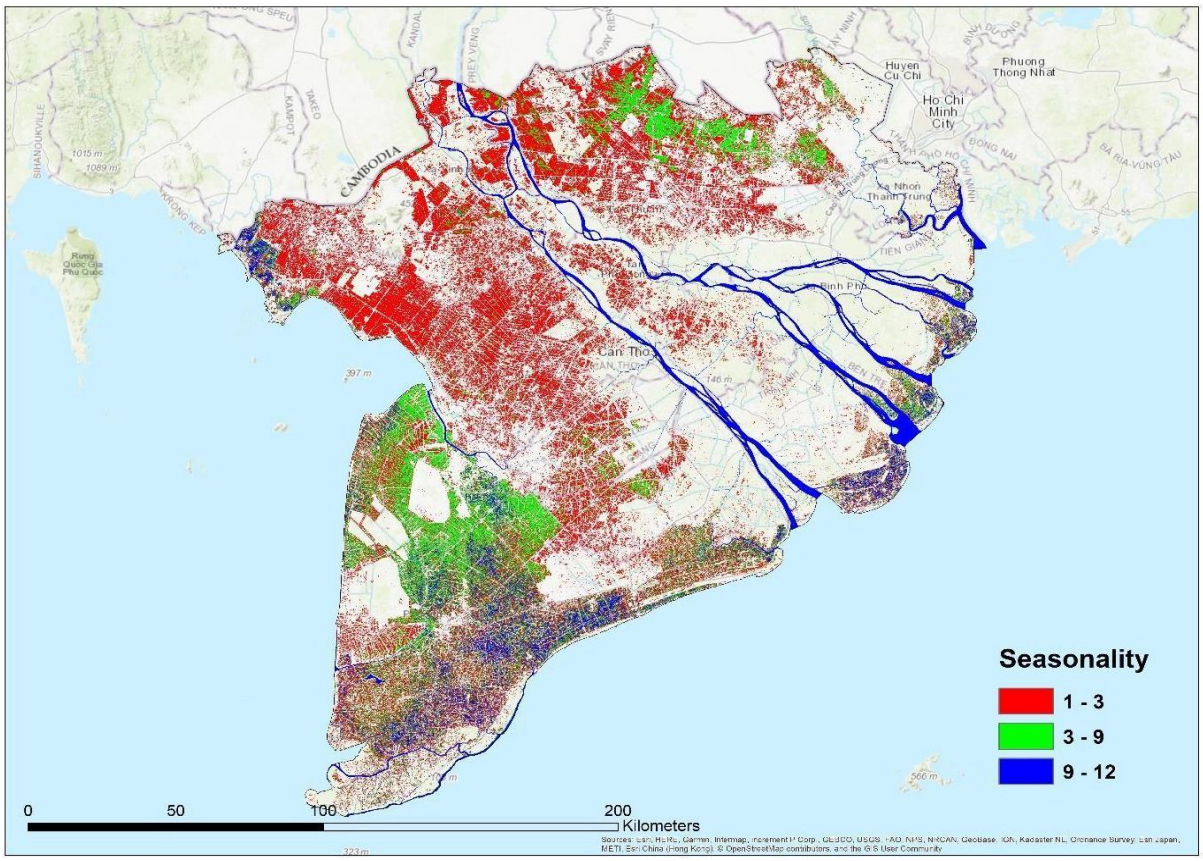

Figure 2. Surface Water Seasonality (Months).

A choice of an ideal agricultural product for the land depends on the hydrology of the region. Several external factors, such as irrigation development, market demand for the products, and climate change influence, have also been a reason for the land use transition in the VMD (MARD, 2016). In addition to seasonality and occurrence, surface water transition is also a helpful dataset that provides an overview of the changes in water resources. Spatiotemporal transitions of surface waters from 1982-2022 were examined by visual inspection using the imagery of different dates and locations in VMD.

The dynamics of the surface waters are presented in Figure 3. Areas that showed significant changes, like new permanent, lost permanent, seasonal water changed to permanent water and permanent water changed to seasonal water, are represented by the water transition. For example, Figure 4 shows a region that identified most pixels as new permanent water. From the given historical satellite image of 1985 and the recent satellite image of 2023 (from Google Earth), it is visible that the area pointed out using the red dot was earlier bare land and is now used as aquaculture land.

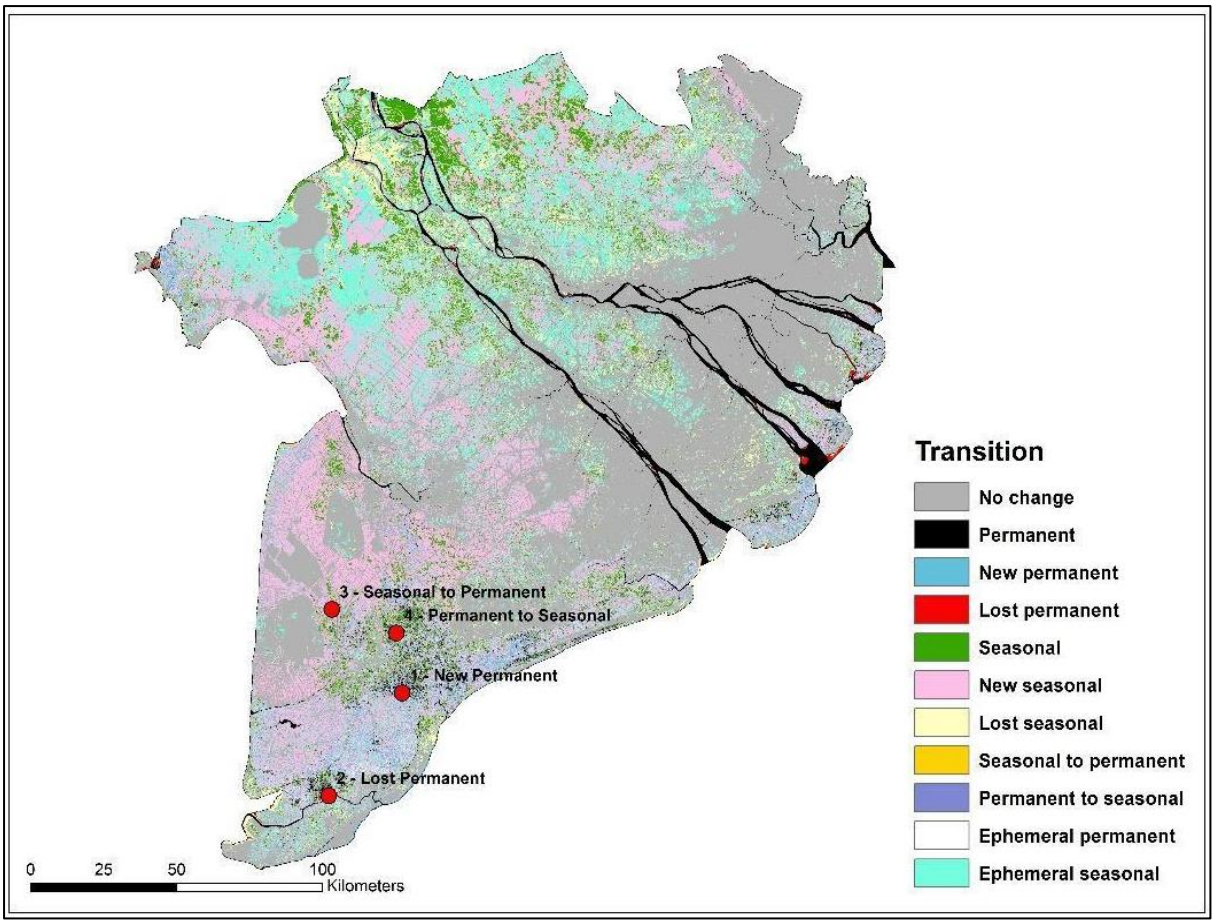

Figure 3. Surface Water Transition in Mekong Delta, Vietnam.

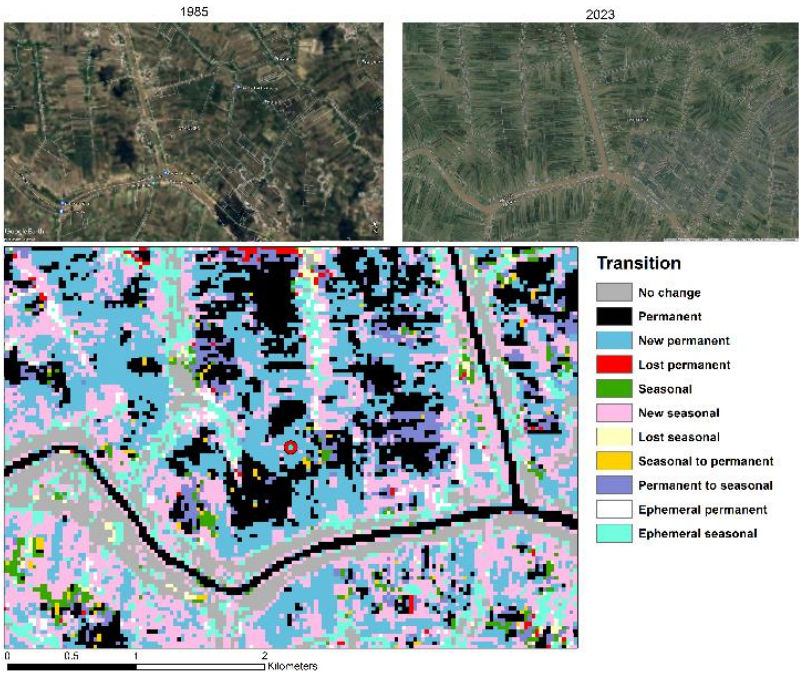

Figure 4. Areas identified as New Permanent Water.

In Figure 5, pixels identified as lost permanent water are shown. The historical image of 1985 and the recent image of 2023 (from Google Earth) depict that an area used earlier for aquaculture is now being used for other cultivations. Figure 6 shows a region that has changed from seasonal to permanent water, while the satellite imagery shows the transition of land from agriculture to aquaculture.

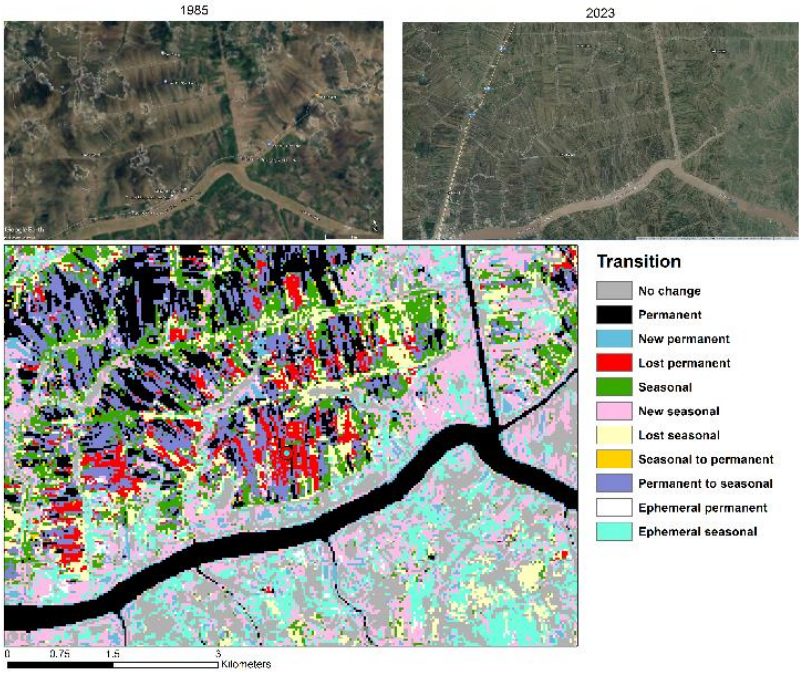

Figure 5. Areas identified as lost permanent water and imagery comparison of the area.

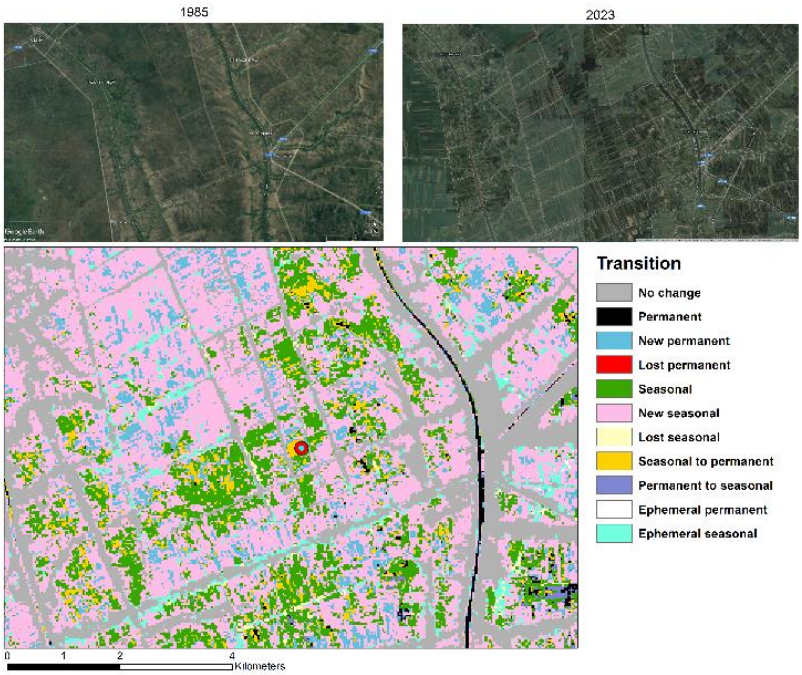

Figure 6. Areas identified as lost permanent water and imagery comparison of the area.

Figure 7 shows areas where the transition from permanent to seasonal water was identified. In the historical image that was taken in 2002, water bodies like tanks or ponds are visible. However, in the recent image taken in 2023, agricultural lands have replaced them. From all the information gathered from JRC Global Surface Water, the evolution of water resources in VMD can be investigated in such a way.

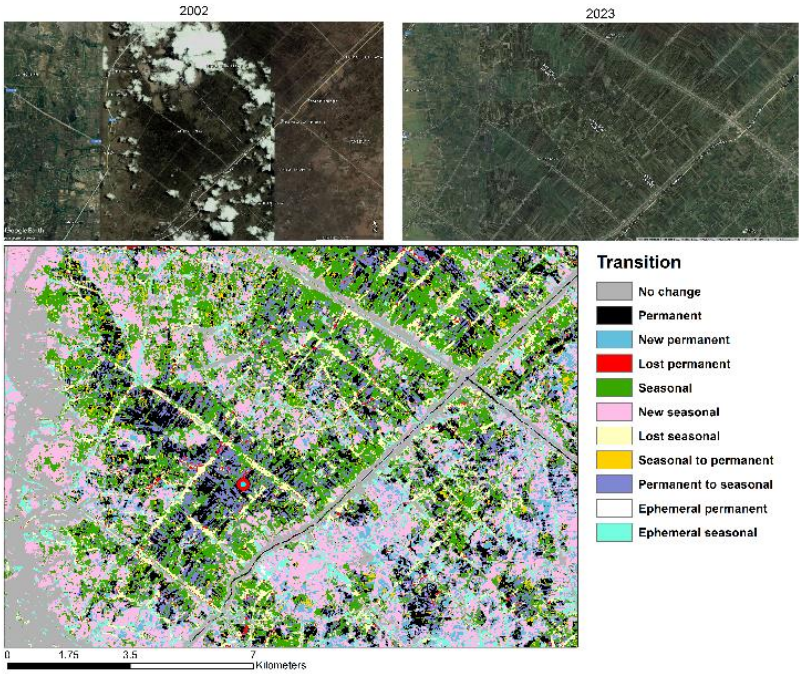

Figure 7. Areas identified as permanent to seasonal transition of water and imagery comparison of the area (2002 vs 2023).

Seasonality and transition of water resources can aid users in differentiating the permanent and temporal water and understanding the evolution of water resources. Identifying the occurrence and other water-related information helps determine the suitability of lands for several purposes. The correct identification of water resources based on their availability and usability leads to bringing forward the appropriate infrastructure management practices that guide the region to achieve sustainable development goals.

3. Water Infrastructure

The infrastructure development in the VMD (Figure 8) is identified as a major concern due to water-related issues, including periodic floods, salinity intrusion, soil acidity, and freshwater shortage. The annual periodic floods affect about 50% of VMD's livelihood and agricultural production. In addition to the modification of crop patterns, the introduction of rice crops with short-growth periods and the promotion of aquaculture, prevention methods such as the use of flood-control dikes and sluices were developed under the infrastructure to control flood-induced damage (MARD, 2016). VMD has approximately 13,000km of flood-control dykes (MARD, 2016) along the current canals. The government and other organizations should consider the requirement of a proper infrastructure system that meets the water management demands to achieve the region's sustainable development goals. Each sub-region of the VMD focuses on common initiatives as follows.

1. Flood protection measures in residential areas, towns, and cities
2. Working on reducing the flood levels to ensure the two spring-summer-autumn rice production and making the rice seasons clearer.
3. Minimizing the acid soil-related issues with improved water management
4. Integrating the flood control systems with irrigation with the intention of producing a complete irrigation system
5. Increasing the irrigation capacities by dredging canals and linking branches of canals and rivers.
6. Upgrading the drainage pumping capacity of selected regions (Marchand et al., 2011)

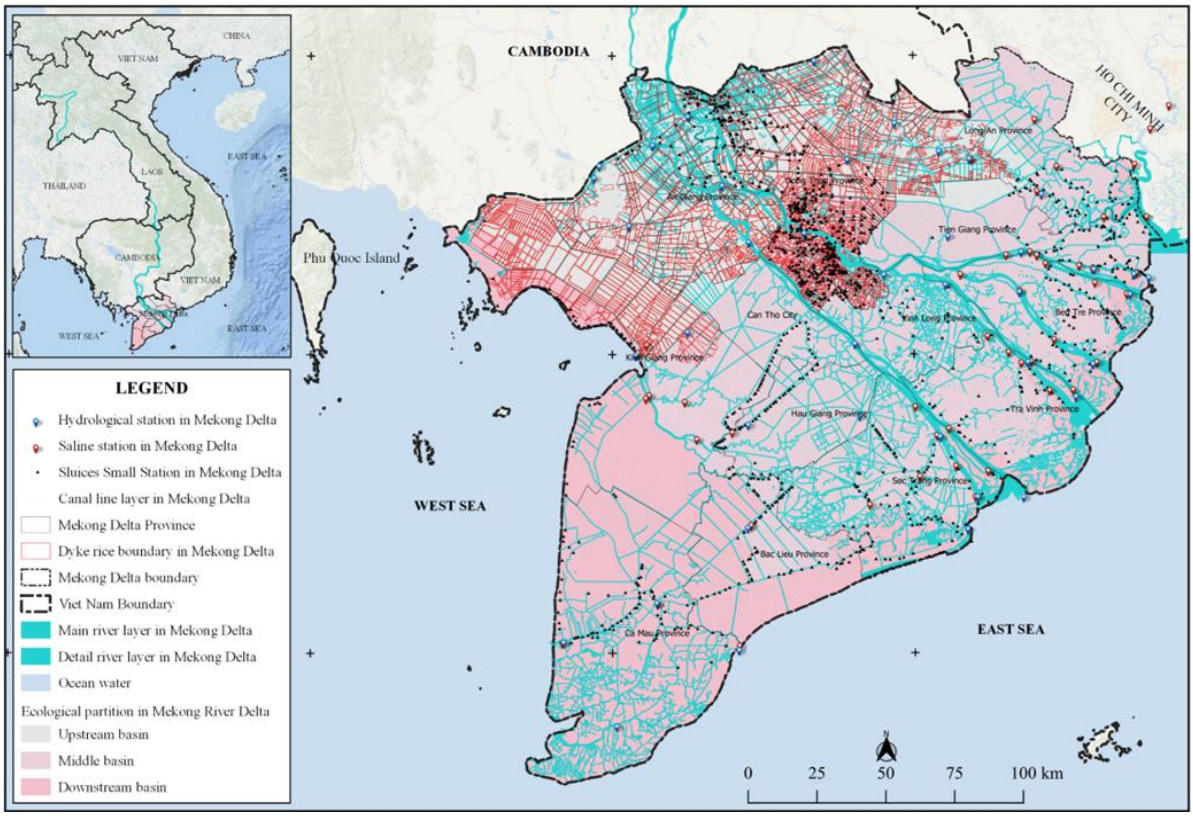

Figure 8. Irrigation Infrastructure of Vietnamese Mekong Delta prepared in QGIS.

Innovative technology like remote sensing and GIS (Geographic Information System) can be used for a wide range of applications relevant to water resource management and mapping. The irrigation infrastructure map of the VMD (Figure 8) prepared in the QGIS platform has data on hydrological stations and saline stations, sluices, the main river layer, the dike rice boundary, and the ecological partition boundary of the VMD, which has been collected from different sources such as the Research Institute for Climate Change (DRAGON -Mekong Institute – https://dragon.ctu.edu.vn/en/- Last Access on 05-01-2024), College of Environment and Natural Resources (https://cenres.ctu.edu.vn/en/home.html - Last Access on 05-01-2024); Southern Institute of Irrigation Science, Viet Nam Meteorological and Hydrological Administration (http://www.siwrr.org.vn/?lang=e – Last Access on 05-01-2024).

4. Water Extent Dynamics of Small Reservoirs

The VMD has limited freshwater reservoirs. The text provides information about reservoirs in An Giang and Ben Tre provinces. Figure 9 shows the locations of reservoirs in An Giang province. It highlights the role of these reservoirs in overcoming water shortages, especially during droughts and saline intrusion events. The ongoing construction of new reservoirs to enhance water security is mentioned. It can show the seasonal variation in reservoir water extent using satellite imagery (Rajakaruna et al., 2023). It is challenging to map small reservoirs using satellite imagery due to the lower resolution of the available satellite data, which renders the accuracy very low. Therefore, it is difficult to contrast the monthly water extent of small reservoirs using only satellite data.

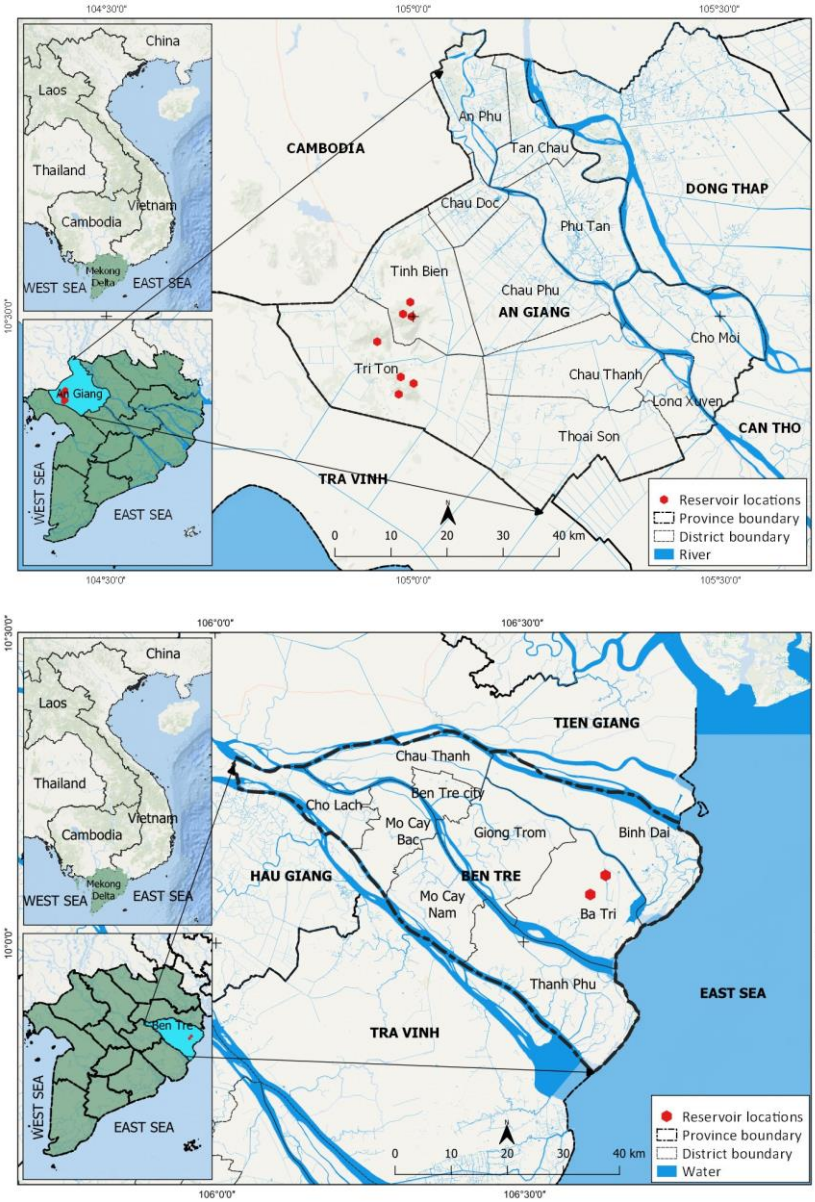

Figure 9. Location of Reservoirs in An Giang Province.

To get an idea of the seasonal variability of small reservoirs in An Giang province, O Ta Soc reservoir is selected from the three reservoirs of VMD mentioned in the study (Rajakaruna et al., 2023) The monthly extent of the O Ta Soc reservoir was analyzed using Sentinel-1 satellite data in GEE and Figure 10 illustrates the results of the study.

The Sentinel-1 Ground Range Detected (GRD) dataset consists of daily updating image collection since 2014. The dual polarization system, which gives the ability to record co-polarized and cross-polarized backscatter values, enhances the applicability of Sentinel 1 for different purposes (Sentinel Online - Polarimetry, 2023). One key advantage of using radar satellite imagery like Sentinel-1 for change detection is that the clouds do not affect them as radar penetrates through clouds. Pre-processed Sentinel-1 imagery can be imported from the GEE data catalogue, and it helps the user avoid all the pre-processing complexities and concentrate on the use and analysis of the data (Ghosh et al., 2022). The monthly collections of Sentinel-1 radar imagery for the selected reservoir area were imported from the GEE catalogue to the GEE code editor as the first step of the process. Then, terrain correction and speckle filtering functions were implemented to obtain a corrected scene. A threshold is required to distinguish the surface water from other land use of the region; the OTSU algorithm can automatically generate the global threshold based on the largest between-class variance criterion and has a high rate of correct classification for images with uniform bimodal gray histogram distribution was used in this classification (Tan et al., 2023). With that, a unique threshold value for both VV (co-polarized) and VH (cross-polarized) bands of Sentinel 1 imagery, considering the time and region, is generated and provides a more accurate result. Monthly surface water images are produced by applying the generated thresholds to the satellite imagery. The surface water extent is calculated for each image as follows.

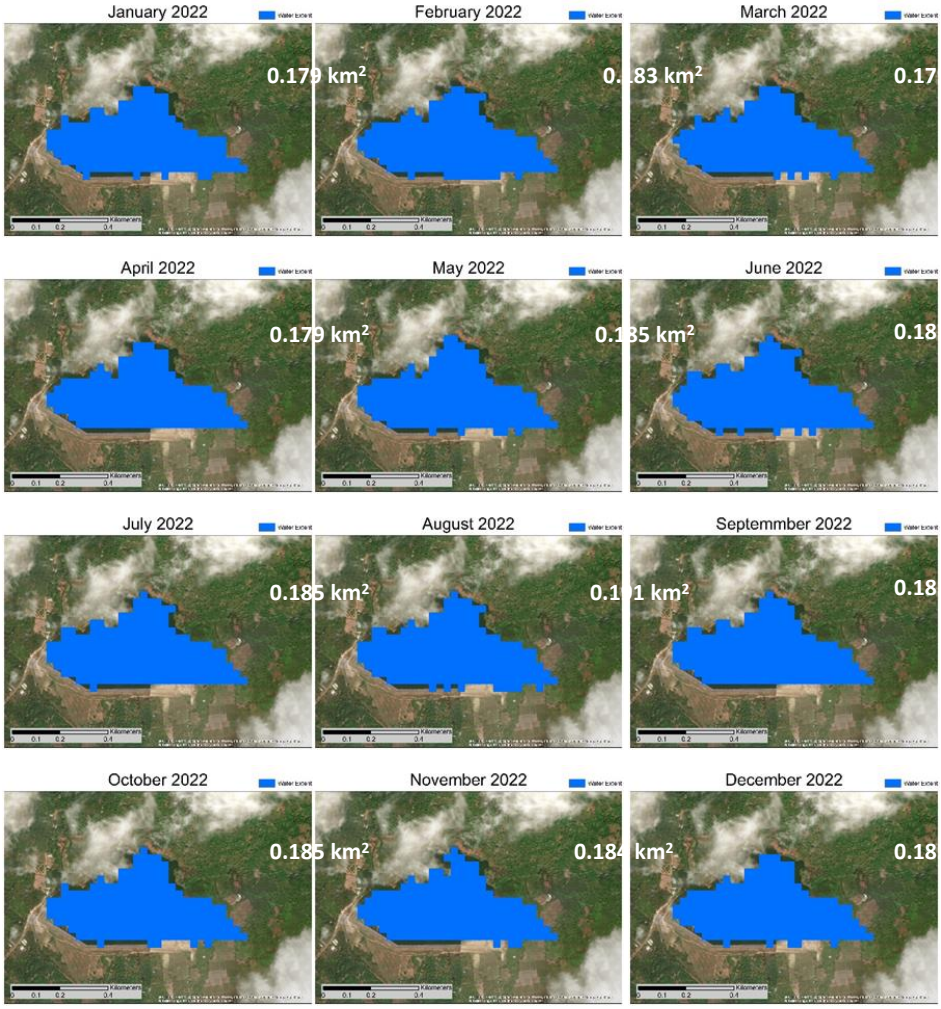

Figure 10. Monthly reservoir extents of O Ta Soc, An Giang Province in 2022 generated using Google Earth Engine (GEE).

5. Ground Water Pumping

More than 900 million cubic meters of water is extracted from the wells located in shallow and deep aquifers of VMD annually to aid the household, agricultural and industrial uses of 50% of the population. Previous studies have mentioned that nearly 600 billion cubic meters of fresh groundwater can be collected from the aquifers in VMD (Gunnink et al., 2021). The authors cautioned, however, that mixing of fresh groundwater with brackish and/or saline groundwater (Figure 11) is a serious risk to the fresh groundwater volume, resulting in an apparently modest groundwater extraction regime easily becoming non-sustainable.

The number of groundwater (GW) pumping stations located within the VMD has been estimated at around 5,900 and provides water to approximately 920,000 ha of agricultural lands. According to the province-level statistics, An Giang province had the largest number of GW pumping stations and agricultural lands. So, approximately 280,000 ha of cultivated lands receives water supply from around 1800 GW pumping stations. Ben Tre province had the least cultivated land, which was only 3126 ha, and only 16 GW pumping stations in 2020 (Tuan, 2013; Tuan et al., 2020). The GW pumps need an external energy source such as diesel fuel and electricity. For that, the size of the GW pumps and motors used should be compatible with the task, and users should have a major concern about possible frictional losses. Increasing GW pumping efficiency may reduce the negative impact of their use in agricultural activities, particularly during the dry season. If current rates of groundwater extraction continue, land subsidence of approximately 0.88 meters (range from 0.35 to 1.4 meters) is expected by 2050 (MARD, 2016). However, solar-powered GW pumps will slightly reduce the adverse impacts of GW pumping in tropical regions with adequate sunlight because direct solar pumping is more efficient since harvested power is entirely used for pumping, and no other losses are associated (Sathre, 2021).

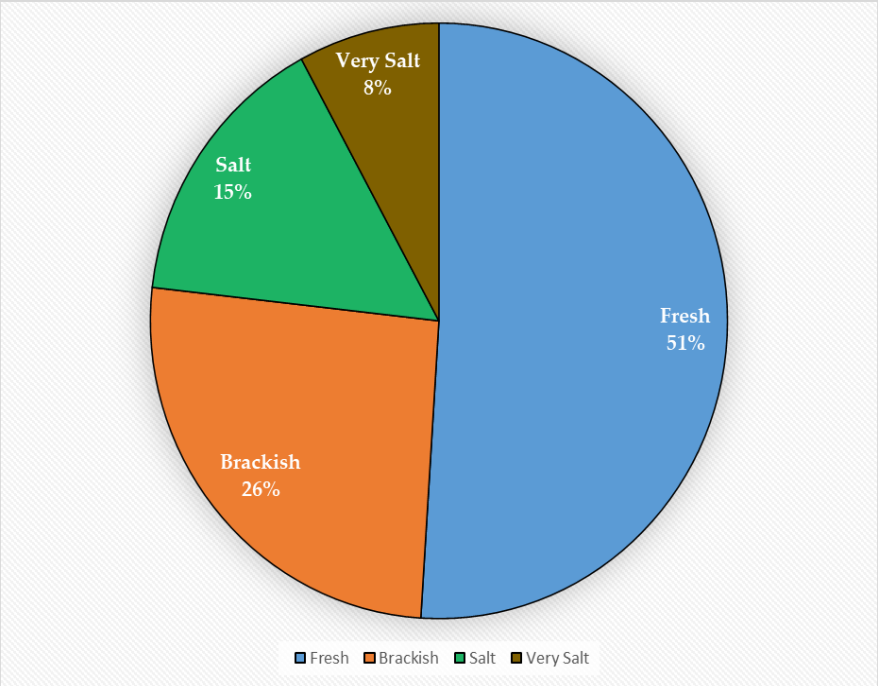

Figure 11. Salinity status of groundwater reserves in Vietnamese Mekong Delta
(Source: Towards a Mekong Delta Plan, 2013)

6. Water Resource Dashboard

GEE is a cloud-based platform with numerous publicly available datasets that enable spatial analysts to design several applications matching the requirements. GEE code editor can be used to build several applications for change detection, disaster management, climate monitoring, water management, food security, etc.

A GEE-based tool has been developed to map water infrastructure in the VMD at the district level (Figure 12). The tool uses Landsat 5, 7 and 8 imagery and Sentinel 2 satellite imagery as background information. In addition to that, the available data collected from irrigation-related agencies in the Mekong Delta, such as the Research Institute for Climate Change (DRAGON -Mekong Institute), College of Environment and Natural Resources, Southern Institute of Irrigation Science, and Vietnam Meteorological and Hydrological Administration.

The left side of the user interface is for selection purposes, and the visualization of the analyzed results can be seen on the right side. Since this application is specifically created for the VMD, a shapefile containing the district boundaries of VMD was uploaded to the code editor as the study area. The initial step of the application is selecting the area of interest (AOI) using that shapefile. First, the province should be selected from a drop-down menu, and then the district should be selected. After selecting the AOI, the required satellite and date range must be selected. Since the availability of satellites differs with the period, it is the user's responsibility to select a matching date range with the selected satellite. After selecting all the required information, the process data button should be clicked, and the satellite image scene, Land Surface Water Index (LSWI) image, Surface Water identified using the OTSU thresholding method, and the canal layer of the selected region can be viewed. The canal layer is also a pre-uploaded shapefile prepared using the existing data.

The tool can be used to visualize the surface water of a particular region for different time ranges using different satellites and compare the results to better understand the surface water resources of VMD. This can be modified and upgraded to map any selected region's other factors and information associated with water resources.

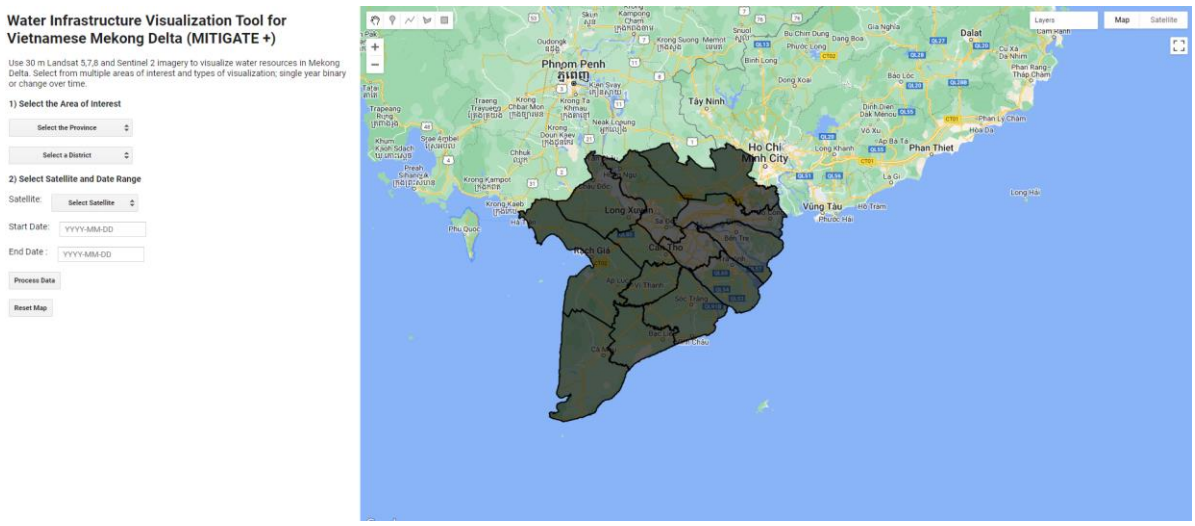

Figure 12. GEE Application to visualize water resources in the Vietnamese Mekong Delta at district level.

7. Institutional Arrangements

In the past, adaptive measures were altering institutional practices, increasing the storage capacity by building reservoirs or other structures (*e.g.*, structural flood defences), changing the operating rules available for existing structures and systems, demand management, etc. The adoption of the "Rice First" policy in Vietnam resulted in the prioritization of rice cultivation during the period of 1990-1997, and the use of water resources for agricultural purposes was promoted due to that. Later, during 2000-2007, priority was given to agricultural diversification and promoted fruit and aquaculture production. Attention was given to irrigation development and flood management following the rice export promotion policy during 2007-2013 (MARD, 2016).

International agencies such as the World Bank and initiatives such as the Global Water Partnership have been working to promote new ways of managing water resources more effectively (Snidvongs et al., 2003). The 1995 Mekong Agreement commits four countries to use water resources reasonably and equitably, maintain mainstream flow, and prevent harmful effects. Local solutions were recommended to enhance community engagement in water resource management. These include notifying water customers and operators of projections, requesting operational changes, evaluating drought contingency plans, raising awareness education programs, exploring alternative water sources, informing authorities of navigation challenges, and monitoring bank erosion (Phoumin & To, 2020).

On the other hand, the Vietnamese constitution contains the law on water resources (Law No: 17/2012/QH13), which explains the general provisions concerning water resources, obligations involved with water resource protection, water resource extraction and use, preventing and overcoming floods and other water-related disasters, exploitation and protection of water conservation work, worldwide water resource interactions and rewards, handling of violations, and implementing provisions related to water resources. Civil law in Vietnam considers water rights and disputes. Usually, the state-adapted laws and regulations have legal authority in Vietnam. Therefore, the civil laws concerning water rights and disputes are limited within the territory. The Vietnamese constitution declares that water resources in the country belong entirely to the people and must be managed by the state, allowing people to access water resources through a system of permits. The government has introduced various taxes and license fees related to water rights (FAO, 2023). Poor water management practices relevant to agriculture may lead to an increase in GW pumping, which needs to be under control. Other than the direct involvement in water resource management, there are recent government policies and adaptations to manage the negative consequences associated with water resources, such as increased GHG emissions due to GW pumping. "1 Must Do and 5 Reductions" is a policy that aids in regulating activities such as poor water management and excessive use of pesticides and fertilizer to control emissions but positively impact water resources.

One of the larger remaining issues is linked to the legal and policy framework, characterized by gaps and inconsistencies, which often engenders conflicts between key agencies like the Ministry of Natural Resources and Environment (MONRE) and the Ministry of Agriculture and Rural Development (MARD). The lack of collaboration between top to bottom-level stakeholders for tasks associated with managing water resources resulted in the inefficient utilization of critical irrigation projects. The overemphasis on administrative boundaries rather than physical water limits further compounds these problems, leading to the misallocation of valuable resources.

8. Conclusion and Way Forward

The VMD faces a myriad of ongoing challenges that have posed significant threats to its sustainable development for many years. Challenges, ranging from underperformance of existing water infrastructure (operating below design capacity) to inconsistencies in the legal and policy framework, exacerbate inefficiencies in the region. A severe deficiency in qualified human resources compounds these challenges, with an acute shortage in quantity and qualifications. Since a poorly defined decentralized irrigation management system leads to underperforming irrigation systems and limited farmer engagement, it can be recommended that the collaborative parties propose several adaptation and resilience strategies to address these issues and enhance the resilience of the Mekong Delta.

To overcome increased GHG emissions due to GW pumping, it is better to move for more conventional water management practices, adapting to divergent systems such as restoring the natural flood regime and modifying cultivation patterns in a favourable way. Agri-food and water systems are heavily impacted by the diverse effects of climate change and the other way around, with agri-food systems contributing to one-third of GHG emissions. To minimize the adverse impact, regenerative agriculture, innovative investment, national transformation pathways, water conservation, strengthening the infrastructure availability, integrated governance and effective management of water food systems can be encouraged. A high-level consultation approach involving the ideas of all the representatives and stakeholders in decision-making processes and in executing and evaluating plans is possible to enhance the efficiency of water resource management. Furthermore, establishing formal cooperative mechanisms, especially among riparian countries, can be suggested for policy coordination to address current water security challenges and enhance governance. International collaboration through initiatives like the Lancang-Mekong Cooperation and Lower Mekong Initiative (LMI) plays a pivotal role in promoting sustainable natural resource management in the region. Embracing recent technological advancements for monitoring water resources and fostering research in water resource management is essential for developing more effective and efficient solutions to the ongoing challenges faced by the Mekong Delta when achieving the SDGs. These adaptation and resilience strategies collectively offer a path towards ensuring the long-term sustainability and prosperity of the Mekong Delta's vital ecosystems and communities.

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