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A Subregional Model of System Dynamics Research on Surface Water Resource Assessment for Paddy Rice Production under Climate Change in the Vietnamese Mekong Delta

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Abstract: Effective water management plays an important role in socioeconomic development in the Vietnamese Mekong Delta (VMD). The impacts of climate change and human activities (that is, domestic consumption and industrial and agricultural activities) vary in different subregions of the delta. In order to provide intersectoral data for determining the significantly impacted subregions of the VMD, the present study simulated interactions between local climatic patterns, human activities, and water resources using a system dynamics modeling (SDM) approach with each subregion as an agent of the developed model. The average rainfall and temperature of 121 subregions in the VMD were collected during 1982–2012, and the future changes of climate by provinces were based on the Representative Concentration Pathways (RCP) scenarios (RCP4.5 and RCP8.5) by the end of 21st century. The assessment was based on the levels of impact of various factors, including (1) water consumption, (2) differences between evapotranspiration and rainfall, and (3) spatial distribution of salinity intrusion over the delta scale. In the coastal areas, as well as the central and upstream areas, water resources were projected to be affected by environmental changes, whereas the former, characterized by the lack of surface freshwater, would be affected at a greater scale during the dry season. Besides, the sea level rise would lead to an increase in negative impacts in the eastern coastal areas, suggesting that water-saving techniques should be applied not only for agriculture, but also for industry and domestic water consumption during the dry season. In addition, the south subregions (that is, the western subregions of the Hau River except for An Giang) were likely to be flooded due to the simulated high rainfall and seasonal rises of sea level during the wet season. Therefore, the alternative forms of settlement and livelihood should be considered toward balance management with changing delta dynamics.

Keywords: system dynamics; water resources; climate change; Vietnamese Mekong Delta

1. Introduction

Freshwater is vulnerable to climate change and population growth throughout the world [1,2]. Various models have been developed to assess the impact of climate change on water resources, such as hydrologic models based on water balance in hydrologic cycle, that is, precipitation, evapotranspiration, and surface runoff [3–6], and water resources assessment models based on the relation between the hydrologic cycle and water demands of domestic consumption, industrial, and agricultural activities, and population growth [7–10]. In the assessment models, the water scarcity is determined based on water stress, which is the fraction of total water withdrawal and water availability [9,11]. Besides, sea level rise also impacts the freshwater resources through salinity intrusion in coastal areas [12–14].

The Vietnamese Mekong Delta (VMD) is one of the most vulnerable areas of Southeast Asia under the impacts of climate change and sea level rise [15,16]. In the seasonal flood area of the VMD (Long Xuyen Quadrangle and Dong Thap Muoi), the surface water resources are sufficient for human activities, but the local residents face a high flood risk [17–19]. In contrast, the farmers in the coastal areas (Ben Tre and Tra Vinh, Soc Trang, Bac Lieu) and the Ca Mau Peninsula (Ca Mau and the south Kien Giang) face the frequent freshwater shortage and salinity intrusion [20–23]. In addition, due to a sharp increase of groundwater extraction, the land subsidence in the VMD has become serious in the past 25 years [24,25]. In order to solve those problems, the effective management of water resources (both surface water and groundwater) is key. Therefore, it is important to determine the areas where water resources are highly vulnerable to climate change and human activities, supporting local and central government (Resolution 120 of the Government of Vietnam of sustainable developing the VMD and adaptation to climate change [26]). In order to have an effective water resources management, it is necessary to synthesize different factors, including (1) good coordination of the stakeholders (managers, suppliers and users), (2) high capacity of human to prevent the water scarcity, and (3) large proportion of population having access to the freshwater resources [18,27–30].

System dynamics modeling (SDM) is based on mathematical simulation to understand the dynamics and interactions among the components of a system in time [31]. In Vietnam, previous studies have been rarely conducted based on the system dynamics modeling approach, such as the application of SDM approach to study the interaction between economy of growers and rice agriculture in An Giang of the VMD [32] and in the north of Vietnam [33]. In the VMD, an SDM approach (SWR-VMD model) was applied to assess impacts of climate change and the adaptation solution based on Resolution 120 of the Government of Vietnam of sustainable development the VMD and adaptation to climate change [34]. The model indicated that water scarcity would increase in the dry season under the impact of climate change in the 2050s. However, the change of land use from triple to double rice systems could mitigate the water stress on rice cropping.

Actual water demand (AWD) includes water demand in domestic, industry, and irrigation [35]. AWD may be defined depending on each specific demand. For example, it could be the difference between water demand and the amount of rainwater, soil-water, and evapotranspiration [36]. In the present study, AWD was determined as the difference between available surface water (that is, local rainfall and surface flow subtract evapotranspiration) and total withdrawn water.

Decision 417, issued by Prime Minister of Vietnam in 2019, issued the integrated actions to implement Resolution 120 [37]. There are six promoted actions, including developments of policy and regulation, intersectoral data, master plans, social plans, infrastructures, and labors. This study aimed to provide intersectoral data for forecasting natural disaster events, erosion, and subsidence using the SDM approach for each subregion in the VMD. The present model, incorporated with the geographic information system (GIS) method, could forecast the subregions facing high risks of water scarcity, flood, or subsidence due to climate change (that is, temperature and rainfall changes) and human activities (that is, domestic, industrial, and agricultural activities).

2. Methodology

2.1. Model Development

The system dynamics model was developed based on the SWR-VMD model throughout the VMD [34]. Surface water resources, human activities, and government policies had interactions with each other and were connected using the SDM method. Because the water flow from upstream countries was excluded in this research, the AWD for each subregion of the VMD was used instead of water stress to assess the water resource dynamics. The changes in surface water dynamics depend on human activities. It indicated that water consumption amount depends on irrigated and industrial land use, and population. In addition, the changes in climate (that is, temperature and rainfall) affect water availability [34]. The equations used in this model were referred from the previous model but calculated for a smaller scale (subregional scale). The results and GIS data were analyzed using Vensim and ArcGIS programs, respectively [31,38].

2.2. Study Area

Using management units could support to assess the change in water resources based on the impacts of various sectors in more detail. Figure 1 shows that there were 121 management units (subregions) of 13 provinces in the VMD. The GIS data were collected from DIVA-GIS [39]. The islands in the West Sea and East Sea were not included in the study. The subscribed subregions and provinces in details are presented in Table 1. The three subregions without rice growing are Nam Can, Ngoc Hien, and Cu Lao Dung (that is, ST1, CM4, and CM5, respectively).

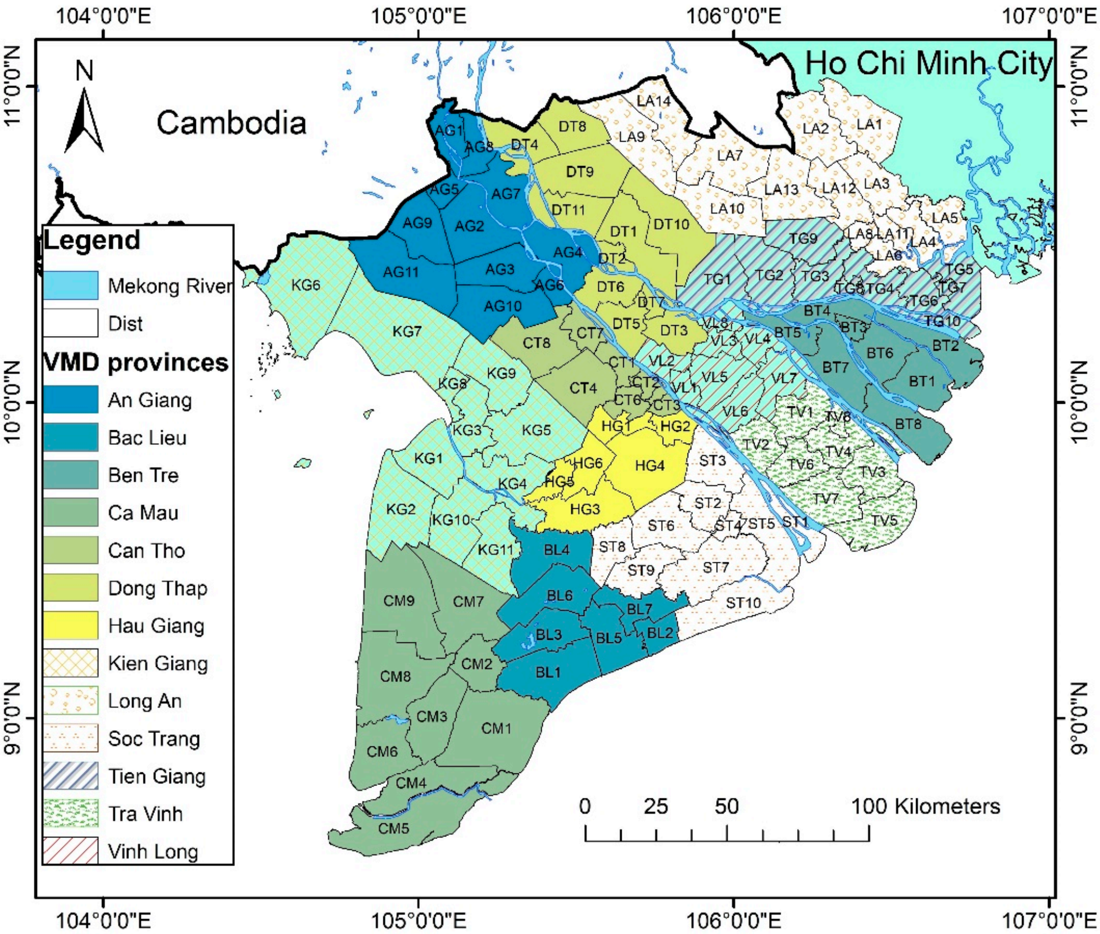

Figure 1. Identification of subregions in the Vietnamese Mekong Delta (VMD). There were 121 subregions in the research area with different climate data.

Table 1. Subscription of provinces and subregions in the VMD.

Province (pro)	Subregion (k)	Name of Subregion
Dong Thap	DT1-DT11	Cao Lanh, Cao Lanh City, Chau Thanh, Hong Ngu, Lai Vung, Lap Vo, Sa Dec City, Tan Hong, Tam Nong, Thap Muoi and Thanh Binh.
An Giang	AG1-AG11	An Phu, Chau Phu, Chau Thanh, Cho Moi, Chau Doc City, Long Xuyen, Phu Tan, Tan Chau, Tinh Bien, Thoai Son and Tri Ton.
Bac Lieu	BL1-BL7	Dong Hai, Bac Lieu City, Gia Rai, Hong Dan, Hoa Binh, Phuoc Long and Vinh Loi.
Ben Tre	BT1-BT8	Ba Tri, Binh Dai, Ben Tre City, Chau Thanh, Cho Lach, Giong Trom, Mo Cay and Thanh Phu.
Ca Mau	CM1-CM9	Dam Doi, Ca Mau City, Cai Nuoc, Nam Can, Ngoc Hien, Phu Tan, Thoi Binh, Tran Van Thoi and U Minh.
Can Tho	CT1-CT9	O Mon, Binh Thuy, Cai Rang, Co Do, Ninh Kieu, Phong Dien, Thot Not and Vinh Thanh.
Hau Giang	HG1-HG6	Chau Thanh A, Chau Thanh, Long My, Phung Hiep, Vi Thanh City and Vi Thuy.
Kien Giang	KG1-KG11	An Bien, An Minh, Chau Thanh, Go Quao, Giong Rieng, Ha Tien City, Hon Dat, Rach Gia City, Tan Hiep, U Minh Thuong and Vinh Thuan.
Long An	LA1-LA14	Duc Hoa, Duc Hue, Ben Luc, Can Duoc, Can Giuoc, Chau Thanh, Moc Hoa, Tan An City, Tan Hung, Tan Thanh, Tan Tru, Thu Thua, Thanh Hoa and Vinh Hung.
Soc Trang	ST1-ST10	Cu Lao Dung, Chau Thanh, Ke Sach, Soc Trang City, Long Phu, My Tu, My Xuyen, Nga Nam, Thanh Tri and Vinh Chau.
Tien Giang	TG1-TG10	Cai Be, Cai Lay, Chau Thanh, Cho Gao, Go Cong Dong, Go Cong Tay, Go Cong, My Tho City, Tan Phuoc and Tan Phu Dong.
Tra Vinh	TV1-TV8	Cang Long, Cau Ke, Cau Ngang, Chau Thanh, Duyen Hai, Tieu Can, Tra Cu and Tra Vinh City.
Vinh Long	VL1-VL8	Binh Minh, Binh Tan, Long Ho, Mang Thit, Tam Binh, Tra on, Vung Liem and Vinh Long City.

Source: [39].

2.3. Subregional Temperature and Rainfall

The initial rainfall and temperature of each subregion during 1982–2012 were collected from climate-data.org (based on the climate model with a number of data points all over the world and the climate classification system) [40,41]. The subregional water quantity and demand were calculated using the same method of the whole VMD with different conditions of subregions. The coldest and hottest months were January and April in most of the subregions in the VMD (Figure 2).

The northeast had higher rainfall than the southwest. In the dry season and wet season, the subregions in the south and southwest had higher rainfalls than the east and northeast of the VMD (Figure 3). February could be the driest month (most of the subregions had rainfall) and September could be the wettest month (most of the subregions had high rainfall). Generally, the northeast was hot and dry, while the rest was colder and wetter.

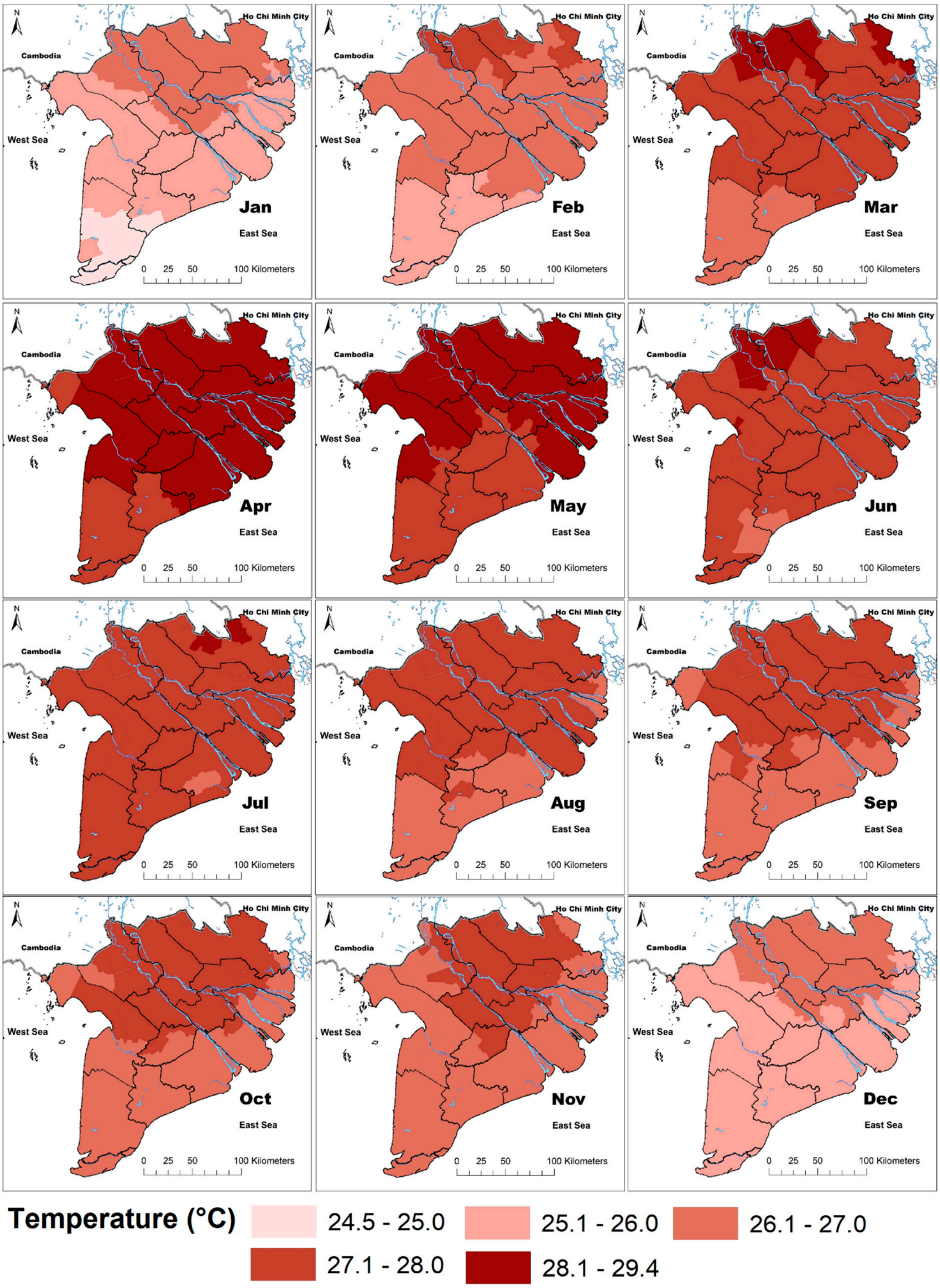

Figure 2. Historical average temperature of 121 subregions in the VMD during 1982–2012. The minimum temperature was 24.9 °C in the south and the maximum temperature was 29.4 °C in the north of the VMD (Source: [41]).

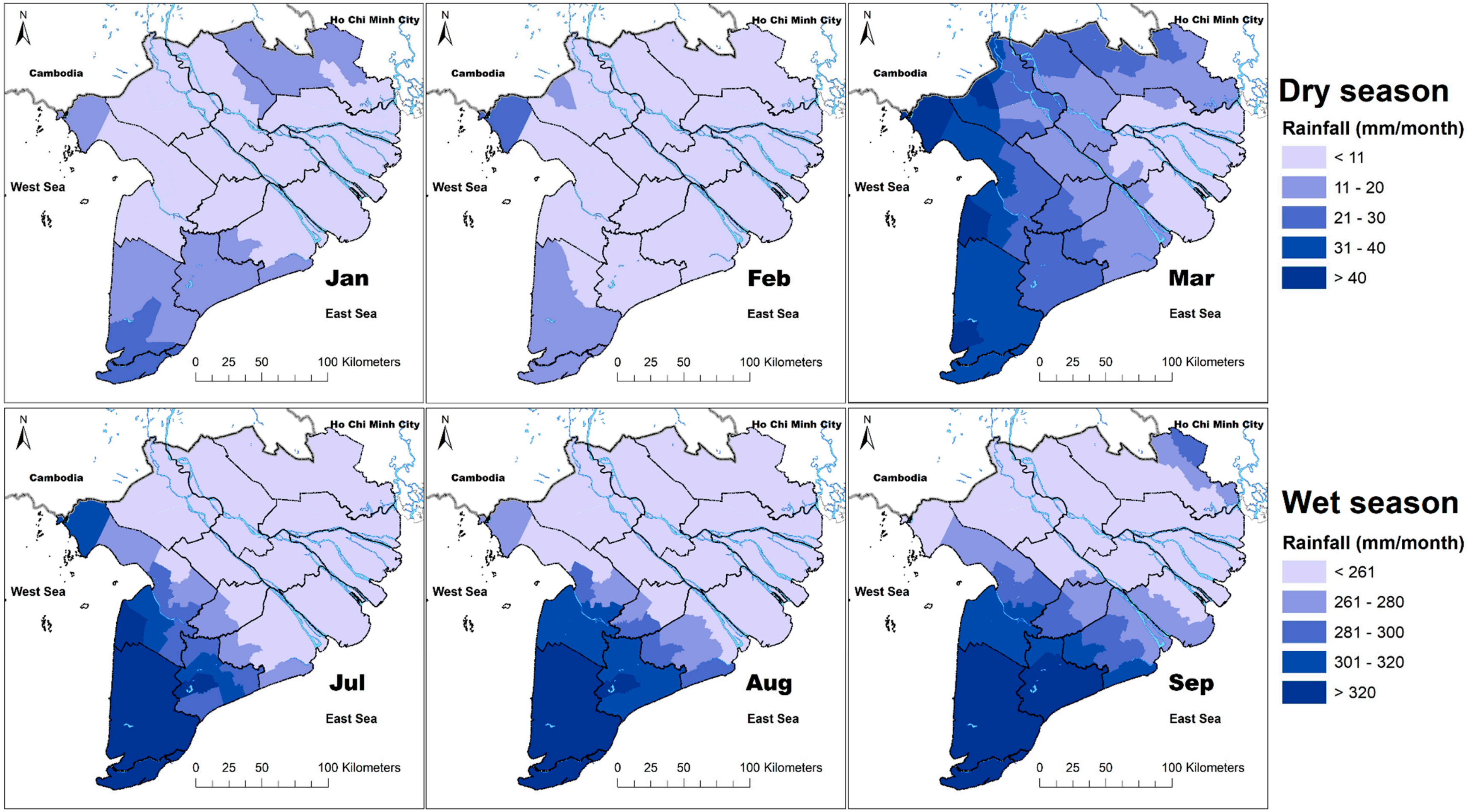

Figure 3. Historical average rainfall of 121 subregions (mm/month) during the dry season (January to March) and wet season (July to September) in the VMD during 1982–2012 (Source: [41]).

Under the impact of climate change, the regional temperature was calculated using Equation (1).

$$T_{k,cc} = T_k + \Delta T_{pro} \tag{1}$$

where T_k is the historical average temperature of subregion k (°C), $T_{k,cc}$ is the average temperature of subregion k under climate change (°C), and ΔT_{pro} is the temperature change of each province (°C) (Ministry of Natural Resources & Environment [42]. The regional rainfall was calculated using Equation (2).

$$RF_{k,cc} = RF_k \cdot \left(1 + \Delta RF_{pro}\right)/100 \tag{2}$$

where RF_k is historical average rainfall by subregion k (mm/month), $RF_{k,cc}$ is rainfall of each subregion under climate change (mm/month), and ΔRF_{pro} is percentage of rainfall change in each province (%) [42].

2.4. Socioeconomic Assumptions by Subregions

For domestic use, the water withdrawal per capita of the VMD was assumed to be similar in all subregions. The water demand of each person was the same, however, the urban residents received a better service of water treatment and supply. In this model, we did not include the water treatment for supply in the urban area. The population and industrial area of each subregion were different according to Provincial Statistics Offices.

According to Decision 1581/QD-TTg of Prime Minister of Vietnam Government, the total industrial area is projected to be 50,000 ha in 2050. However, the recent Resolution (120/NQ-CP) of The Government of Vietnam planned to enhance the green industry (that is, low emissions, no damage to natural ecosystem) and develop renewable energies and coastal protection. Therefore, it was assumed that only the area of existing industrial zones (in 2010) will increase in the future (in 2050), meaning the industrial area of 0 ha would be unchanged. The future industrial area of each subregion was calculated based on the fraction of industrial area and the total industrial area of the VMD (Equation (3)).

$$A_{i,k,2050} = \left(\frac{A_{i,k,2015}}{A_{i,2015}}\right) \cdot A_{i,2050} \tag{3}$$

where $A_{i,k,2015}$ and $A_{i,k,2050}$ are industrial area values of subregion k in 2015 and 2050 (ha), respectively, and, $A_{i,2015}$ and $A_{i,2050}$ are total industrial areas of the VMD in 2015 and 2050 (ha), respectively. Figure 4 indicates the projected area of industrial zones by subregions in 2050. Except for urban subregions, the large industrial zones were projected to be along with the upstream of the main rivers (Tien and Hau Rivers) and the subregions near the urban city (Ho Chi Minh City).

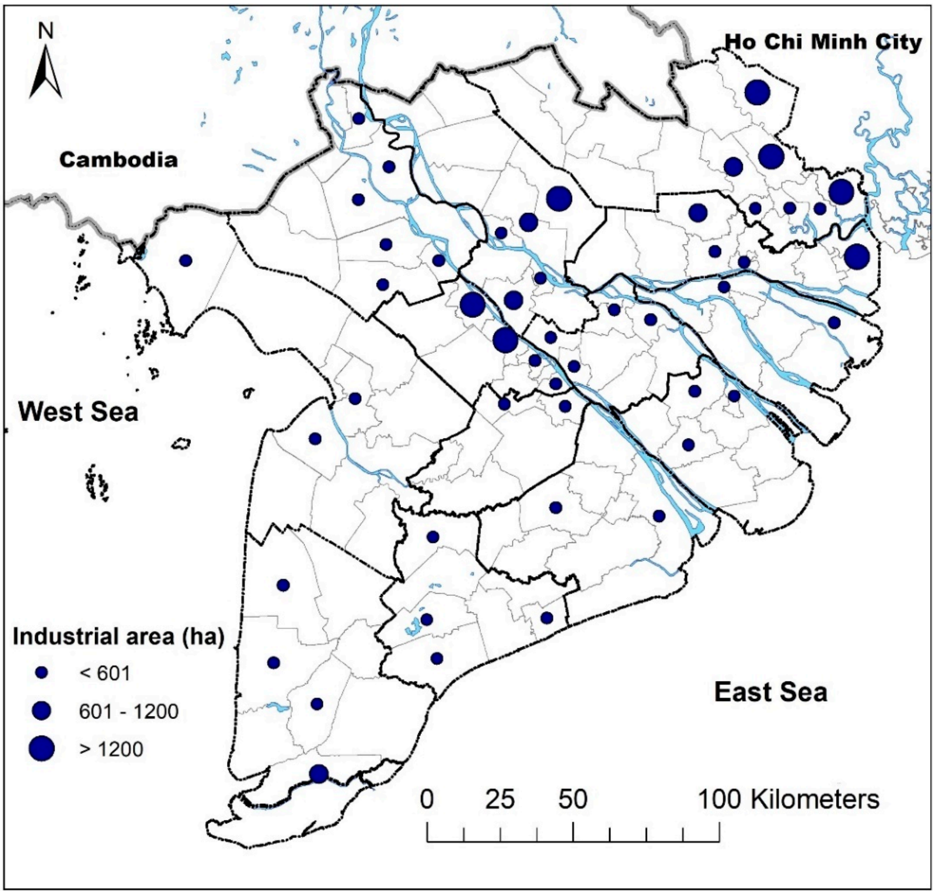

Figure 4. Projected industrial land area (ha) by subregions in 2050.

The land area of each subregion was obtained from the map of Vietnam [39]. The irrigated area of each subregion was analyzed from the land-use map in 2010 provided by College of Environment and Natural Resources, Can Tho University, Vietnam.

The future regional population was estimated based on the population of SWR-VMD model and the fraction of population by subregion (Equation (4)).

$$P_{k,2050} = \left(\frac{P_{k,2015}}{P_{2015}}\right) \cdot P_{2050} \quad (4)$$

where $P_{k,2015}$ and $P_{k,2050}$ are the population sizes of subregion k in 2015 and 2050 (people), respectively, and P_{2015} and P_{2050} are the total population sizes of the VMD in 2015 and 2050 (people), respectively.

2.5. Actual Water Demand

AWD was calculated as the difference between total irrigation water withdrawal and regional available flow (that is, regional surface flow) by subregion k (Equation (5)).

$$AD_k = W_{aw,k} - SF_k \quad (5)$$

where AD_k is regional AWD for paddy rice (m^3/month), $W_{aw,k}$ is total regional irrigation water demand for paddy rice (m^3/month), and SF_k is regional surface water flow (m^3/month). The positive values of AWD ($AD_k > 0$) present the lack of water, while the negative values ($AD_k \leq 0$) indicate the adequacy of available water.

2.6. Scenarios of Climate and Land Use Change

The four Representative Concentration Pathways scenarios of climate change are based on the concentration of greenhouse gas emissions (that is, RCP2.6, RCP4.5, RCP6.0, and RCP8.5, indicating radiative forcing values of 2.6, 4.5, 6.0, and 8.5 W/m^2 in 2100, respectively) [43]. According to the authors of [34], RCP4.5 and RCP8.5 are the most possible and worst scenarios of climate change impact in Vietnam, in which there are nine future scenarios of climate change (RCP4.5 and RCP8.5) and land use changes (including the changes in upper and coastal zones). The present research suggested five climate and land use changes, including the base scenario, climate change scenarios, and scenarios of land use responding to climate change (Table 2).

Table 2. Future scenarios of climate and land use changes for regional assessment.

Scenario	Climate	Land Use	Simulated Year	References
1	Base period	Base land use system in 2010	2015	[34]; Can Tho University
2	RCP4.5	Unchanged land use in 2010	2050	
3	RCP8.5			
4	RCP4.5	Land use change in the whole VMD: Triple rice systems in both upper and coastal zones is shifted to Winter Spring—Summer Autumn (WS-SA) and Summer Autumn—Autumn Winter (SA-AW), respectively	2050	[34]; Resolution 120 of the Government of Vietnam
5	RCP8.5			

3. Results and Discussion

3.1. Actual Water Demand for Paddy Rice

The AWD for paddy rice irrigation varied among different months depending on different land use systems (triple, double, and single rice systems) and climate conditions (monthly temperature and rainfall). Most of the values of AWD in the dry season were higher than the wet season under the base scenario (Figure 5). The AWD values in the dry season (that is, in February, March, and April) were higher than the others. The northwest of Kien Giang required a large surface water amount (over 150 million m^3/month) because of the large area of irrigation for paddy rice. However, the water shortage was solved with supplies by the rivers from upstream countries. In addition, many subregions in coastal provinces (that is, Hau Giang, Bac Lieu, Soc Trang, Tra Vinh, and Ben Tre) slightly lacked water for rice.

In the VMD, there was an event of high salinity intrusion in recent years, damaging nine out of thirteen provinces in the VMD, that is, from December 2015 to March 2016 [22]. According to Figure 5, the western coastal subregions in Kien Giang and most of the eastern coastal subregions were at risk of being affected by salinity intrusion from December to March through the lack of freshwater. In the future, the construction system for salinity prevention needs to be improved.

The main factors affecting the AWD for rice included crop systems (the triple, double, and single rice systems), temperature, and rainfall. In a year, the AWD varied based on different temperatures, rainfall and crop systems. The high AWD occurred in the dry season in both upper and the coastal zones due to the high temperatures. In the wet season, the AWD was low due to high rainfall, especially in the coastal zone.

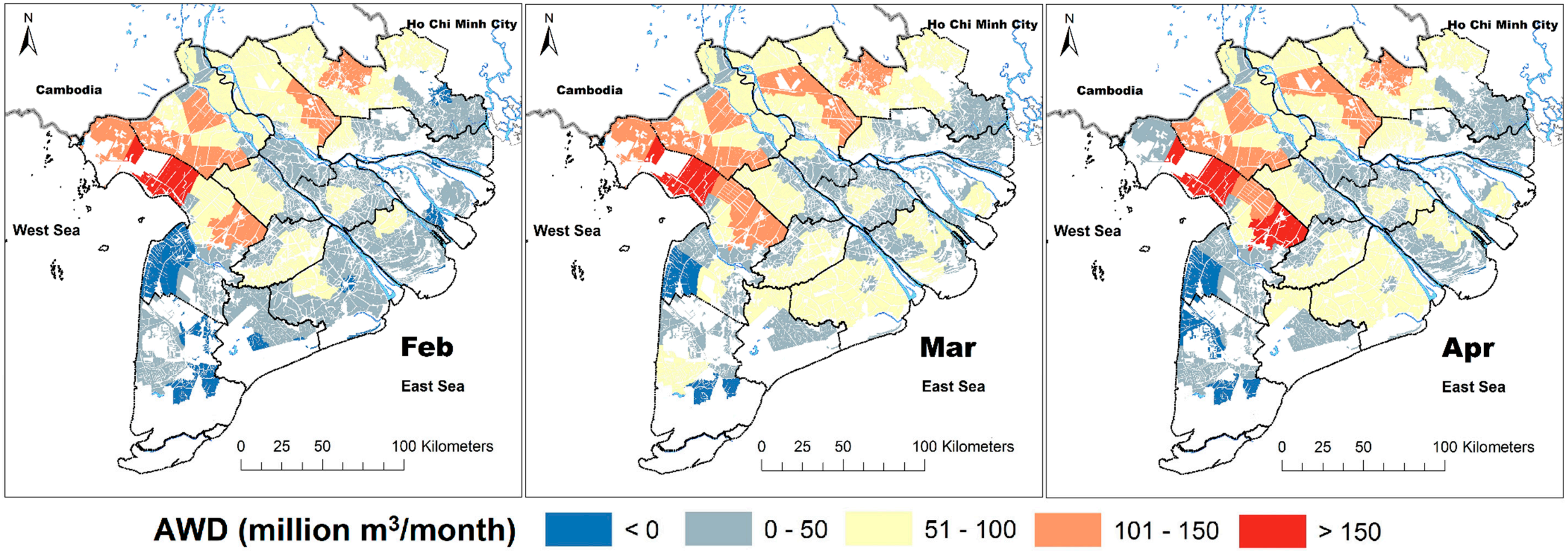

Figure 5. Simulated actual water demand (AWD) for paddy rice under Scenario 1 (unchanged climate and land use) in 2015 (million m^3/month). The positive values (≥0) present the water shortage and the negative values (<0) indicate that the available water is sufficient.

3.2. Climate Change Impact

3.2.1. In the Dry Season

Under the impact of rising rainfall, the AWD in most subregions tended to decrease in November and January (Figure 6). In contrast, under the impact of temperature increase, the AWD increased under RCP4.5 in Ca Mau in November (over 2 million m^3/month), and the RCP8.5 impacted the AWD in the upper subregions in January, such as An Giang, Dong Thap, and Long An. In the period February-April, climate change affected most of the subregions, especially in March and April under RCP8.5 (Figure 7).

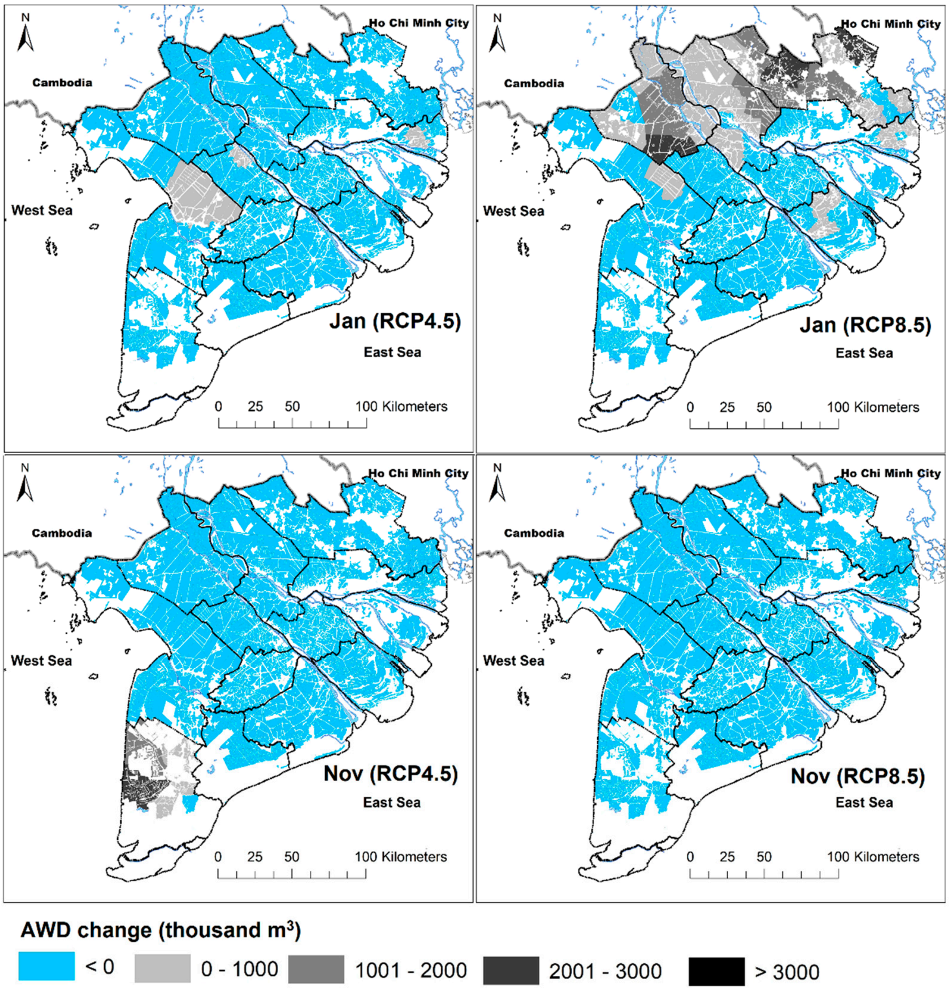

Figure 6. Changes of AWD for irrigation under the impact of climate change in 2050 (Scenarios 2 and 3), compared to the base scenario (Scenario 1), from November to January (thousand m^3/month) in case of unchanged land use of paddy rice.

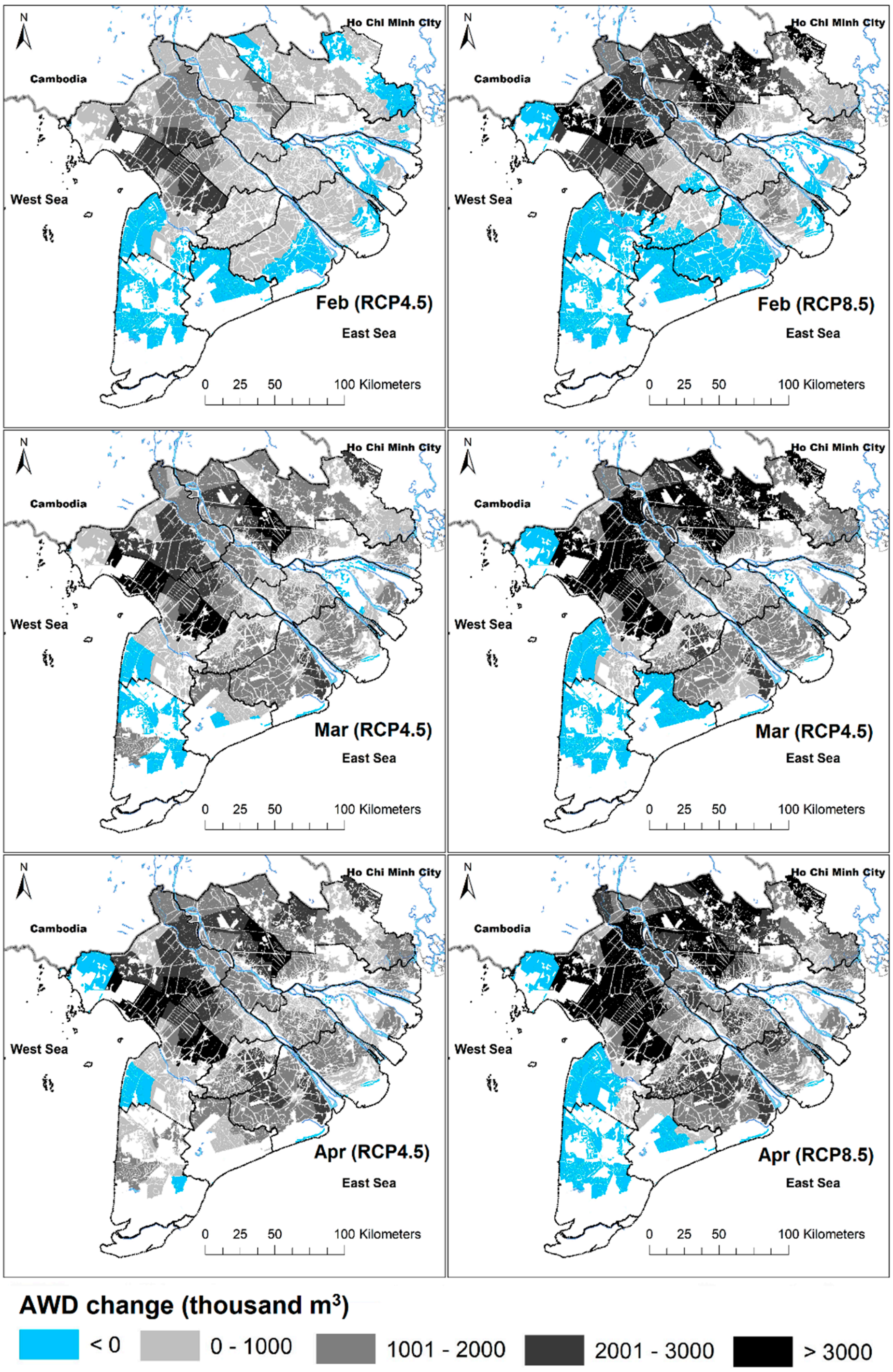

Figure 7. Changes of AWD for irrigation under the impact of climate change in 2050 (Scenarios 2 and 3), compared to the base scenario (Scenario 1), from February to April (thousand m^3/month) in case of unchanged land use of paddy rice.

Comparing the two climate change scenarios, the AWD was more affected under RCP8.5 in the east and north of Hau River. In the upper subregions, the high water demand could be supplied by the high surface flow from the upstream countries (over 90% surface water from foreign countries [44]. However, the development of the hydropower dams in the upstream leads to changes in seasonal water flow and suspended sediment concentration in the downstream regions, especially the VMD [45–47].

If the reduction of upstream flow discharge continues occurring, the agricultural activities in both upstream and coastal zones would be more severely impacted [23,48].

In the coastal subregions, under the salinity intrusion impact, the coastal zone faced freshwater scarcity in the cropping period Winter-Spring (from December to May) according to Water Resources Directorate, Ministry of Agricultural and Rural Development of Vietnam. Recently, the salinity intrusion highly impacted the VMD during the dry season, damaging a large area of paddy rice production, especially in March 2016 [22]. If salinity intrusion occurs in 2050 due to sea level rise according to the study in Reference [23], the eastern and western coastal zones are likely to be affected.

3.2.2. In the Wet Season

Figure 8 indicates the changes of AWD for paddy rice under the two climate change scenarios in case of unchanged land use from May to July. Scenario 2 (RCP4.5) shows its high impact (>3 million m^3/month) on AWD in the West Hau River, especially in Kien Giang, Ca Mau, Bac Lieu, Soc Trang, and Hau Giang. Under Scenario 3 (RCP8.5), the AWD decreased or showed fewer increases due to the high rising rainfall. In August, the provinces An Giang, Kien Giang, and Ca Mau were highly impacted under Scenario 2 (RCP4.5). In the period August-October, Scenario 3 (RCP8.5) hardly impacted the AWD due to the high increase in rainfall (Figure 9). Only Ca Mau could be slightly impacted (>1 million m^3/month) under Scenario 2 (RCP4.5) in September and October.

Four coastal provinces with a high demand for water were Kien Giang, Ca Mau, Bac Lieu, and Soc Trang, in which Ca Mau was most affected. Under RCP8.5, due to high rainfall increase in the wet season, the AWD for paddy rice was projected to decrease from August to October. Such excess water could lead to flooding in most subregions of the VMD.

The regional model can simulate the AWD under climate change. The AWD tended to increase in the dry season due to the rising temperatures. However, it was likely to decrease in the wet season due to high rainfall. In the dry season, the AWD in the upper zone was higher than the coastal zone, however, it was solved by the water supply from the upstream countries. Comparing the two climate change scenarios (RCP4.5 and RCP8.5), RCP8.5 caused the high increases in AWD due to the high increase of temperature in the dry season (especially from February to April). In contrast, the AWD sharply declined under RCP8.5 due to higher rainfall than RCP4.5 (especially from August to October).

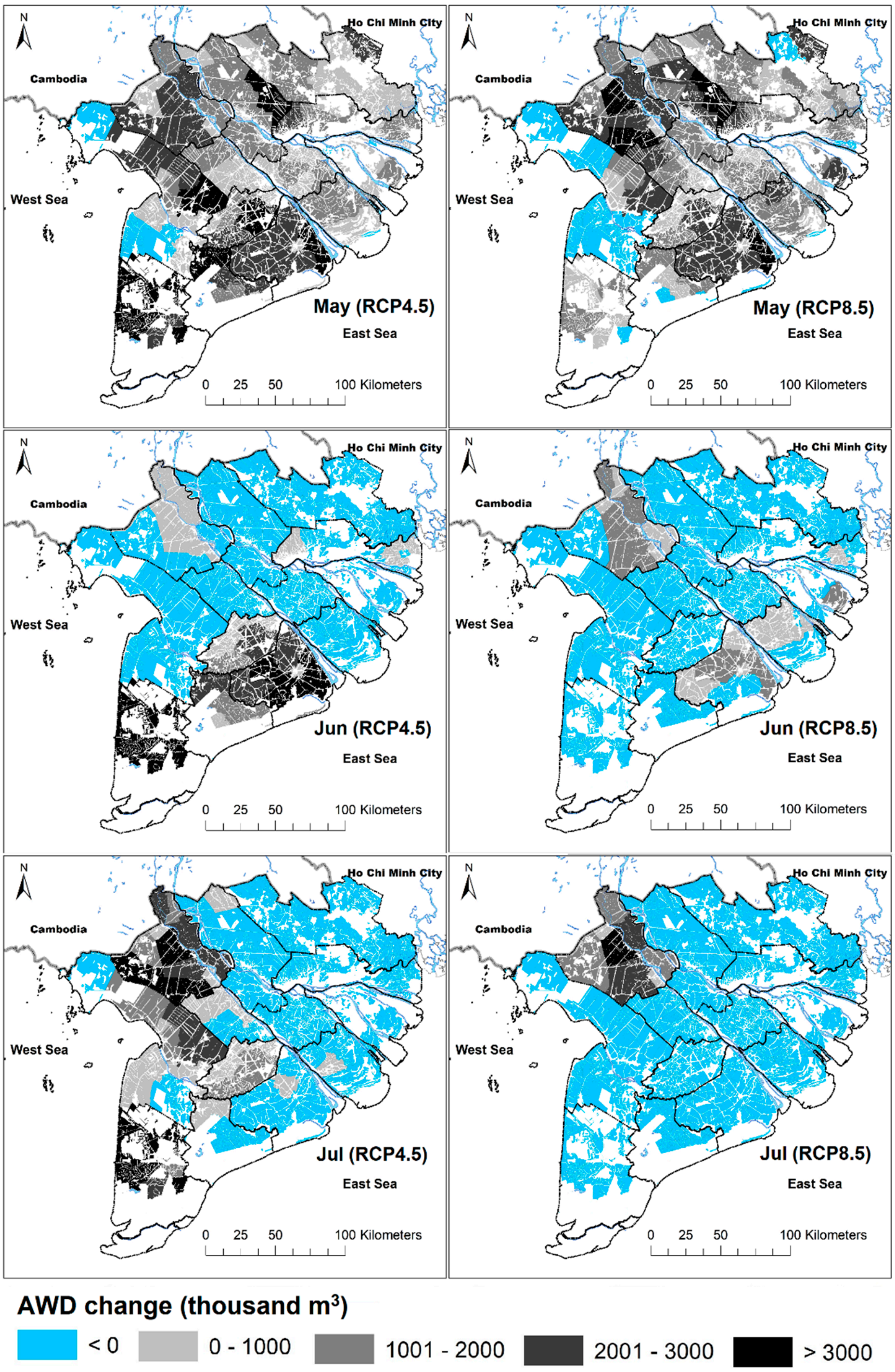

Figure 8. Changes of AWD for irrigation under the impact of climate change in 2050 (Scenarios 2 and 3), compared to the base scenario (Scenario 1), from May to July (thousand m^3/month) in case of unchanged land use of paddy rice.

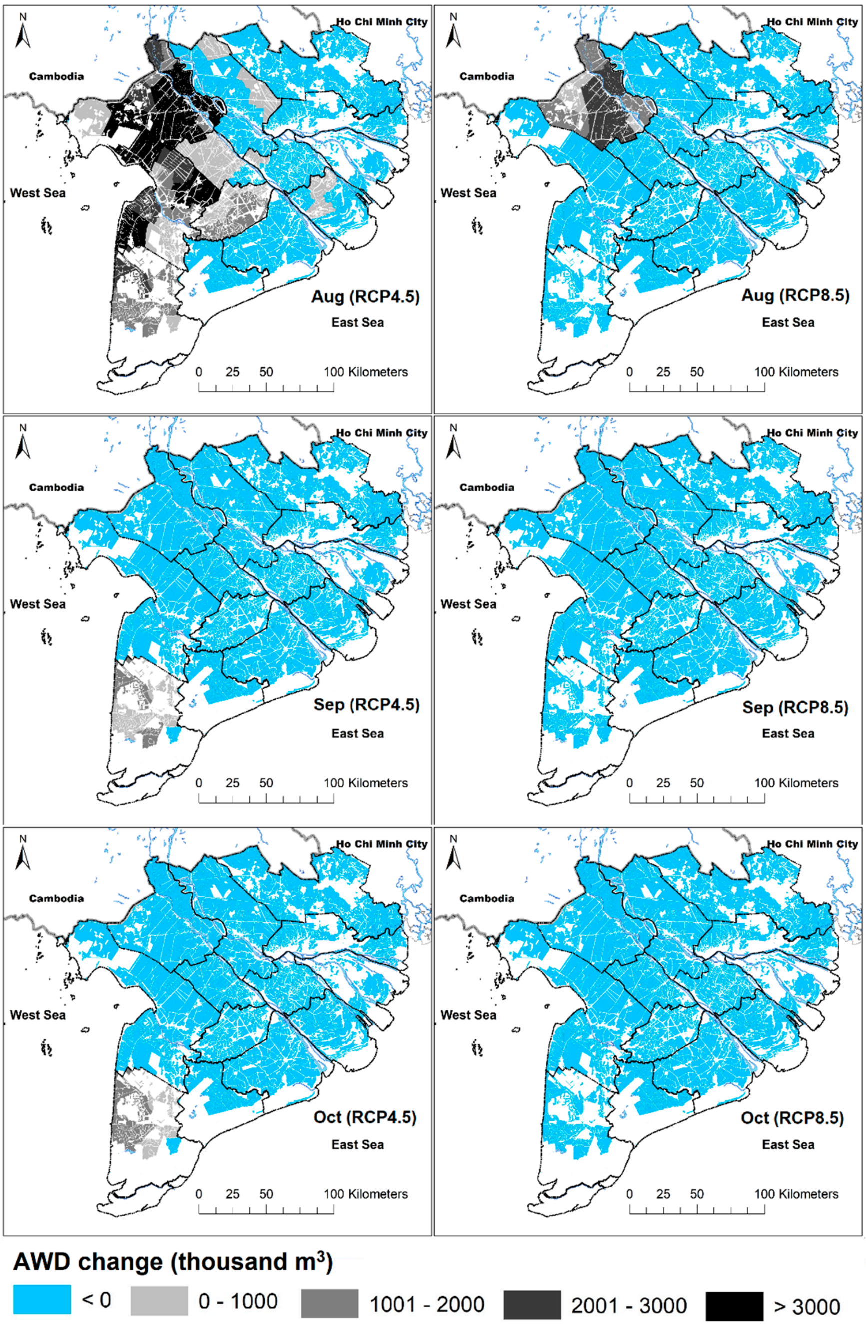

Figure 9. Changes of AWD for irrigation under the impact of climate change in 2050 (Scenario 3 and 4), compared to the base scenario (Scenario 1), from August to October (thousand m^3/month) in case of unchanged land use of paddy rice.

3.3. Land Use Change Responds to Climate Change

3.3.1. Dry Season

Land use change was effective in the coastal zone during the dry season under climate change (Figure 10). AWD was projected to decrease under land use change in the west (that is, Kien Giang) and the east (that is, Long An, Tien Giang and Tra Vinh) of the coastal zone. The land use solution was more effective in February in more subregions than January, such as Kien Giang, Hau Giang, Soc Trang, Vinh Long, Tra Vinh, Ben Tre, Tien Giang, and Long An. In general, the coastal zone was positively affected by land use change, except for the Ca Mau and Bac Lieu provinces.

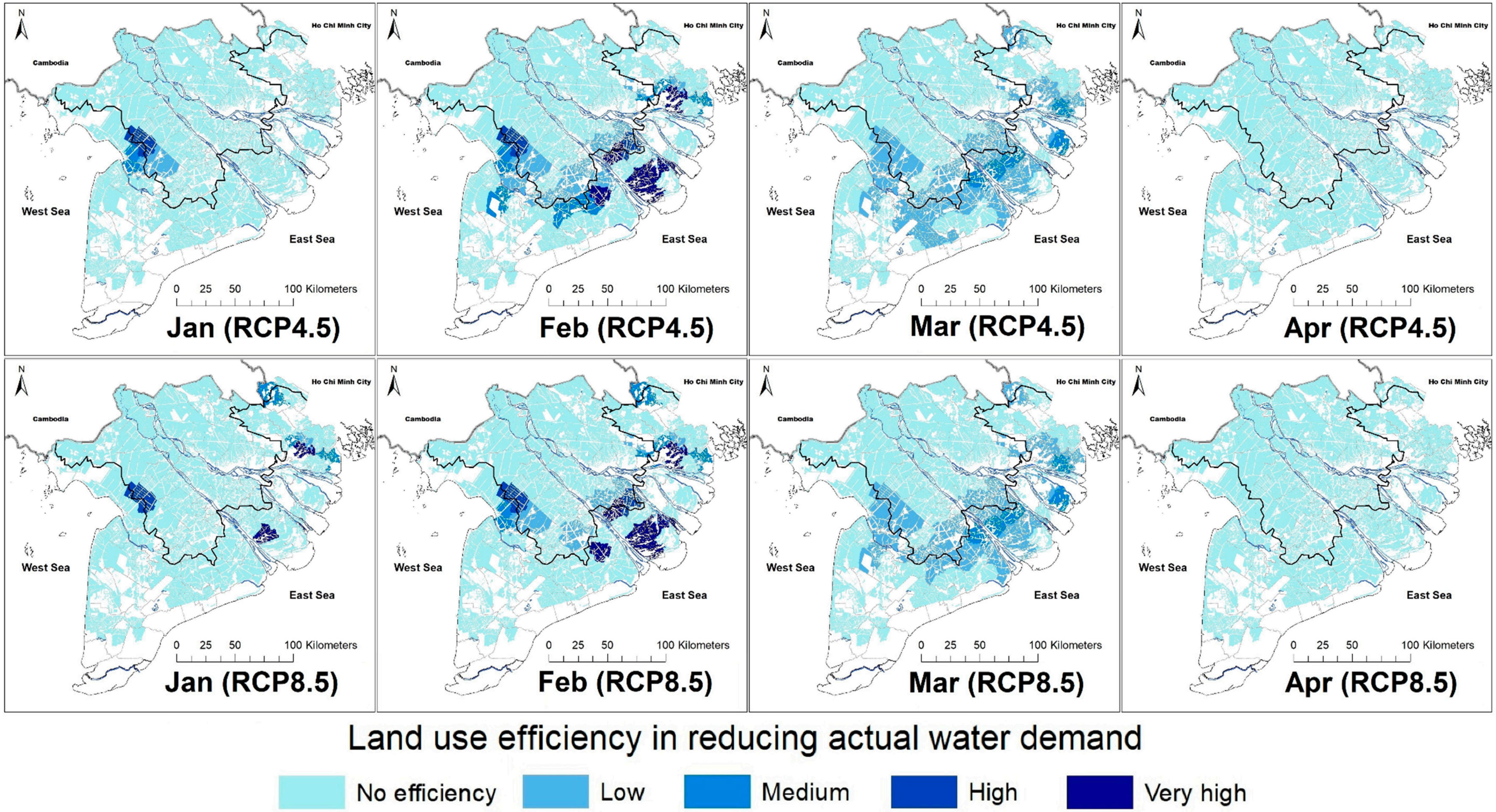

Figure 10. Reduction of increase in AWD under land use change solution in the condition of climate change during the dry season (from January to April).

3.3.2. Wet Season

The upper zone was positively affected by land use change during the wet season under RCP4.5, especially in May (Figure 11). From June to August, land use change under RCP8.5 was efficient in a smaller area than RCP4.5 due to its lower impact on AWD.

The change of triple to double rice systems in all subregions (Scenarios 10 and 11) was effective in upper and coastal zones during the wet and dry seasons, respectively. In the upper zone, AWD for paddy rice would be reduced due to the disappearance of AW (from August to December). In the coastal zone, the demand for surface water for paddy rice would be reduced due to the disappearance of WS (from November to March). However, the results indicate the efficiency of land use change during WS (January and February) and SA (from April to August) in both upper and coastal zones.

AWD depends on different cropping schedules (sowing and harvesting periods) in different subregions. Cropping schedules vary based on the decision of farmers and managers. For example, the sowing time ranges from April to May in An Giang and from March to June in Hau Giang. In this study, the cropping schedule was fixed in all subregions of the VMD to assess the changes of water demands under climate and land use change. In further studies, cropping schedules need to be considered in each specific subregion.

According to Reference [47], the main livelihood of An Giang is rice growing. However, the full-dyke system has been developed more completely. Therefore, rice growers would not be willing to change to other livelihoods, leading to a low capacity to adapt to climate change. Rice is the main product the ensure food security in Vietnam. Therefore, it needs to be maintained in a specific quantity. Many kinds of models have been combined to create different livelihoods, such as rice growing incorporation with fish farming, rice growing incorporation with shrimp farming, and the rotation of rice and vegetable growing [49].

In the coastal subregions, the shift from rice to other livelihoods during the dry season has also been considered due to salinity intrusion. The alternative livelihoods could be shrimp farming, shrimp farming—rice growing (shrimp is more important), rice growing—shrimp farming (rice is more important), and shrimp farming—forest growing [50].

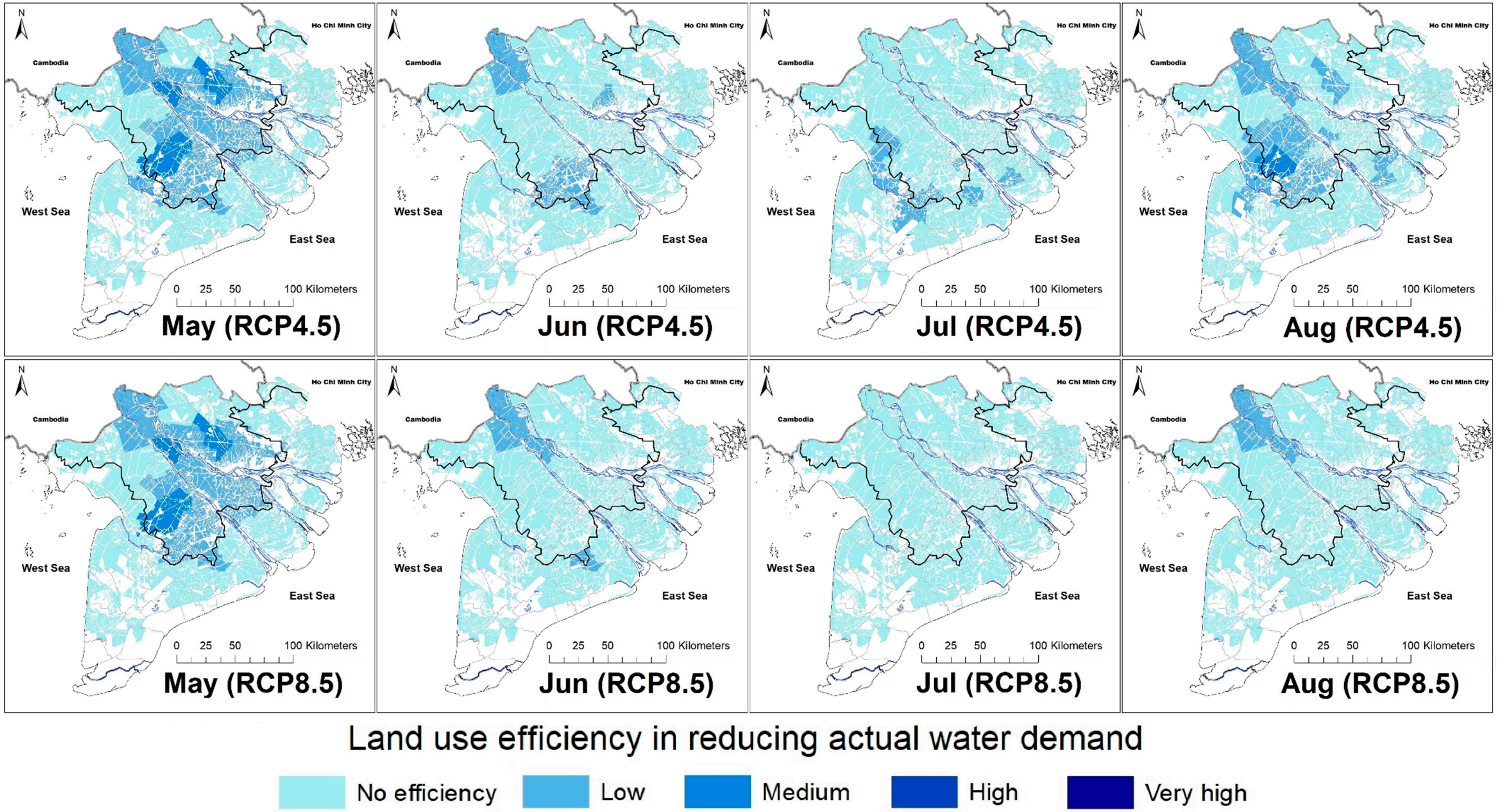

Figure 11. Reduction of increase in AWD under the impact of land use change compared to RCP8.5 in the wet season (from May to August).

4. Conclusions

The research is qualitative and can forecast a future trend of water availability and demand. In addition, the model reflected the differences in water demand from place to place. The results demonstrated that the SDM method can be applied to different subregions of the VMD with different conditions of climate and land. Through the combination of SDM and GIS, the significantly affected regions may be determined.

The results of the model indicated that the AWD for paddy rice was high in the upper zone during the dry season, however, it could be supplied by surface flow from upstream countries. In the coastal zone, water shortage was not as great as the upper zone, however, it can become worse under the impact of saline intrusion due to sea level rise during the dry season. AWD was highly affected under the extreme scenario of climate change (RCP8.5) due to the high increase of temperature, however, the demand under RCP8.5 would decline or less increase than RCP4.5 during the wet season due to the high increase of rainfall. Thus, the intensity of droughts and floods under RCP8.5 may be larger than RCP4.5. The land use change solution was effective for both upper and coastal zones, especially in the crops WS (January and February) and SA (from April to August). The current land use policy focuses on sustainable agriculture and effective water use. Changes in agriculture production are also necessary for the context of climate change. The model could be a timely tool for decision making on land use in the VMD, especially flood and salinity intrusion. Further research will focus on the analysis of groundwater resource and land use changes in detail.

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