

CLIMATE CHANGE AND ADAPTIVE WATER MANAGEMENT IN LOWER CHAO PHRAYA AND THA CHIN BASINS, THAILAND

CHANGEMENT CLIMATIQUE ET GESTION ADAPTATIVE DE L'EAU DANS LES BASSINS INFÉRIEURS DE LA CHAO PHRAYA ET DE LA THA CHIN, THAÏLANDE

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ABSTRACT

Climate change is one of the most pressing threats to sustainable development across the globe. There are expected to have significant effects on water resources planning and management, especially in estuary areas. A number of works have used numerical models attempting to simulate river catchment hydrological processes of rainfall-runoff, sediment transport, salinity intrusion and coastal erosion processes as well as to study the impact of climate change. However, there are a few application studies in Thailand. Wongsa et al. have exploited MIKE11 model to predict sea level affecting salinity intrusion and agricultural production in Tha Chin, Mae Klong and Chao Phraya rivers. Metropolitan Waterworks Authority (MWA) and Royal Irrigation Department (RID) reported that salinity intrusion, raw water supply and agricultural productivity in Chao Phraya and Tha Chin Rivers were affected by climate change. The objective of this study is to evaluate of the vulnerability and adaptability for water management in Chao Phraya River Basin and Tha Chin River Basin under drought conditions by using the MIKE11 software. Performance of the numerical model was applied to simulate flow events in 2100, which are water level change and salinity intrusion on agricultural and raw water supply in the proposed study areas. The study covered the area from Chao Phraya Dam, Chai Nat Province and Pho Phraya Regulator, Suphan Buri Province and to the river estuary at the Gulf of Thailand for Chao Phraya and Tha Chin rivers, respectively. The results of comparison between models and observation data revealed order of forecasting error (R^2) in the range of 0.77-0.99 for water level and 0.75-0.86 for salinity. For model applications, the SSP1-2.6 and SSP5-8.5 scenarios from IPCC report were simulated. Results indicated an increase salinity at Sam Lae Pumping Station were 0.83-0.87 g/l, the value of 0.25 g/l exceeding standard and the pointed tip of salinity was at Ko rain sub-district, Ayutthaya Province in Chao Phraya river, and the value of 2.0 g/l exceeding standard and the pointed tip of salinity was at Sam Phran district, Nakhon Pathom Province in Tha Chin river. The intrusion of salinity into two rivers has increased significantly. For agriculture, salinity values effect on economic plants in Nonthaburi, Ratchaburi, Nakhon Pathom and Prachinburi provinces. This intrusion of salinity affects growth of economic plants such as rice, durian, coconut, lychee, mango and, etc. Developing salt tolerant crop varieties and farming methods, and funding infrastructure projects to prevent saltwater flooding, groundwater contamination by seawater intrusion can help coastal farms remain viable as sea levels rise. It will also be important to regulate brackish aquaculture to avoid conflicts between rice farmers and shrimp/fish farmers. However, Metropolitan Waterworks Authority (MWA) reported that climate change affected salinity intrusion and raw water supply in Lower Chao Phraya River. The observed effects demonstrated that Sam Lae Pumping Station will not be available when salinity is over 0.25 and/or 0.50 g/l, and water supply shortage. The mitigation plan has suggested that the diversion from Mae Klong River and construction of new pump station for short-term and long-term, respectively. the proposed locations of new raw water pump station along the Chao Phraya River from Ayutthaya to Singburi Province. It was found that the most suitable sites when evaluation by multi-criteria analysis (MCA) is the site at Klong Pongpheng, Ayutthaya Province. The findings of this study will provide guidance for adapting the

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management of water resources for water supply and agriculture in the lower Chao Phraya and Tha Chin river basins.

Keywords: Climate Change, Salinity Intrusion, Adaptation Measures, Water Management, MIKE11 Software.

RESUME

Le changement climatique fait face à l'une des menaces les plus pressantes en ce qui concerne le développement durable à l'échelle mondiale. Il devrait exercer des impacts importants sur la planification et la gestion des ressources en eau, en particulier dans les zones estuariennes. De nombreux travaux ont utilisé des modèles numériques pour essayer de simuler les processus hydrologiques des bassins versants (écoulement naturel, transport sédimentaire, intrusion saline et érosion côtière) ainsi que pour étudier l'impact du changement climatique. Cependant, peu d'études ont été menées relevant de l'application en Thaïlande. Wongsat et al. ont utilisé le modèle MIKE11 pour prédire l'impact du niveau de la mer sur l'intrusion saline et la production agricole dans les bassins versants de Tha Chin, de Mae Klong et de Chao Phraya. L'Autorité métropolitaine des eaux (MWA) et le Département royal de l'irrigation (RID) ont signalé que l'intrusion saline, l'approvisionnement en eau brute et la productivité agricole des bassins versants de Chao Phraya et de Tha Chin étaient affectés par le changement climatique. Cette étude vise à évaluer la vulnérabilité et la capacité d'adaptation de la gestion de l'eau des bassins versants de Chao Phraya et de Tha Chin en conditions de sécheresse, à l'aide du logiciel MIKE11. Les performances du modèle numérique ont été utilisées pour simuler les événements d'écoulement prévus en 2100, à savoir les variations du niveau d'eau et l'intrusion saline, ainsi que leurs effets sur l'agriculture et l'approvisionnement en eau brute dans les zones d'étude proposées. L'étude a couvert la zone s'étendant du barrage de Chao Phraya (province de Chai Nat), du régulateur de Pho Phraya (province de Suphan Buri) jusqu'à l'estuaire (golfe de Thaïlande) pour les fleuves Chao Phraya et Tha Chin, respectivement. Les résultats obtenus de la comparaison faite entre les modèles et les données d'observation ont révélé un coefficient de détermination (R^2) compris entre 0,77 et 0,99 pour le niveau d'eau et entre 0,75 et 0,86 pour la salinité. Pour les applications des modèles, les scénarios SSP1-2.6 et SSP5-8.5 issus du rapport du GIEC ont été simulés. Les résultats ont indiqué une augmentation de la salinité à la station de pompage de Sam Lae comprise entre 0,83 et 0,87 g/l, la valeur de 0,25 g/l dépassant la norme, et le pic de salinité a été observé dans le sous-district de Ko Rain, dans la province d'Ayutthaya, sur le fleuve Chao Phraya, avec une valeur de 2,0 g/l dépassant la norme, et le pic de salinité se situant dans le district de Sam Phran, dans la province de Nakhon Pathom, sur le fleuve Tha Chin. L'intrusion saline dans deux cours d'eau a augmenté de manière considérable. Dans le domaine agricole, les niveaux de salinité ont exercé un impact sur les cultures commerciales dans les provinces de Nonthaburi, Ratchaburi, Nakhon Pathom et Prachinburi. Cette intrusion saline exerce un impact sur la croissance des cultures commerciales telles que le riz, le durian, la noix de coco, le litchi, la mangue, etc. Le développement de variétés des cultures et de méthodes agricoles tolérantes au sel, ainsi que le financement des projets d'infrastructure visant à prévenir les inondations d'eau salée et la contamination des eaux souterraines par l'intrusion d'eau de mer, peuvent aider les exploitations agricoles côtières à rester viables confrontés à l'élévation du niveau de la mer. Il sera également important de régler l'aquaculture en eau saumâtre afin d'éviter les conflits entre les riziculteurs et les éleveurs de crevettes ou de poissons. Cependant, l'Autorité métropolitaine des eaux (MWA) a constaté que le changement climatique avait exercé un impact sur l'intrusion saline et l'approvisionnement en eau brute du cours inférieur du fleuve Chao Phraya. Les observations ont démontré que la station de pompage de Sam Lae ne pourrait pas être opérationnelle lorsque la salinité dépassera 0,25 et/ou 0,50 g/l, ce qui entraînera une pénurie d'approvisionnement en eau. Le plan d'atténuation propose un détournement du fleuve Mae Klong et la construction d'une nouvelle station de pompage à court et à long terme respectivement. Les emplacements envisagés pour la nouvelle station de pompage d'eau brute se situent le long du fleuve Chao Phraya, entre la province d'Ayutthaya et celle de Singburi. Il a été établi que le Klong Pongpheng, dans la province d'Ayutthaya est le site le plus approprié pour l'analyse multicritères (MCA). Les conclusions tirées de cette étude serviront de lignes directrices pour adapter la gestion des ressources en eau destinées à l'approvisionnement en eau et à l'agriculture dans les bassins versants du cours inférieur de Chao Phraya et de Tha Chin.

Mots-clés : Changement climatique; Intrusion saline; Mesures d'adaptation; Gestion de l'eau; Logiciel MIKE11.

INTRODUCTION

Changes in climate has already affected people's health, land and marine ecosystems, water supplies, and people's livelihoods around the world. The effects observed have been local, and the most part were negative. The most notable effects have had to do with extreme weather events, such as heavy rains, heat waves, and draught. Climate change causes serious risks to the well-being of nature and people all over the world. Countries all over the world have begun to develop climate change adaptation plans and strategies. The changes in climate and land use can act as triggers for increases in sea water level, salinity and sediment transport. Within the estuaries, sea water level can be the important controls of water level and salinity. Although the precise effect of climate change on estuaries dynamics and its processes in the alluvial river system is still not clear, there seems to be no doubt that it influences sea water level and salinity intrusion.

Recently, numerical modelling has been shown to answer some of these problems. A number of works have used numerical models attempting to simulate river catchment hydrological processes of rainfall-runoff, sediment transport and salinity intrusion processes as well as to study the impact of climate change. In addition, the numerical model has been applied to predict hill slopes and river channels (eg. Kirby, 1987; Wicks and Bathurst, 1996; DHI, 2000; Wongsa and Shimizu, 2004; Wongsa, 2004). Thus, it is clear that the numerical models appear to have considerable potential as tools for investigating hydrodynamic, sediment transport and water quality over long period simulation. Wassmann et al. (2004) have predicted that sea level affected rice production in Mekong Delta, Vietnam, during the flood season. However, there are a few application studies in Thailand. Sanit et al. (2009, 2010a, b, 2019) have exploited MIKE11 model to predict sea level affecting salinity intrusion and agricultural production in Tha Chin and Mae Klong rivers. Metropolitan Waterworks Authority (2011) reported that salinity intrusion and raw water supply in Chao Phraya River was affected by climate change.

This paper addresses these issues by using a pro-proposed MIKE11 numerical modelling to simulate the effects on water level change and salinity intrusion. Performance of the numerical model was applied to simulate flow events in 2100, which are water level change and salinity intrusion on agricultures and raw water supply in the Lower Chao Phraya and Tha Chin Basins, Thailand.

STUDY AREA DESCRIPTION

The proposed model was applied to Lower Chao Phraya and Tha Chin basins. Chao Phraya River is the most important and largest river flowing from Chai Nat Province to estuary at the Gulf of Thailand in Samut Prakan Province, located at central part of Thailand. **Figure 1** shows the selected study area. Cities along the Chao Phraya include Chai Nat, Singburi, Ang Thong, Ayutthaya, Pathum Thani, Nonthaburi, Bangkok and Samut Prakan, listing from north to south. The Tha Chin river is splits from Chao Phraya River at Chai Nat Province to estuary at the Gulf of Thailand in Samut Sakhon Province. The climate of the Chao Phraya and Tha Chin basins have a tropical wet and dry or savanna climate, which generates wet and dry seasons of more or less equal length. The monsoon season is usually from May until late September and/or early October. In the wet season, averagely 1-2 tropical depressions occur over much of the area from August to October of the year. The average annual discharge is 800 – 1,500 m³/s and rainfall varied between 1,122 to 1,511 mm, depending on monsoon direction and elevation.

However, some parts of the basin continue to suffer from drought problems due to the uneven distribution of rainfall. Some areas experience both flooding and drought conditions in a single year, due to temporal and spatial uncertainties in the monthly rainfall or the poor management of the conveyance infrastructure. The Chao Phraya River also imports water from Mae Klong River (right bank) to boost water supply, which can also multiply the risk of flooding in the downstream and Bangkok metropolitan areas. The common practice in Thailand is to manage the risks after considering which areas are likely to be vulnerable to either flood or drought. Failure to manage risk by addressing one aspect at a time

can lead to adverse results. Therefore, climate change and an association with managing flood and drought risks are new challenge in Thailand and becoming increasingly important.

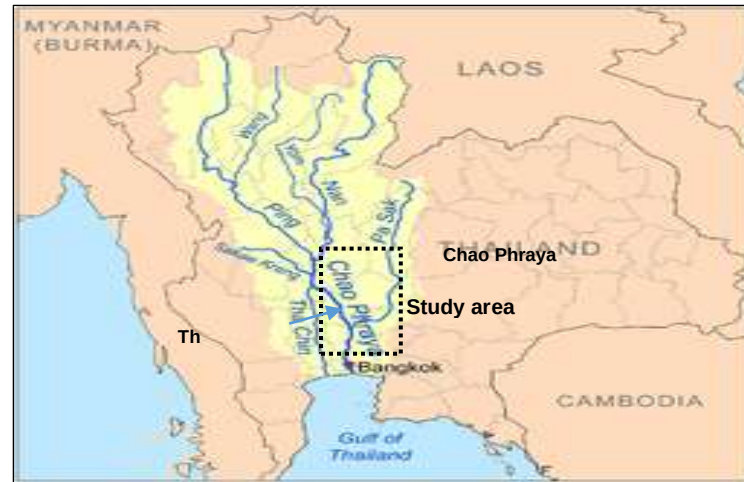


Figure 1. Study area of the Lower Chao Phraya and Tha Chin Basins.
(http://en.wikipedia.org/wiki/Chao_Phraya_River)

MODEL DESCRIPTION

To assess the influence of the water flow and salinity impacts on climate change of the Lower Chao Phraya and Tha Chin Basins, the MIKE11 model has been used. This numerical model simulates water flow and salinity as a consequence of low flow conditions. The shallow water equation for one-dimensional unsteady flow can be expressed as following,

Continuity equation:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \quad (1)$$

Momentum equation:

$$\frac{\partial Q}{\partial t} + \frac{\partial \left(\alpha \frac{Q^2}{A} \right)}{\partial x} + gA \frac{\partial h}{\partial x} + \frac{gQ|Q|}{M^2 AR^{4/3}} = 0 \quad (2)$$

where, Q = flow discharge (m^3/s), A = flow section area (m^2), q = side flow discharge (m^2/s), h = flow depth (m), R = hydraulic radius (m), g = acceleration (m/s^2), α = momentum correction factor, M = Manning's Number ($M = 1/n$; n = Manning's roughness coefficient), x and t = flow direction and time, respectively.

For transportation of mass, such as, salinity can be obtained from,

Advection-Dispersion equation:

$$\frac{\partial AC}{\partial t} + \frac{\partial QC}{\partial x} + gA \frac{\partial h}{\partial x} \left(AD \frac{\partial C}{\partial x} \right) = -AKC + qC_2 \quad (3)$$

where, C = salinity concentration (mass/volume), D = dispersion coefficient (m^2/s), K = consumption rate (s^{-1}) and C_2 = Source/Sink Concentration (mass/volume).

To modelling the river network of the Lower Chao Phraya, a digital elevation map (DEM) has been used. The model input data were cross-section, flow discharge, water level, side flow and salinity. The MIKE11 program, 6-points Abbott's finite difference scheme was used to solve governing equations, consisting of separate modules each representing a different procedure in calculation process. A first module

calculated hydrodynamics of river flow (HD module), and the next module of transportation of mass (salinity intrusion; AD module). The model setup of plan view and longitudinal profile of the Lower Chao Phraya and Tha Chin Basins are shown in **Figure 2**.

MODEL SIMULATION

The Lower Chao Phraya and Tha Chin Basins were used for calibration and verification of the proposed model. The calibration and validation has focused on the applicability of water flow and salinity intrusion by using flow conditions in the year of 2010, 2012 and 2013, respectively. Performance of the foregoing numerical model was applied to simulate scenario from IPCC Emissions Scenarios, consisting of SSPs, the predicted global average sea level rising from 1990 to 2100 for the Emissions Scenarios by using GCMs. SSP5-8.5 (Fossil-Fueled Development): The worst case scenario, global markets rely heavily on fossil fuels and energy-intensive lifestyles, causing temperatures to potentially soar by 4.4 °C or more warming. (IPCC, 2021).

For model simulation, flow discharge at station C.13 (Chao Phraya Dam) and water level at Chao Phraya River Estuary (Marine Department) were adopted for upstream and downstream boundaries. For Tha Chin, flow discharge at Pho Phraya Regulator and water level at Tha Chin Estuary were adopted. Before the water flow and salinity calculation was carried out, the model was run to provide the steady state of necessary flow variables.

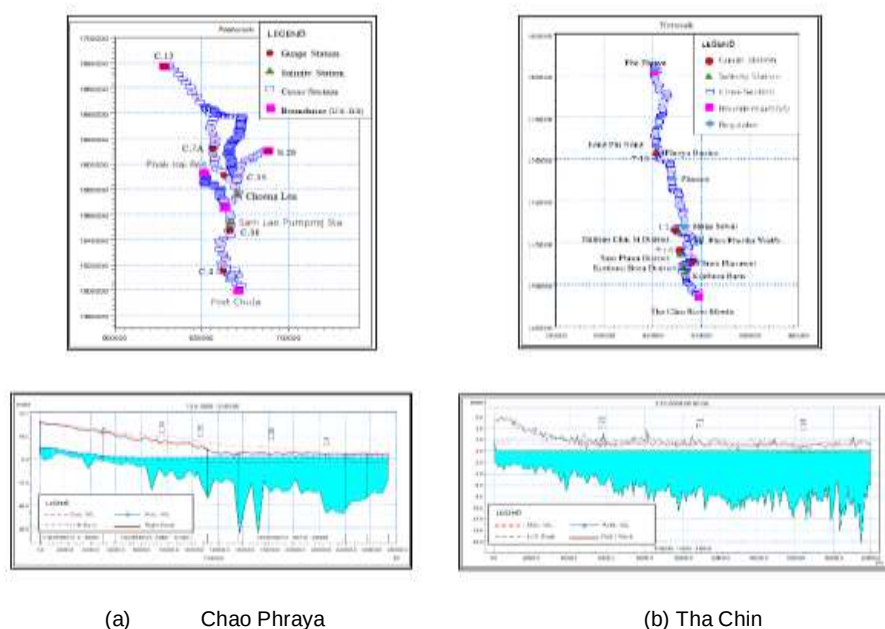


Figure 2. Model setup Lower Basins of (a) Chao Phraya (CPY) and (b) Tha Chin (TC).

MODEL CALIBRATION

The comparison of time series of measured and simulated water surface level and salinity at two major gauge stations on Chao Phraya and Tha Chin are shown in **Figures 3-4**. Good agreement between the simulated and measured hydrographs for the low flow events was achieved by considering side flow and pumps in the areas. The coefficient of determinant (R^2) and Index of agreement (IA) have been used as the main criteria to judge whether the data fitted between measurement and simulation. The comparison models were followed by adjusting important coefficient for two parts. The study results, manning (n), global dispersion factor, global exponent and K_{mix} were in the range of 0.022, 500-1,800 m^2/s , 0.1-0.8 and 500-1,800 hr^{-1} , respectively. The results of comparison between models and observation data revealed order of forecasting error, R^2 and IA were in the range of 0.76-0.96, 0.77-0.97 for water level and 0.82-0.75, 0.74-0.82 for salinity. These indicate well fitted between measured data and this proposed model.

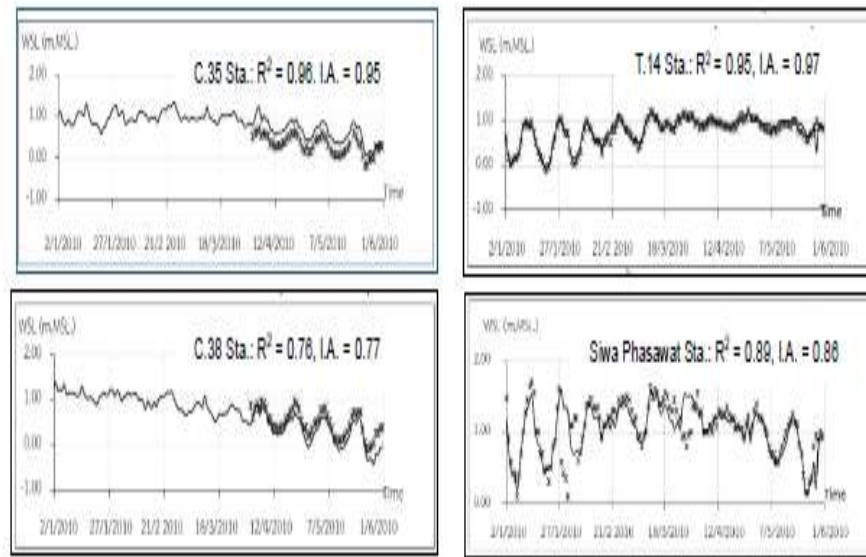


Figure 3. Comparison of time series of stage hydrograph between simulated results (smoothed-line) and measured data (dotted) at the major gauge stations (model calibration).

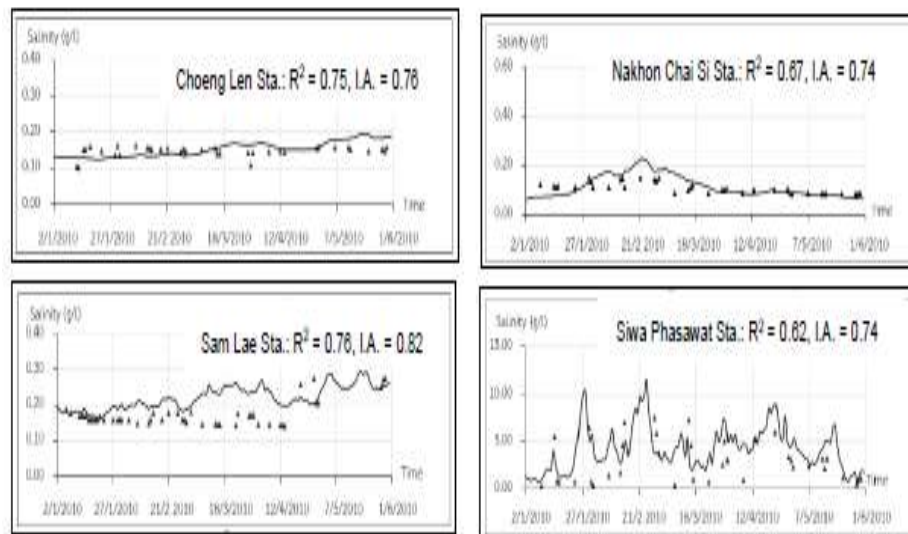
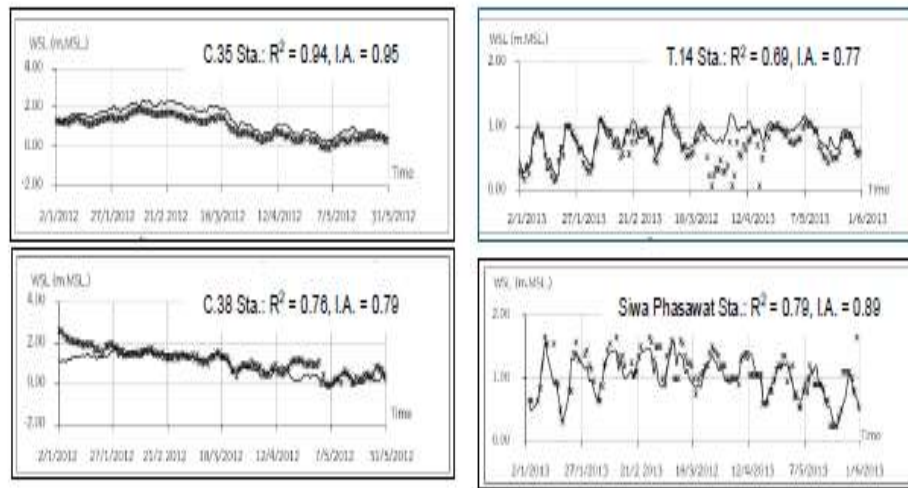


Figure 4. Comparison of time series of salinity between simulated results (smoothed-line) and measured data (dotted) at the major gauge stations (model calibration)

Model verification

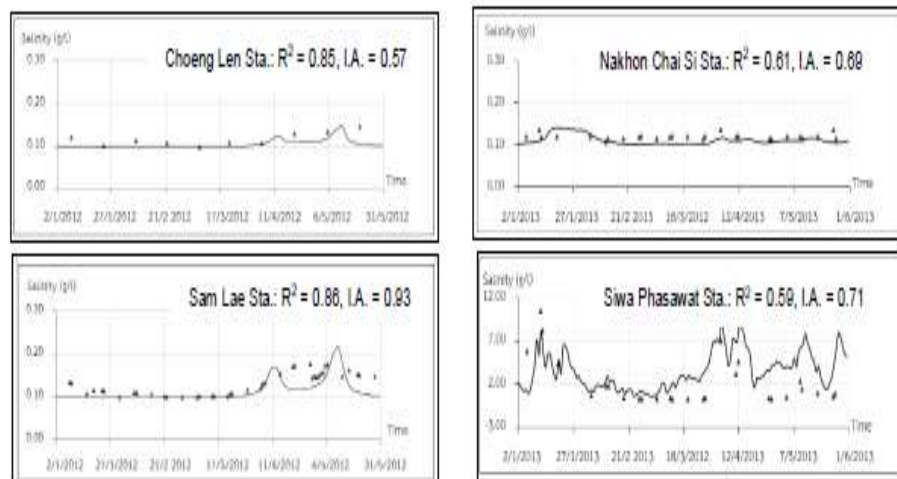
The comparison of time series of measured and simulated water surface level and salinity at two major gauge stations are shown in **Figures 5-6**. Good agreement between the simulated and measured water surface level was achieved by considering side flow and pumps in the areas. It was observed that the values of R^2 and IA for two major gauge stations in verification period were between 0.69-0.94, 0.79-0.95 for water level and 0.59-0.80, 0.57-0.93 for salinity, indicating well fitted between measured data and this proposed model. Good performance of simulated results was observed in both water flow and salinity intrusion characteristics, therefore, indicating that model simulation is reasonable.



(a) Chao Phraya

(b) Tha Chin

Figure 5. Comparison of time series of stage hydrograph between simulated results (smoothed-line) and measured data (dotted) at the major gauge stations (model verification).



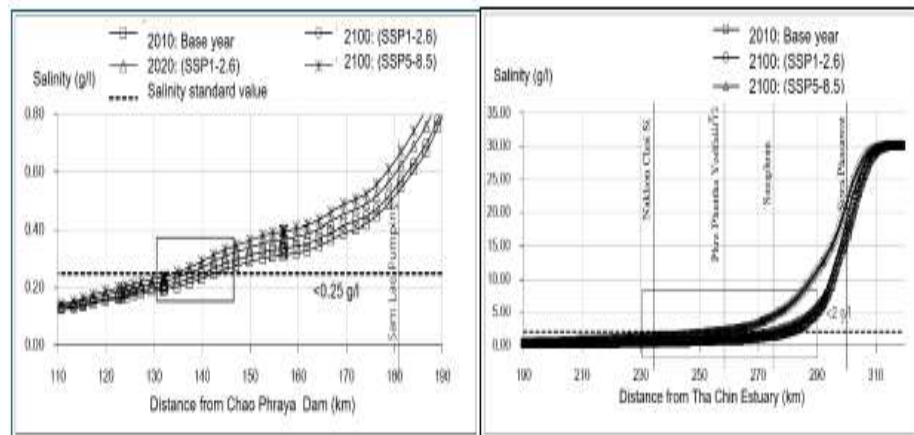
(a) Chao Phraya

(b) Tha Chin

Figure 6. Comparison of time series of salinity between simulated results (smoothed-line) and measured data (dotted) at the major gauge stations (model verification).

Model application

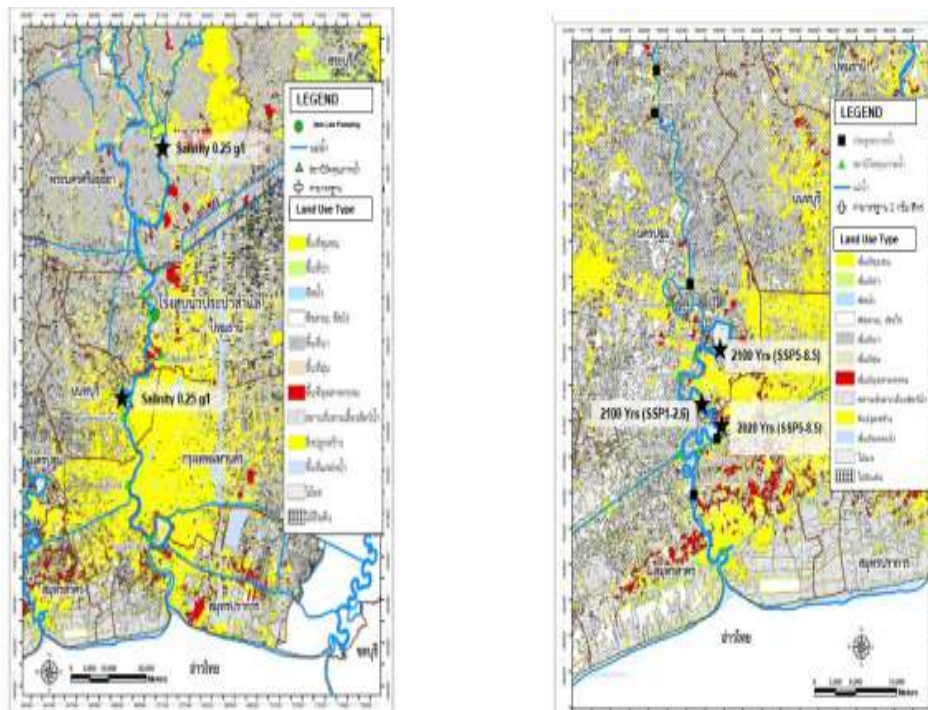
For model application, SSPs scenarios from IPCC report were simulated, sea water level rising in was 0.48 m in the year of 2100. The comparison of time series of measured and simulated flow discharge at the major gauge stations are shown in **Figures 7-8**. It was found that sea water level at the Chao Phraya estuary had rising and be taking tendency to intrusion of sea water level. Salinity was shown to be in the same tendency. For IPCC SSPs in the year of 2100, sea water level rising in scenario was 0.48 m, and salinity values and intrusion distant were in the range of 0.38-0.45 g/l and 142.0-157.0 km (from Chao Phraya Dam), and salinity at Sam Lae Pumping Station were 0.29-0.37 g/l. The value of 0.25 g/l exceeding standard and the pointed tip of salinity was at Bang Sai District, Ayutthaya Province. The worst case scenario, a constant value of salinity of 30 g/l was adopted at the Gulf of Thailand. It was found that salinity at Sam Lae Pumping Station was 0.99-1.70 g/l, the value of 0.25 g/l was at Pratuchai Sub-district, Ayutthaya Province, 133.0 km from Chao Phraya Dam. We could also observe these effects gained a more conspicuous large against higher sea water level rising.



(a) Chao Phraya

(b) Tha Chin

Figure 7. Salinity in the year of 2100, with sea water level rising in SSP1-2.6 and SSP5-8.5 (IPCC scenarios).



(a) Chao Phraya

(b) Tha Chin

Figure 8. Salinity in the year of 2100 (IPCC scenarios), with 0.48 m sea water level rising in SSPs scenario and salinity 30 g/l at downstream (Gulf of Thailand).

The years of 2100, SSP5-8.5: salinity less than 2.00 g/l encroaching into the Chao Phraya River from the river mouth to Koh Kret Sub-district, Pak Kret District, Nonthaburi Province. It affects mango and durian trees, but not coconut, because its can tolerate salinity up to 10.00 g/l. Thonburi area was formerly famous for its Bang Mod oranges, also known as Bang Mod green sweet oranges.

While much of the area was used for orange cultivation, several problems, such as, flooding, salinity intrusion, and factory wastewater, hampered cultivation. Oranges have low salinity tolerance (1.28-2.56 g/l), and this led many farmers in the area to abandon their farming operations. In the Tha Chin basin was founded that increased salinity impacting agricultural crops. At the Krathum Baen, Samut Sakhon province, the highest salinity recorded in 2020 was 2.16 g/l, suitable for all crops. However, in 2100, the SSP1-2.6 reached a maximum salinity of 3.09 g/l, affecting pomelo, lime, and mango, except for coconut and rice. The SSP5-8.5 reached a maximum salinity of 6.21 g/l, impacting rice and all crops except coconut.

However, Metropolitan Waterworks Authority (MWA, 2011) reported that climate change affected salinity intrusion and raw water supply in Lower Chao Phraya River. The observed effects demonstrated that Sam Lae Pumping Station will not be available when salinity is over 0.25 and/or 0.50 g/l, and water supply shortage. The mitigation plan has suggested that the diversion from Mae Klong River and construction of new pump station for short-term and long-term, respectively. **Figure 9** shows the proposed locations of new raw water pump station along the Chao Phraya River from Ayutthaya to Singburi Province. It was found that the most suitable sites when evaluation by multi-criteria analysis (MCA) is the site (4) (at Klong Pongpheng, Ayutthaya Province).



Figure 9. Location of new raw water pump station.

CONCLUSIONS AND DISCUSSTION

In this study, the MIKE11 model was exploited to simulate the effects of climate and sea level changes on the raw water supply of MWA in the lower part of Chao Phraya and Tha Chin Basins in the year 2100. The study covered the area from Chao Phraya Dam, Chai Nat Province to the Gulf of Thailand at Samut Prakan Province. IPCC scenarios predicted that in the year 2100, sea water level rising in SSP5-8.5 scenario was 0.48 m. Based on this information, the simulation showed that salinity at Sam Lae will be exceeded 0.25 g/l. Therefore, it suggested to add pump station at Sam Lae to site (4) at Klong Pongpheng, borderline of Ayutthaya and Ang Thong Province). This will help to balance level of salinity in river not over 0.25 g/l. The findings of this study will provide guidance for adapting the management of water resources for water supply and agriculture in the lower Chao Phraya and Tha Chin river basins.

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