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A nalyse the fluctuation and water level trend in Saigon – Dong Nai river system

Luong Van Viet*, Pham Dang Manh Hong Luan, Le Anh Tuan

Sub-Institute of Hydro- Meteorology and Environment of South Vietnam

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Abstract. Beside the effect of gravitational forces, the water level in Sai Gon-Dong Nai River System is also affected by non gravitational forces such a wind, air pressure, rainfall and sea level rise. The purpose of this paper is to simulate the water level of these river based on the tidal and non-tidal constituents, from that assess the role of non-tidal constituents to water variation. In this study, the none-tidal data used includes the wind field at surface, sea level pressure and the rainfall in Sai Gon – Dong Nai Basin. With the analyzed data series from 1980 to 2007, the results show that after supplementing the non-tidal elements, the water level simulation quality is increased, the wind and rainfall have an important role to water level. The results also show that near river mouths, the water level raised 13 cm from 1980-2007 due to the global climate change.
Keywords: tidal harmonic analysis, non-tidal constituents, sea level rise

1. Generalization

The Dong Nai – Sai Gon river system whose watershed area is approximately 45,000 km^2 is the second largest river system in the Southern provinces. These river system comprises of main rivers including La Nga, Be, Dong Nai, Sai Gon, Nha Be and rivers ending up in Ganh Rai bay. It is the watershed covering main economic zone in the South which has many activities related to water resources, the downstream of the area is low and vulnerable to sea level rise effects. Therefore, short – term and long – term forecast of water level in this area is a significant demand.

Tide regime of river system in the researched area is semi-diurnal type with tide amplitude pretty high. Apart from the effect of tide, water level variation in the area is also affected by rainfall, wind field and air pressure.

The yearly average rainfall of this watershed is 2028 mm and concentrates mainly from May to November with above 90% [1]. The rainfall which is not equally distributed and mainly concentrates in rainy season caused significant effect on water level. In addition, dry season and long – lasting heavy rains are also factors that greatly affect water level variation.

The effect of wind on water level rise in the area can be clearly seen in dry season. In this period, the wind at the sea surface has main direction from East to South East. Due to the

* Corresponding author. Tel.: 84-4-38275971
E-mail: lgviet@yahoo.com

land – sea interaction, there is sharp daily change of daily wind direction. From 5 am to 12 am, the prevalent wind direction is usually between East and East North East which nearly matches the wind direction on the sea. From 2 pm to 2 am, due to the effect of sea – land wind, the prevalent wind direction is South East [1]. This wind direction matches the direction of river mouths in Ganh Rai bay, contributing to the transporting of salinity deep in the land as well as raising water level. Compared with daily average wind speed, the South East wind speed can increase from 1.5 to 2 times [2]. At areas near the sea, the water level can increase significantly when this wind zone is strong.

Due to the frequent appearance of wind with direction from NE to SE in dry seasons (from the end of October and lasting till the end of April), the water level rises and salinity intrudes to the land, which can bring on the effects on agriculture production so that the wind is also named "Chuong Wind" in tradition. However, the most significant wind is still SE wind because of its high velocity and due to the fact that it runs parallel to the river mouths. Apart from the edge of Asia continental cold high pressure system, Chuong Wind is also originated from breeze and edge of North Pacific Ocean high pressure system.

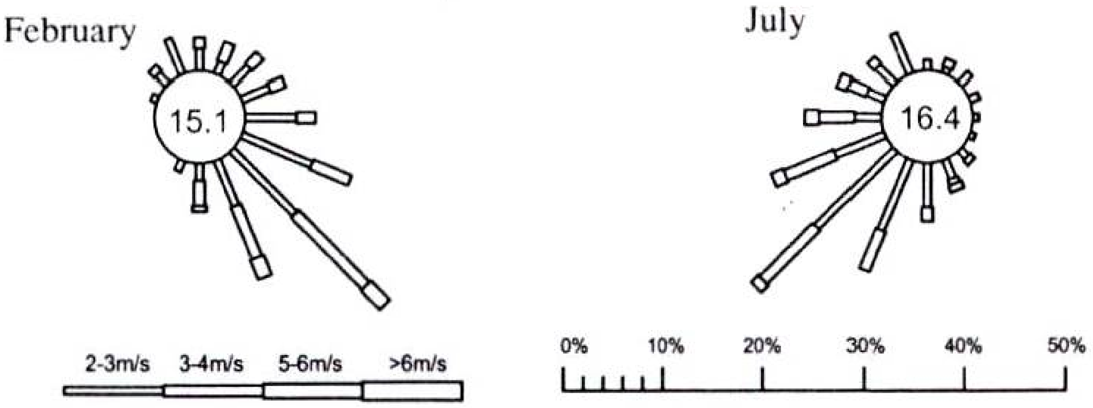

Fig. 1. Wind rose of February and July, Tan Son Nhat station.

Beside the effect of tide – forming forces, wind and the rainfall in the area, there is also huge impact of sea level rise due to climate change on water level. The analysis of the roles of non-tidal factors on water level is strongly necessary in water level forecasting.

2. Methodology and data used

2.1 Methodology

The analysis of water level fluctuation and trend is based on harmonic analyzing method supplemented with non-tidal elements. Water level at a certain time is considered the sum of tidal water level and the affected part of non-tidal elements:

$$\hat{Z}_t = z_t + z'_t \tag{1}$$

In which $\hat{Z}_t$ is the simulated water level at time t, z_t is the tidal water level, z'_t is variation part of the water level due to non-tidal factors.

The tidal water level z_t, according to harmonic analyzing method, was:

$$z_t = z_0 + \sum_{i=1,n}^{n} f_i H_i \cos(q_i t + (V_0 + u)_i - g_i) \tag{2}$$

Here, z_0 is the constant; H_i, q_i, g_i, f_i, $(V_0+u)_i$ are amplitude, speed and initial phase angle, amplitude scaling factors and phase angle offsets of i^{th} constituent, with i = 1, 2, ..., n and n is the number of constituents. The values of f_i and $(V_0 + u)_i$ depend on time and can be look up from table or calculated by astronomical functions.

In this study, component z'_t includes water level variation by wind ($z_t^{W'}$), air pressure ($z_t^{P'}$), rainfall ($z_t^{R'}$) in the watershed and the trend of water level rise due to global climate change ($z_t^{Tr'}$):

$$z'^{t} = z_t^{R'} + z_t^{W'} + z_t^{P'} + z_t^{Tr'} \quad (3)$$

Components in z'_t are considered the total of the linear impacts and equation (1) can be solved by linear regression method with the following steps of assuming sub-unknown:

By assuming $R_i = f_i H_i$ and $\zeta_i = g_i - (V_0 + u)_i$, z_t will become:

$$z_t = z_0 + \sum_{i=1}^{n} R_i cos(q_i t - \zeta_i) \quad (4)$$

By assuming $x_i^1 = R_i cos(\zeta_i)$ and $x_i^2 = R_i sin(\zeta_i)$, (4) can be performed as:

$$z_t = z_0 + \sum_{i=1}^{n} [\cos(\zeta_i) x1_i + \sin(\zeta_i) x2_i] \quad (5)$$

By assuming $a1_i = cos(\zeta_i)$ and $a2_i = sin(\zeta_i)$, equation (5) becomes the following linear equation:

$$z_t = z_0 + \sum_{i=1}^{n} [a1_i x1_i + a2_i x2_i] \quad (6)$$

In this study, components of z'_t in equation (3) can be expressed by the following linear function:

$$z'_t = \sum_{j=1}^{m} a3_j x3_j \quad (7)$$

In this equation, m is the number of affecting factors, $a3_j$ are constants, $x3_j$ is affecting factors, j = 1, 2, ..., m. With rainfall, the affecting factors include total rainfall on the watershed accumulated from 1h to 24h, 25h – 96h, 97h – 264h and 265h – 624h before time t. With wind speed and air pressure, affecting factors include wind vector 10 m, sea surface pressure. These components are averaged on the chosen area with cumulative time ranges 0h – 1h, 2h – 5h, 6h – 14h, 15h – 30h, 31h – 55h before time t. Components expressing water level trend driven by global climate is the last component of z'_t with value of $a3_m x3_m$ in which $x3_m$ is equal t.

Combine equation (6), (7), and (1), the function performing $\hat{Z}_t$ is:

$$\hat{Z}_t = z_0 + \sum_{i=1}^{n} [a1_i x1_i + a2_i x2_i] + z'_t \quad (8)$$

Or:

$$\hat{Z}_t = z_0 + \sum_{i=1}^{n} [a1_i x1_i + a2_i x2_i] + \sum_{j=1}^{m} a3_j x3_j \quad (9)$$

With these transformations, equation (9) has linear form with following variables: $x1_i$, $x2_i$ and $x3_j$. This equation will be solved by multiple linear regression method which is based on minimum square method. However, in order to choose suitable tidal as well as non-tidal factor, in this study, only multiple linear regression is applied. The sequential multiple linear regression is similar to multiple linear regression in which the equation quality gained is the best by rotating matrix of affecting factors chosen from equation building steps.

After solving out variables $x1_i$ and $x2_i$ through intermediate steps, R_i and ζ_i can be defined and then H_i and g_i can also be defined. By replacing these values into (2), tidal water level will be defined at any given time.

In order to improve the quality of $\hat{Z}_t$ manipulation, the process to build the equation follows two steps below:

- Step 1: Building $a3_j$ factors through equation (9) for every month with water level observed from 1980 to 2004.
- Step 2: Building values of H_i and g_i through one – year data of observed water level chosen randomly from data series of time period from 1980 to 2004 through equation (8) when the value of z'_t is solved out from values of $a3_j$.

The assessment of the quality of the equation is through statistical factors including Fisher statistical index, the deviation of regressive factors, defining factors, mean error and max error. These factors are also determining factor for the number of wave to be chosen. The number of wave will be dependent on the length of analyzing series and the features of every area. For the studied area, if the length of data series is long enough, the number of wave chosen will range from 18 for on and near- sea locations to 22 for locations lying deep in the land.

Besides, the quality of simulating water level is also assessed by observed water level data which is not included to build a_j^3, H_i and g_i factors. This data is taken from 2005 to 2007.

2.2 Data used

The data used in this study includes data of observed water level, rainfall, wind and air pressure. Time range of these data series is from 1980 to 2007. The water level data is hourly observed data. The rainfall data is daily data, the wind and air pressure data type are taken 4 times a day. In order to transform these data to the same time resolution with water level data, they will be be interpolated by using linear method

The water level monitoring stations that are used in the analysis include Vung Tau, Nha Be, Phu An, Hoa An, Ben Luc and Tan An. The locations of these stations are illustrated in Figure 2.

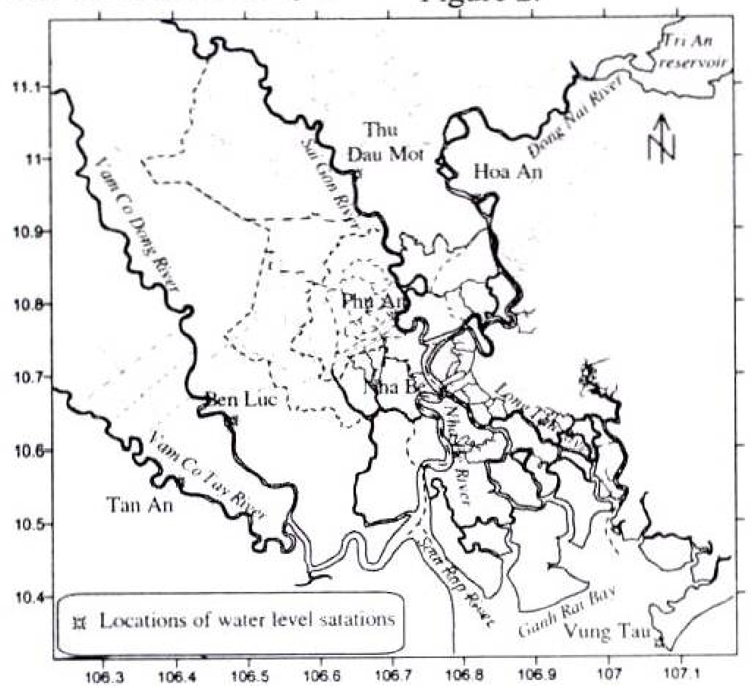

Fig. 2. Location of water level stations.

The wind and air pressure data are from global reanalyzed data of NCEP in the following link http://www.cdc.noaa.gov/data/gridded/data.ncep.reanalysis.surface.html, these data have the resolution of 2.5 x 2.5 degree. The chosen area from 102.5^0 to 112.5^0E and 5^0 to 15^0N is illustrated in Figure 3.

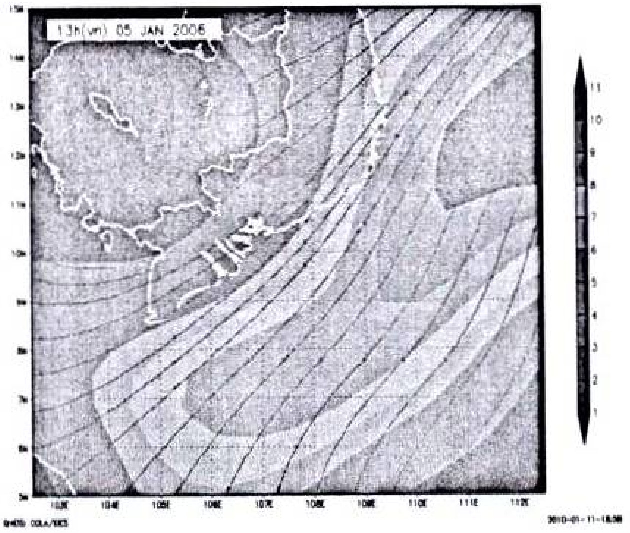

Fig. 3. Surface wind field of the studied area.

The rainfall monitoring data is taken from stations lying in the studied area, in order to improve the quality of simulation, some stations nearby are also included. The area for choosing rainfall monitoring stations is from 106^0 to 108^0E and 10^0 to 12^0N. There are totally 13 rainfall monitoring stations taking part in the calculation including Bao Loc, Bien Hoa, Dac Nong, Dong Phu, Moc Hoa, Phuoc Long, So Sao, Tan An, Tan Son Hoa, Tay Ninh, Tri An, Vung Tau, Xuan Loc. Apart from these stations, data from 12 rainfall gauging site in the studied area are also used. The data form to be used is the average rainfall in pixel with resolution of 0.5 x 0.5 degree.

3. Results and Discussion

3.1 The quality of simulation of water level with the supplementation of non–tidal components

After supplementing non – tidal components, the values of amptitute (H_i) and initial phase (g_i) of tidal wave in water level simulation are changed. The illustration of this change at Vung Tau station is shown in table 1, here, change mainly occurs in tidal wave ssa, sa and k1. In addition, there exist change in component z_o, in Vung Tau station, the values of z_0 before and after adding non – tidal components are -24 cm and -22 cm respectively.

The quality of the simulation of water level fluctuation with the supplementation of non-tidal components is accessed through the determined coefficient and the mean error. Time of assessment is the time range that was not included in building the factors $a3_j$, H_i and g_i, from 2005 to 2007. There are two types of assessment including:

- Determining the quality of the simulation of tidal water level by equation (2) with values of H_i and g_i built from step 2.

- Determining the quality of the simulation taking in account component z'_t used to calibrate the water level variation due to non-tidal factors.

Table 1. The amplitude and initial phase values of tidal wave in Vung Tau station

No.	Symbol	Phase (^{0}/h)	Without non-tidal Element		With non-tidal Element	
			H_i (cm)	g_i (^{0})	H_i (cm)	g_i (^{0})
1	m2	28.9841042	76.07120	63.76976	76.06539	63.76058
2	k1	15.0410686	59.36825	-33.73985	59.46649	-33.08949
3	o1	13.9430356	44.57975	-82.60097	44.57684	-82.59804
4	s2	30.0000000	30.09205	107.23598	30.06174	107.52096
5	sa	0.0410686	20.67649	-86.21850	20.00824	-86.52581
6	p1	14.9589314	18.86379	-36.50550	18.84166	-36.13764
7	n2	28.4397295	15.93458	40.51535	15.90711	40.57601
8	k2	30.0821373	9.27898	115.71067	9.33931	116.03352
9	q1	13.3986609	8.52208	-104.10203	8.49669	-104.27054
10	ssa	0.0821373	6.15398	91.27816	3.27434	105.56152
11	m1	14.4920521	2.02516	-71.72914	2.02822	-71.59688
12	j1	15.5854433	2.30905	6.97230	2.30199	6.40569
13	mk3	44.0251729	2.82627	-120.98422	2.82923	-120.94674
14	mu2	27.9682084	2.48928	-2.44140	2.48340	-2.40553
15	op2	28.9019669	2.07748	-94.18789	2.08401	-94.22076
16	2n2	27.8953548	2.43837	14.16457	2.44413	14.12801
17	oo1	16.1391017	1.73745	33.41912	1.72919	33.24114
18	mo3	42.9271398	1.94380	179.61837	1.94238	179.56725

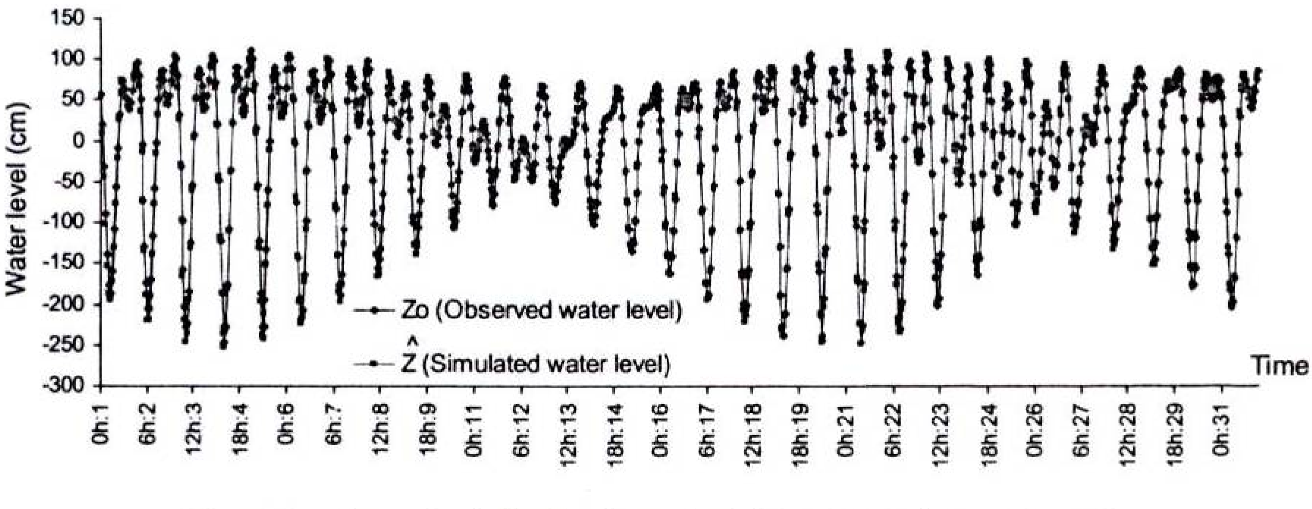

Fig. 4. The observed and simulated water level in Jan/2007 of Vung Tau station.

Assuming R^2_1, Er_1 are defining coefficient and mean error when simulating the tidal water level by equation (2), which means not taking into account the variation by wind, air force and rain of water level; R^2_2, Er_2 are defining coefficient and mean error when simulating the tidal water level by equation (2) in case the values of H_i and g_i already take into account the effect of weather elements; R^2_3, Er_3 are defining coefficient and mean error when simulating the water level with the effect of weather elements is already taken into account (in equation (8)). The assessment result is based on the difference before and after supplementing the affecting factors and displayed on Table 2.

Table 2. Change of defining coefficient and mean error

Coefficient	Vung Tau	Nha Be	Phu An	Bien Hoa	Thu Dau Mot	Ben Luc	Tan An
R^2_2-R^2_1	0.002	0.007	0.009	0.010	0.012	0.013	0.013
R^2_3-R^2_1	0.007	0.024	0.022	0.032	0.026	0.029	0.028
Er1-Er2 (cm)	0.5	1.1	1.4	1.2	1.5	1.3	1.3
Er1-Er3 (cm)	2.2	4.8	4.1	3.5	3.4	3.4	3.2

Result from Table 2 shows that with the supplementing of weather elements in building harmonic constants, the quality of simulating the tidal level is improved with the mean error reduced above 1 cm from on-river stations. The maximum mean error for all stations decreases 5 cm which is pretty meaningful in building tidal water level tables. Table 2 also suggests that when simulating water level with the supplementing of weather factors, the quality of simulation is improved significantly. Except for Vung Tau station which has mean error decreasing 2.2 cm, the in river stations have the decreasing level of 3 cm. The maximum error averaged from stations decreases 14 cm.

3.2 Analyzing the role of non-tidal components

To see the effect of rainfall, wind and air pressure on the variation of gauged water level, these components are separated from coefficient of simulating equation. In general, the simulating result of the water level variation due to non-tidal elements has pretty good relationship with the difference of the observed water level and the tidal water level. The nearer the station is to the river mouth, the better this relationship is. Figure 5 is the illustrating result for Vung Tau station in 2005.

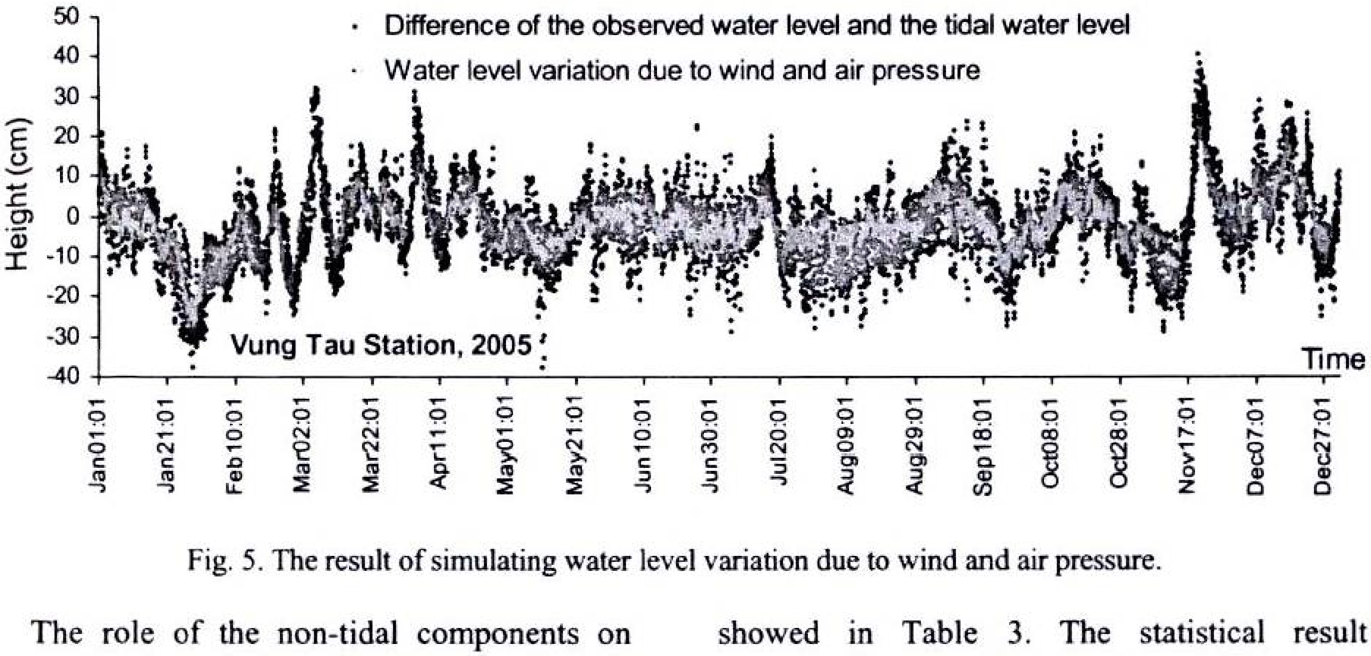

Fig. 5. The result of simulating water level variation due to wind and air pressure.

The role of the non-tidal components on water level variation is showed through standard deviation (S) of water level simulating data series of these components. The result is showed in Table 3. The statistical result suggests that at stations on the sea (Vung Tau station), S in dry season has values greater than in rainy season. This feature is due to the difference of North East and South West seasonal wind in term of wind velocity and direction as well as wind period. At Nha Be and Phu An stations has similar characteristics, however, at stations lying deep in to the land, the effect of rainfall on S is more clearly. At these stations, the value of S is pretty high in the end of dry seasons (March and April) and especially in the mid of rainy seasons (from July to September).

Table 3. Standard deviation of non-tidal water level

Month	Vung Tau	Nha Be	Phu An	Bien Hoa	Thu Dau	Ben Luc	Tan An
1	7.9	6.1	5.2	4.0	3.8	3.1	2.8
3	7.2	6.6	5.5	4.2	4.3	3.8	3.5
5	5.1	5.9	4.7	4.4	3.4	3.4	3.0
7	4.0	4.6	3.4	5.4	2.5	2.1	1.8
9	5.7	6.5	5.4	7.4	4.3	4.5	4.4
11	7.2	6.7	5.3	4.2	3.7	2.9	2.8

Table 4. Trend of water level at observation stations during period 1981-2007

Station	Vung Tau	Nha Be	Phu An	Bien Hoa	Thu Dau	Ben Luc	Tan An
Trend of water level (cm)	13	12	11	9	8	11	11

The water level trend at observation stations is defined from $a3_m$ coefficient, the calculation result is shown in Table 4. Due to calculation method, this result is mean water level increase. This result show that in the period 1978 – 2007, the average water level at observation stations had increased significantly. The maximum increase is 13 cm at observation stations on the sea (Vung Tau station), which is approximately equal to the rising of water level at inshore stations of Vietnam [3-5]. At stations on the river, the rising level is lower and has values ranging from 8 cm to 12 cm. Due to the fact that the accuracy of the result of water level simulating is not really high for the stations on the rivers, this is only considered the referencing data.

Conclusions

The assessment show that the quality of water level simulation on Sai Gon – Dong Nai river system is improved considerably and maximum error decreases significantly when taking into account non-tidal components. The impact of wind on water level variation is considerable, especially in dry season. The rainfall also plays an important role to the water level variation on the rivers which is revealed most clearly in the middle of months of rainy season. The supplementing of water level trend component into analysis improves the quality of the simulation and shows off a rise at alert level of water level due to global climate change in Sai Gon – Dong Nai river system.

In order to improve the quality of simulation, it is necessary to improve the affecting factors especially the data of flow in the upper stream. The application of this method in forecasting water level in the studied area is feasible when it is cooperated with products from weather models.

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