Research Article
Turkish Journal of Maritime and Marine Sciences Volume: 5 Issue: 2 (2019) 97-111

Hydrographic study of Shatt Al-Arab estuary in the context of climate change

Türk Denizcilik ve Deniz Bilimleri Dergisi Cilt: 5 Sayı: 2 (2019) 97-111

Ali Bassal MAHMOOD[1,*]

[1]*Marine Science Center, University of Basrah, Garmat Ali Campus, Basrah, IRAQ*

ABSTRACT

This paper presents the first key results for the impacts of the North Atlantic Oscillation (NAO), the Indian Ocean Dipole Mode (DMI) and the Southern Pacific Ocean Oscillation (SOI) events on the hydrographic and climatic parameters at the mid of Shatt Al-Arab estuary (i.e. Basrah city center) by using correlation analysis and standard ordinary linear regression as an autoregressive process of order 1. The analysis examined the discharge, salinity, sea surface water temperature, and air temperature over the period 2005-2014 (i.e. interannual, monthly and seasonal datasets). The formal regressions have been estimated by using the first-degree autoregressive AR (1) model, which includes calculations of the GLS-Generalized Least Square Error Minimization regression method, for obtaining more stable solutions in the context of climate change. The correlation is accounted for using the standard ordinary bivariate linear regression method. The main results indicated that the hydrographic and climatic variables in the study region experienced general trends of decrease in discharge of 2.0936 (m^3/sec), increase in salinity of 0.0071 (‰), increase in air temperature of 0.0178 (°C) and increase in sea surface temperature of 0.0098 (°C). Significant correlations, as well as prediction equations, were found between discharge and SOI, then, salinity and sea surface temperature with NAO, and finally between air temperature with NAO/DMI/SOI. The Pardé coefficients reflect the Karun influence during spring in the context of climate change .

Keywords: Shatt Al-Arab estuary; North Atlantic Oscillation; Dipole Mode; Southern Oscillation; Parametric methods

Article Info
Received: 25 July 2019
Revised: 07 December 2019
Accepted: 09 December 2019

* (corresponding author)
E-mail: ali.baisel@uobasrah.edu.iq

1. INTRODUCTION

Shaṭṭ Al-Arab estuary formed by the confluence of Tigris and Euphrates rivers. It flows southeastward for 204 km from the confluence point. Besides, it receives fresh water from the eastern side by Karun River. Its width increases about 400 m at Basrah city center to 2 km at its mouth. The drainage basin area is around 1000000 km2. The hydraulic gradient rate is between 1-1.5 cm/km. Thus, the study region (Figure 1) is very important for the Iraqi economy, where it used for fishery, oil transportation, and shipping, which links between many harbors in the Persian/Arabian Gulf. The Northern Arabian/Persian Gulf showed significant correlations between each of the climatic events: North Atlantic Oscillation-NAO; El Nino Southern Oscillation-SOI; and Indian Ocean Dipole-DMI with air temperature, barometric pressure, and precipitation during seasonal variations of the period (1973-2012) by following Al Senafi and Anis (2015). The climate in the region is vulnerable to the increased in air temperature especially, in the context of climate change. The influence of climate change on the increase of sea surface water temperature has been increasing constantly (Attrill, 2009). Thus, the current study examines the effects of the atmospheric events on Shatt Al-Arab hydrographic and climatic parameters.

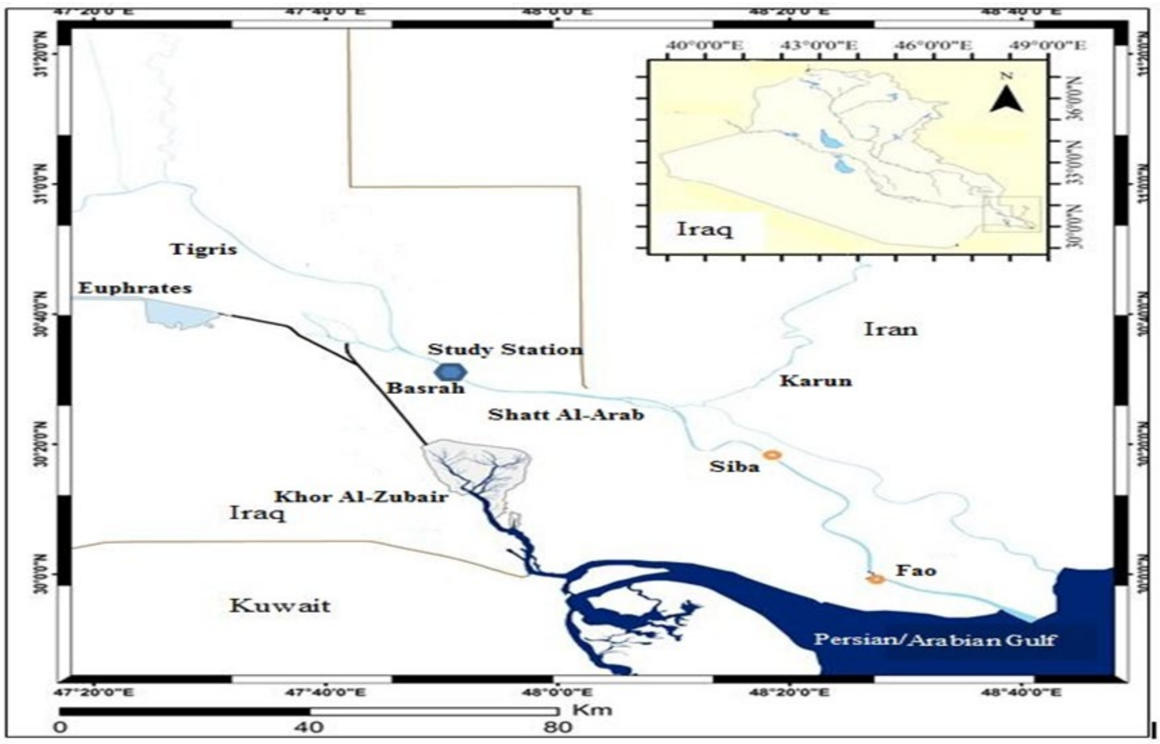

Figure 1. A map showing the study region, i.e. Shatt al-Arab estuary (MSC, 2016).

Determining the regression/ correlation between the above-mentioned events and the hydrographic and climatic parameters (i.e. River discharge-Rd, salinity-S, sea surface water temperature-SST, and air temperature-AT) is the aim of the present work. The linear trend for each parameter is the goal of our study as well.

The global and the regional climate change in the Northern Arabian/Persian Gulf have been detected in the last decades (Al Senafi and Anis, 2015; Attrill, 2009; Jones et al., 1997; Jones, 2003; Naidu et al., 2012). So, it is necessary to investigate if Shatt Al-Arab

hydrographic and climatic features suffer a change during the interannual, monthly, and seasonal means at the Basrah city center station in the context of climate change over the time (2005-2016).
Moreover, to detect the increase or decrease in the extreme values of Shatt Al- Arab discharge during the monthly means, the Pardé coefficients should be calculated in accordance with Bormann (2010). The materials and methods are presented in section 2, as well as, the estimated models are submitted in section 2.1. The results are given in section 3, as well as, the discussion and conclusions are submitted in section 4. Then, the references will submit during section 5.

2. MATERIAL AND METHOD

For the implementation of statistical time series analysis (i.e. correlation analysis and standard ordinary linear regression as an autoregressive process of order 1) to the physical features of Shatt Al-Arab estuary in the conducted research, a great deal of data series were used for the period 2005-2014 in the context of climate change:
1) Monthly data series of R_d (m^3/sec), S(‰), SST (˚C), AT (˚C), (see Figure 2), were measured at the mid of Shatt Al-Arab estuary (i.e. Basrah city center station) with latitude/longitude 30°31'08.9"N 47°50'45.9"E (MSC, 2016).
2) Monthly mean data series of the (NAO) index (see Figure 3), i.e. the difference between the normalized sea level pressure over Gibraltar and the normalized sea level pressure over Southwest Iceland in the North Atlantic Ocean, were collected from Climate Research Unit in Norwich, United Kingdom (CRU) and calculated depending on the method given by Jones et al. 1997.
3) Monthly mean data series of the (DMI) index (see Figure 4), i.e. the Sea Surface Temperature SST gradient between the western equatorial Indian Ocean (50E-70E and 10S-10N) and the southeastern equatorial Indian Ocean (90E-110E and 10S-0N) (Saji and Yamagata, 2003).
4) Monthly mean data series of the (SOI) index (see Figure 5), i.e. the normalized pressure difference between Tahiti and Darwin in the equatorial Pacific Ocean, were collected from (CRU) and calculated depending on the method of Ropelewski and Jones (1987).

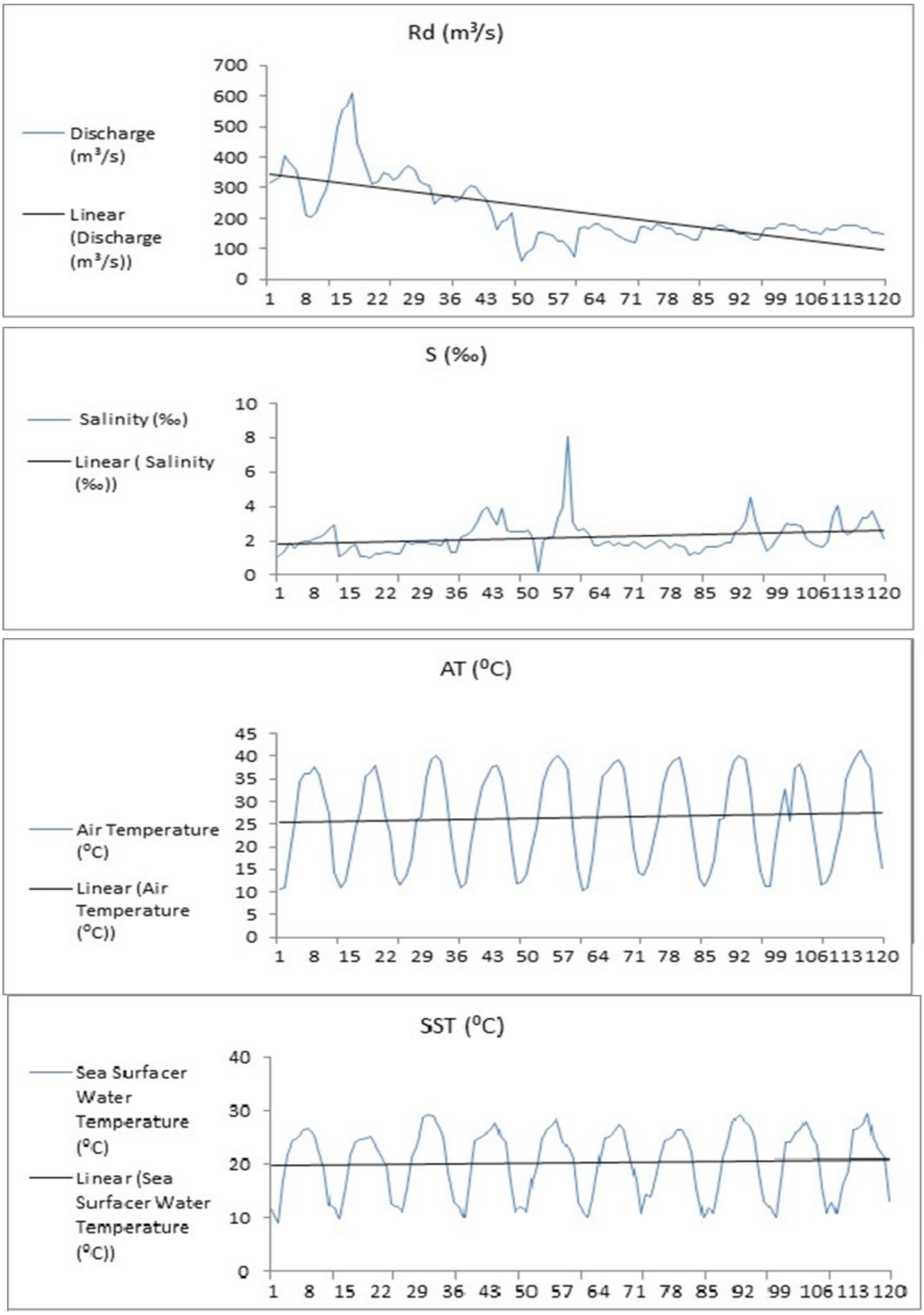

Figure 2. Monthly mean data series of Discharge-Rd, Salinity-S, Sea surface water temperature-SST, and Air temperature-AT at the mid of Shatt Al-Arab estuary (i.e. Basrah city center station) with latitude/longitude 30°31'08.9"N 47°50'45.9"E (MSC, 2016).

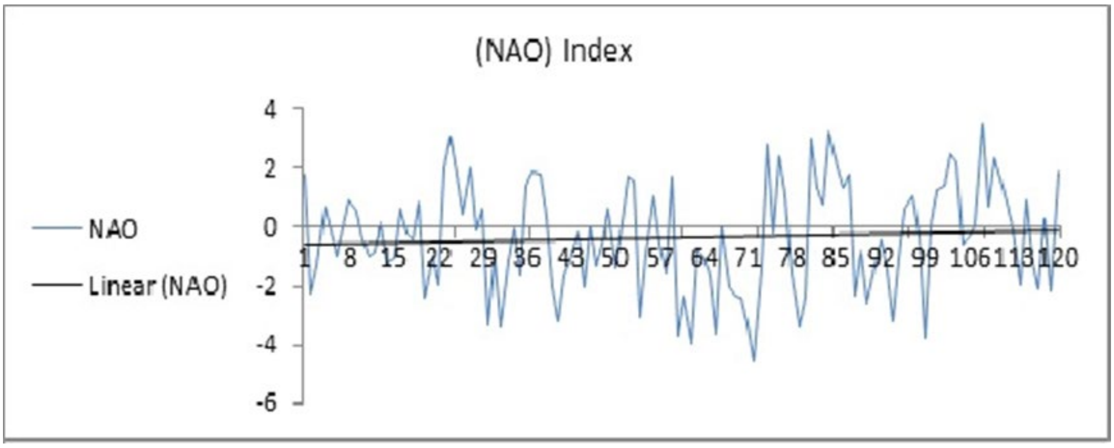

Figure 3. Monthly mean Jones's data series of the (NAO) indices (CRU, 2018).

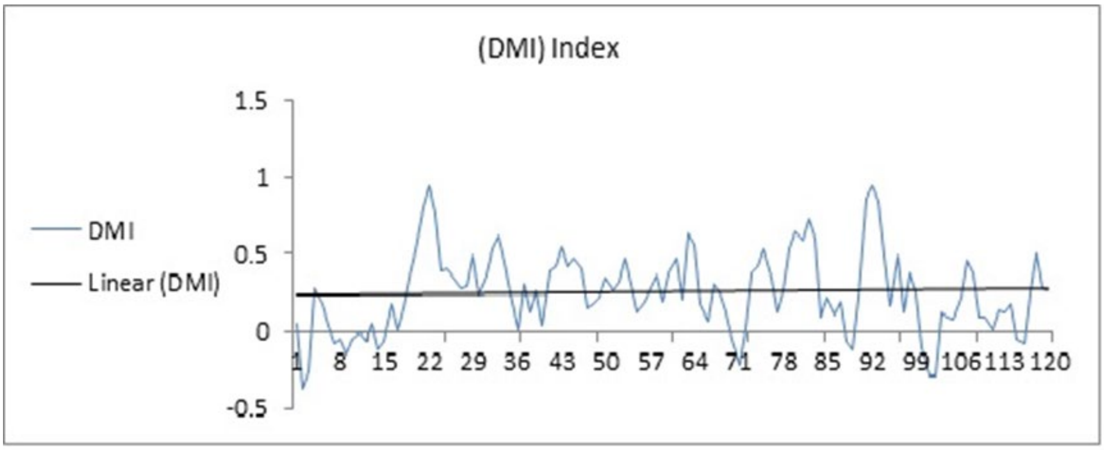

Figure 4. Monthly mean data series of the (DMI) indices (Saji and Yamagata, 2003).

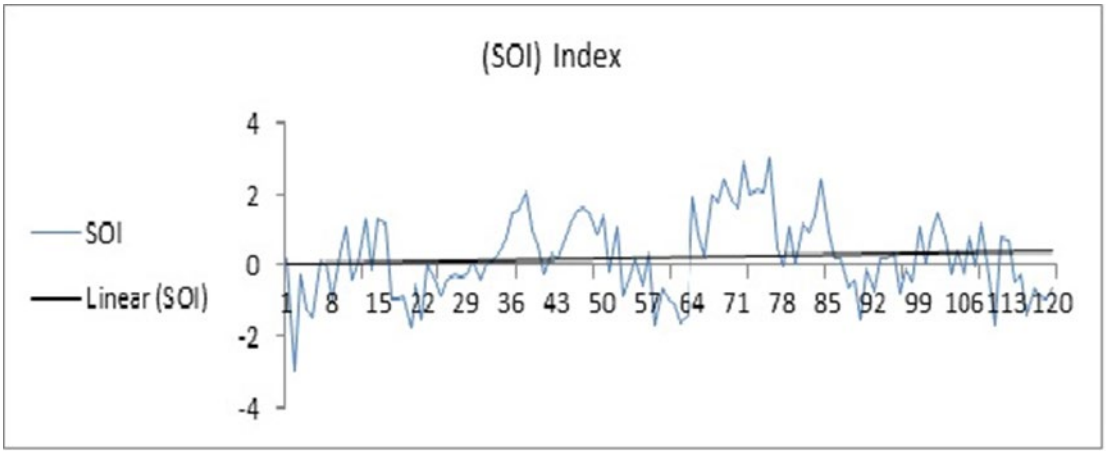

Figure 5. Monthly mean data series of the (SOI) indices (CRU, 2018).

The seasonal form of each studied series were estimated directly such as (the winter season: by the average of December; January and February data series); (the spring season: by the average of March; April and May data series); (i the Summer season: by the average

of June; July and August data series) and (the Autumn: by the average of September; October and November data series). Missing values in any time series, if found, were treated according to Emery and Thomson (2001).
Thus, the total linear trend presented throughout the hydrographic data series (i.e. Rd, S, and SST) and the climatic data series (i.e. AT) was assumed to be linear. Then, it could be described as follows (Mahmood, 2016):

***The total linear trend throughout the hydrographic and climatic series ≈ the linear trend caused by the climatic reasons and the linear trend caused by the other reasons* (2.1)**

Where the trend caused by the climatic reasons is superimposed with the other reasons. The trend calculations should be performed before the calculations of correlations exclusively. Hence, it should remove (linearly detrended) from the individual records, if detected. Where the problem associated with not detrending data series is: The climatic reasons are controlled by different atmospheric circulations in the context of climate change. However, the detrended procedure will also eliminate a whole linear trend.
Furthermore, verifying the adopted datasets (i.e. hydrographic and climatic series) have done by using the SNHT test (i.e. the XLSTAT- statistical software) and obtaining no unrealistic values.

2.1. The Estimated Models

Pearson's correlation coefficient has been adopted in the present study. The value of a t-test should be used to study the significance of Pearson's coefficient R.
Regression analysis aims to determine an average relationship between the variables. In this analysis, one variable is taken as a dependent variable (e.g. Rd, S, SST, and AT), while the other is considered as the independent variable (e.g. NAO, DMI, and SOI). Where, the physical links behind using this analysis were the SST and AT showed linear regression behavior in the Northern Arabian Gulf in accordance with Al-Rashi et al. (2009) and Al Senafi and Anis (2015). Similarly, the Rd and S in Shatt Al-Arab Estuary showed like behavior according to Abdullah et al. (2016) and MSC (2016).
A simple linear regression line is fitted between the two variables (or is fitted for a single variable) based on the observed data. Parametric methods have used for calculating the regression models in the present study.
The standard ordinary bivariate linear regression provides accurate estimations when the regression residuals are corrected for a serial autocorrelation and the variance. Therefore, the estimated Rd, S, SST, and AT are characterized as an autoregressive process of order 1, i.e. AR (1) model, during the calculations of the Generalized Least Square Error Minimization regression (GLS) method and can be expressed in accordance with Mahmood (2016):

$$H_t = a+b\ N_t+\rho_1(H_{t-1}-a-bN_{t-1})+v_t \ . \quad (2.2)$$

i.e.,
a = is the intercept regression coefficient
b= is the linear regression slope coefficient
ρ= is the autocorrelation coefficient (i.e., -1 < |ρ| <1)
v_t= is an independently and identically distributed error term with zero mean and variance.
H_t= $Rd_t/S_t/SST_t/AT_t$ (i.e., River discharge series/Salinity series/Sea surface water temperature series/Air temperature series) t.
N_t = (the NAO series/the DMI series/the SOI series + errors by noise) t.
H_{t-1} = Rd_t-1/S_t-1/SST_t-1/AT_t -1 (i.e., River discharge series/Salinity series/Sea surface water temperature series/Air temperature series) t-1.
N_{t-1} = (the NAO series/the DMI series/the SOI series + errors by noise) t-1.

The linear regression trend T gives accurate estimations when the regression residuals are corrected for a serial autocorrelation and the variance. Therefore, the Rd, S, SST, and AT linear trends are characterized as an autoregressive process of order 1 and can be expressed as follows in accordance with Mahmood (2016):

$$H_t = a+T\ (time)\ t + \rho_1\ (H_{t-1}-a-T\ (time)\ t\text{-}1) + v_t. \qquad (2.3)$$

For correlation and regression coefficients tests, a suitable null hypothesis can be applied, when there is no impact of the atmospheric events on each of the hydrographic and climatic data series during the studied time scales. However, a null hypothesis for the linear trend coefficient test can be applied, when each of the R, S, SST, and AT fluctuate along with constant mean. The statistical tests for these coefficients have been achieved at a critical value of the significance level (P-value). Where a P-value $\leq$ 0.05 is an indication of statistical significance, a straight-line regression model can be used. If P-value > 0.05, it indicates a lack of statistical significance. Consequently, a straight-line regression model cannot be used.
Shatt Al-Arab discharge regime describes the mean monthly of discharge, influenced mainly by the Tigris and Euphrates rivers discharge as well as Karun river discharge which contribute about 50% of the total discharge (Al-Asadi, 2017), i.e. associated with climatic conditions. As well as the other reasons like land use and river regulation. Thus, the monthly Pardé coefficient (PC; the relation between monthly (MR_{dmonth}) and annual (MR_{dyear}) discharge should be used to describe the monthly distribution of discharge over the year (Bormann, 2010):

$$PC=MR_{dmonth}/MR_{dyear} \qquad (2.4)$$

3. RESULTS

3.1. The results in terms of the interannual datasets

The present statistical time series analysis shows a negative correlation between SOI and the discharge series (R=-0.255), see Figure 6. However, insignificant correlations showed with each of the NAO and DMI events. In this context, the linear regression model shows a negative slope as well, (i.e. Rd= 3.872-6.793 x SOI). The linear discharge trend shows a negative response over the studied period (T of discharge series=-2.0936 (m^3/sec)). Also, the analysis shows a negative correlation between NAO and S (i.e. R=-0.211), see Figure 7.
Then, the linear regression equation is constructed, (i.e. S=-1.636-4.313 x NAO), in which a negative regression slope is very clear. The best fit shows a small increase in salinity time series (T of salinity series=0.0071 (‰)). Where, it is proposed that the salinity is influenced by natural and anthropogenic sources in Shatt Al-Arab estuary. However, there is no influence for each of DMI and SOI on the salinity.
The analysis of SST shows similar previous results of salinity in terms of NAO influence (i.e. R=-0.253), see Figure 8.

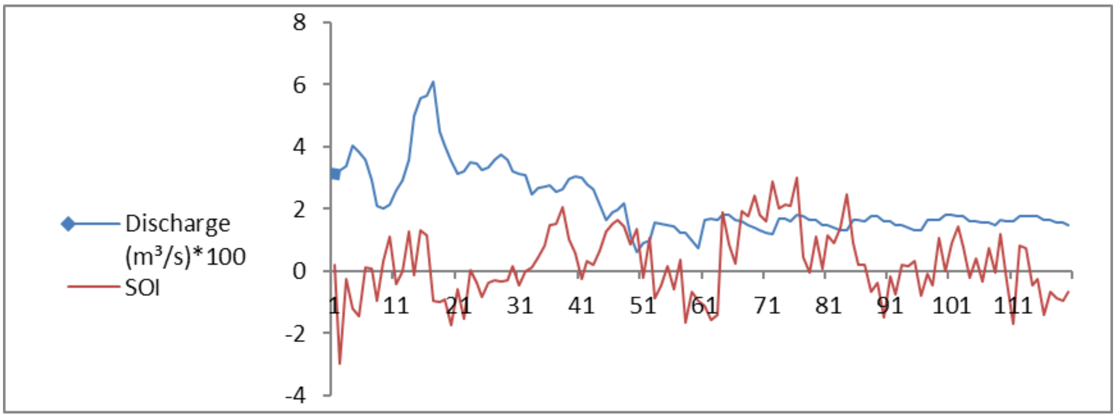

Figure 6. Negative correlation between SOI and the discharge series (R=-0.255) over the period (2005-2014).

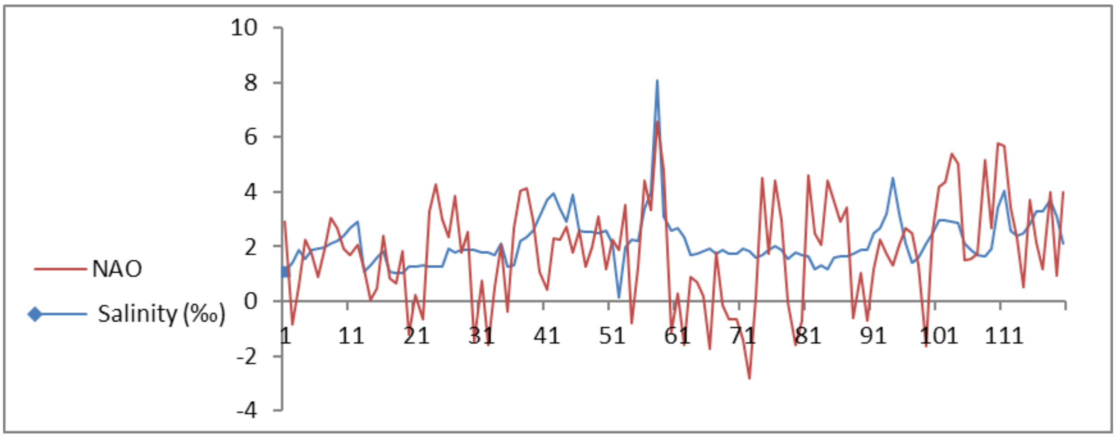

Figure 7. Negative correlation between NAO and the salinity series (R=-0.211) over the period (2005-2014).

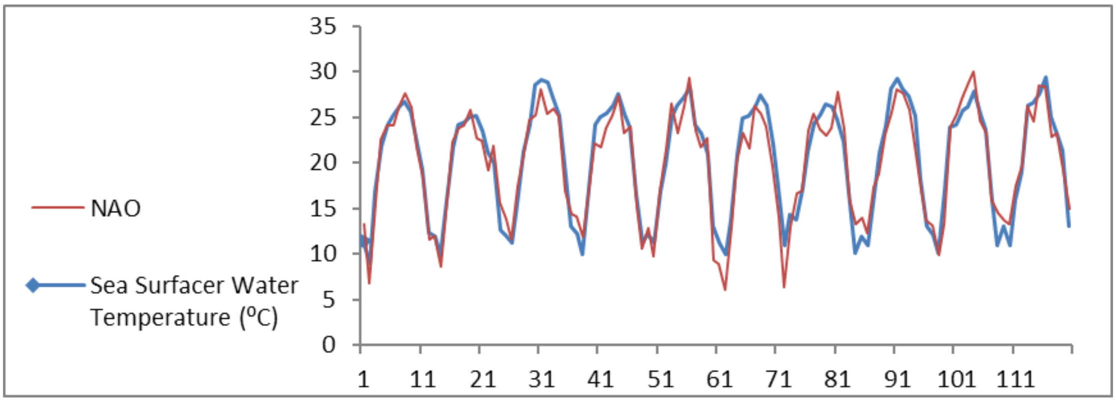

Figure 8. Negative correlation between NAO and the sea surface water temperature series (R=-0.253) over the period (2005-2014).

Where the linear regression equation is (SST = 1.542-4.218 x NAO). On the other hand, there is no influence for each of DMI and SOI on the SST. Results also show a small increase in the SST trend (T of sea surface water temperature series=0.0098(ºC)) could be related to global, regional and local reasons.
The influences of NAO, DMI, and SOI on the AT show significant correlations (i.e., R=-0.335, R=0.183, R=-0.212) respectively, see Figure 9.
These results present three regression equations (i.e., AT= -2.174-5.923 x NAO, AT= -6.682+26.411xDMI, AT= 1.155-5.025 x SOI) respectively. In this regard, the analysis of any air temperature trend indicates an increase in the AT during the same time interval (T of air temperature series = 0.0178 (ºC)).

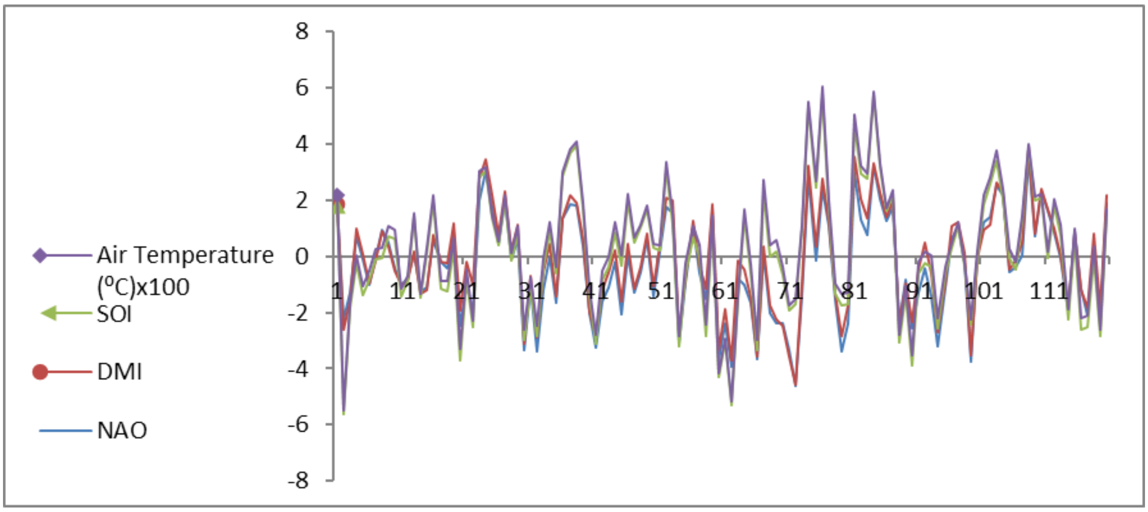

Figure 9. Negative correlation between NAO and SOI with the air temperature series (R=-0.335, R=-0.212), positive correlation between DMI with the air temperature series (R= 0.183) over the period (2005-2014).

3.2. The results in terms of the monthly datasets

A similar analysis has been carried out on the individual month's datasets at Shatt Al-Arab estuary station in the northern Gulf. Results confirm insignificant influences for NAO, DMI and SOI on each of the Rd, S, SST and AT in March, April, May, July, September, and October. In addition, there is no response for each of Rd, S, and AT on the NAO, DMI, and SOI in January and February months.
Insignificant correlations between NAO and DMI with SST have been showed in January. Similar results between NAO and SST showed in February. However, positive significant correlations between SOI and SST during January and February (i.e. R=0.7, R=0.65), what showing a positive regression slope (i.e. SST= -41.518+2.710 x SOI, SST= -47.352+2.515xSOI) respectively. A similar relation has been detected between DMI and SST during February (R=0.64, SST= 49.763+15.768 x DMI).
Moreover, there is no influence for each of the NAO, DMI, and SOI on Rd, S, and SST during June. Also, the results showed an insignificant influence on SOI on AT. However, the negative influence for NAO on the AT (i.e. R=-0.69) and a positive influence for DMI on AT (i.e. R=0.75) have been approved in this analysis. In this regards, regression equations constructed between NAO and DMI versus AT, which showed negative and positive slope respectively (i.e., AT= 22.011 - 6.307 x NAO, AT= 24.740 +

53.609 x DMI). In August, the results confirmed an insignificant relationship between each of NAO, DMI and SOI with Rd, AT and SST respectively. Likewise, an insignificant correlation proved between DMI and SOI with S. However, the results confirmed positive influence of NAO on the S (R=0.7). Thus, the regression equation has been constructed and a positive slope estimated (i.e., S = 16.509 + 11.409 x NAO).
Similarly, insignificant relation manifested between NAO, DMI, and SOI with Rd and S during November. In addition, an insignificant relation between NAO and DMI have detected with each of AT and SST. Furthermore, the conducted results confirmed a negative correlation between each of SOI and AT with SST (i.e., R=-0.79, R=-0.84) respectively, and hence, a negative regression slope was detected between AT and SOI (i.e., AT= -12.039 - 9.137 x SOI). A similar result was detected between SST versus SOI (i.e., SST= -5.945 - 9.272 X SOI).
In December, the analysis manifested an insignificant relation between NAO, DMI, and SOI with S and AT separately. At the same time, no relation demonstrated between DMI and SOI with Rd, as well as, between NAO and DMI with SST. Yet, positive significant correlation between NAO and Rd (i.e., R=0.71), whilst, a negative significant correlation between SOI and SST (i.e., R= -0.67) showed a positive and negative regression slope respectively in the regression models (i.e., Rd= -9.339 + 8.675 x NAO, SST= -39.539 - 2.713 x SOI).
Trend analysis has been carried out on Rd, S, AT and SST data series per each month (T1, T2, T3, …., T12) at the studied station. In general, the results confirmed decreasing in Rd trend per each month (T1 of discharge series = -22.44, T2 = -29.234, T3 = -34.432, T4 = -36.728, T5= -37.239, T6= -28.698, T7= -22.442, T8=-16.737, T9= -11.582, T10= -15.093, T11= -19.321, T12= -21.691 (m3/sec)) but this behavior was more pronounced in March, April and May (i.e. T3, T4 and T5 respectively). The salinity trends showed increase behavior for all months except the December trend (T1 of salinity series = 0.0594, T2 = 0.1018, T3 = 0.1207, T4 = 0.0705, T5 = 0.0729, T6 = 0.067, T7 = 0.1139, T8 = 0.1298, T9 = 0.0869, T10 = 0.1052, T11 = 0.0683, T12 = -0.0328 (‰)), in which December is a winter and cold month. Similarly, the air temperature trends demonstrate increase manner per each month except the last month (T1 of air temperature series = 0.12, T2 = 0.1788, T3 = 0.1776, T4 = 0.0321, T5 = 0.243, T6 = 0.3109, T7 = 0.2533, T8 = 0.2352, T9 = 0.2448, T10 = 0.3624, T11= 0.3006, T12 = -0.0255 (ºC)). The analysis showed negative SST trends in March, April, November, and December (T3 of sea surface water temperature series = -0.0218, T4 = -0.1152, T11= -0.1152, T12= -0.0588 (ºC)) respectively. However, the positive trends have been confirmed for the rest months in Shatt Al-Arab estuary (T1 of sea surface water temperature series = 0.1248, T2 = 0.1776, T5 = 0.0982, T6 = 0.1018, T7 = 0.1236, T8 = 0.2097, T9 = 0.0552, T10 = 0.1176 (ºC)).

3.3. The results in terms of the seasonal datasets

During winter, there is no influence of NAO, DMI, and SOI on the AT and SST. Likewise, insignificant influences of DMI and SOI on Rd as well as on S have been demonstrated. However, the analysis showed positive and negative significant influence for NAO on Rd and S (R= 0.374, R= -0.414) respectively. These results present the following regression equations (i.e., Rd= 5.809 + 5.383 x NAO, S= -9.592 - 6.237 x NAO). Next, the analysis of the spring season shows an insignificant response between NAO, DMI, and SOI with each one (S, AT as well as SST). Similarly, no responses between NAO and SOI with Rd were detected over the studied period but a negative significant effect was very clear for DMI on Rd (R= -0.385). These results showed a negative regression slope in the regression model (Rd= 19.368 - 60.180 x DMI). The statistical analysis of the summer season showed insignificant correlations between NAO, DMI, and SOI with each one (Rd and S). Also, there were no responses detected between NAO and SOI with each one (AT and SST). However, the positive significant effect was detected for DMI on AT and SST (i.e., R= 0.403, R= 0.411), and hence, the positive regression slope was manifested (i.e., AT= 27.606 + 24.352 x DMI, SST= 24.475 + 11.785 x DMI).

Similar analysis has been done on the autumn datasets, the results showed insignificant correlations between NAO, DMI and SOI with each one (S, AT and SST). Next, insignificance responses detected between NAO and DMI with Rd but a negative response was between SOI on Rd (R= -0.465). Thus, the last results lead to a negative regression slope in the regression model (i.e., Rd= 4.757 - 13.154 x SOI).

Trend calculations showed negative values for the discharge change associated with the contemporary bad situation of freshwater discharge for all seasons (T_{winter} of discharge series = -7.1279, T_{spring}= -10.884, T_{summer}= -9.9262, T_{autumn}= -4.8568 (m3/sec)). Hence, the salinity trends showed increase behavior over the studied period for all seasons (T_{winter} of salinity series = 0.0114, T_{spring}= 0.0318, T_{summer}= 0.0282, T_{autumn}= 0.038 (‰)), which is associated with the same reason mentioned above. The results of the AT trends showed negative values during winter (T_{winter} of air temperature series = -0.0124 (ºC)). However, positive trends for the other seasons (i.e., T_{spring} of air temperature series = 0.1003, Tsummer= 0.0482, T_{autumn}= 0.0566 (ºC)) were detected. Similarly, the trend results of the SST for all seasons showed the similar behavior of the AT trends (T_{winter} of sea surface water temperature series = -0.0062, T_{spring}= 0.0524, T_{summer}= 0.046, T_{autumn}= 0.0225 (ºC)), i.e. associated with weather and climate conditions in the context of climate change.

3.4. The results of the Pardé coefficient (PC)

Figure 10, shows the highest values were more pronounced during March, April, and May, i.e. spring season. The increases in Pardé coefficients and the decreases in the discharge trends are associated with Karun river discharge. All the detail evidences for the mentioned results will submit in the next section.

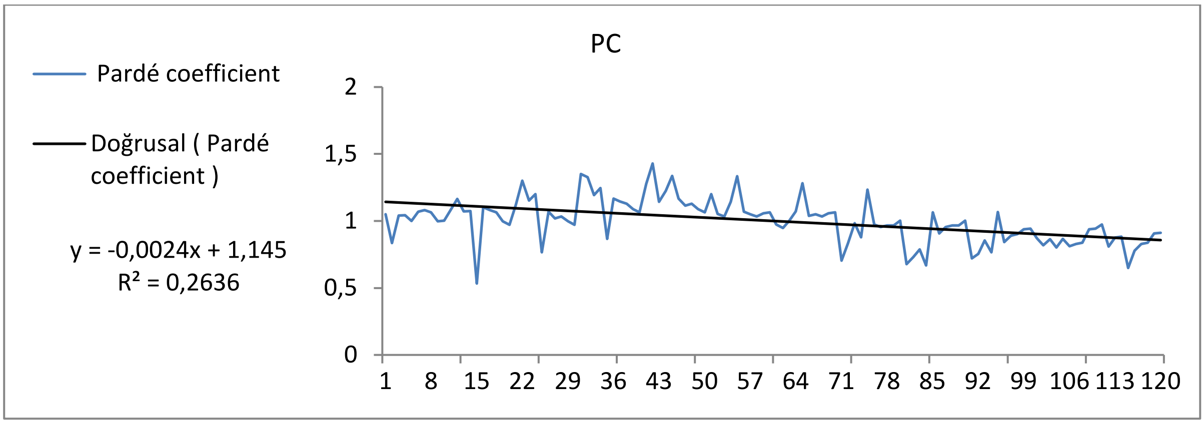

Figure 10. Change in Pardé coefficients describe the variability in discharge regime of Shatt Al-Arab estuary over the period (2005-2014).

4. DISCUSSION AND CONCLUSION

The decrease in the discharge of Shatt Al-Arab estuary (i.e. at study station) is calculated for the time (2005-2014). This station is about 120 km away from the Arabian\Persian Gulf and is proposed to be affected by global, regional, and local effects. Globally, the rainfall amounts in the drainage basin of Shatt Al-Arab what affect the discharge could be affected by the NAO, DMI, and SOI in the context of climate change (Cullen and deMenocal, 2000; Al-Senafi and Anis, 2015). Regionally, the negative trend could be related to the decrease in the Tigris and Euphrates discharges. That is consistent with the fact that the Shatt Al-Arab estuary faced a low freshwater as a result of the decrease in received water from its tributaries. Where it receives a freshwater from the Tigris river only (Al-Asadi, 2017). In this context, Turkey will regulate the flows of Tigris for many uses during the G.A.P. project. In addition, Syria has anticipated regulating the Euphrates flow by operation of three kinds of dams in the mainstream. Locally, Shatt Al -Arab discharge through its estuary is facing serious reductions in freshwater by human interventions as well as due to increased human use with increasing population. On the other hand, the increase in salinity concentration is clear in the conducted results. Generally, the salt concentration in Shatt Al-Arab water is affected by the number of factors, the most important are: the decrease in the discharge, the tide forcing, the evaporation rates, the average temperature, solar radiation, air moisture, and marine waters through the Arabian\Persian Gulf (Al-Muhyi, 2016), where these factors could be increased the salinity levels.

At present time, the trend in salinity along Shatt Al-Arab estuary could be related to the salinity intrusion from the downstream and anthropogenic sources, which could threat people and environment (Abdullah et al., 2016). However, the negative December trend may be related to the fact that the salinity can change from one day to the next depending on the above-mentioned factors. In addition, the majority of the rainfall in Iraq has happened in December (Abd-El-Mooty et al., 2016).

The global carbon dioxide has been increased in the atmosphere since 1950 (from 280 to 399.5 ppm). However, this value has not reached 300 ppm over 650,000 years. The reason behind this rise was the industries, which destroys the natural limit of the atmospheric components (Blasing, 2018). Thus, with other greenhouse gases, the global air temperature has increased by about 0.8ºC during the 20th century, whether the reason is human or natural. The air temperature in the northern Arabian\Persian Gulf showed increased by 0.8 °C during 1973–2012 (Al-Senafi and Anis, 2015). In accordance, the air temperature at the studied station showed a positive trend. However, the decrease in air temperature trends during December and winter season could be related to the climate status of Iraq which is short cold in winters, as well as, it is affected by the location of the country close to the sub-tropical wetness of the Arabian\Persian Gulf (Abd-El-Mooty et al., 2016) .

The conducted research proved that the sea surface temperature has increased. The SST trend is significantly affected by local anthropogenic activities as well as regional and global reasons. Where, the SST measurements showed a positive trend in Kuwait Bay (about 300 km from the studied station) over the period 1985-2002, what affected by the regional and global reasons (Al-Rashidi et al., 2009). On the other hand, the monthly SST trends could be related to an El Nin˜o, which is a significant global Oceanic-atmospheric event affecting the weather in the worldwide and working to reinforcement extreme climatic system, hence, it affects the sea surface water temperature in the Northern Arabian Gulf (Jones et al., 1997; Al-Rashidi et al., 2009). This study also submitted negative SST trends during spring, autumn months and winter season. That may be related to local reasons.

Global warming, i.e. caused by climate changes, is the main global driver affecting the discharge, salinity, air temperature, sea surface temperature, local reasons in Shatt Al-Arab estuary and regional reasons in Arabian\Persian Gulf and Shatt Al-Arab tributaries .

Local reasons could be related to the following points:

1. Gravitational circulation and mixing of seawater in Shatt Al-Arab estuary will affect the salinity, discharge as well as SST.
2. Weather condition may affect the SST, salinity, and discharge.
3. Human activities may impact the air temperature, SST, salinity, and discharge.

In addition to the similar points that above-mentioned, the regional reasons could be related to the following points:

1. The discharges of Euphrates and Tigris, as well as Karun rivers, may affect the discharge, salinity as well as SST.
2. The very large tidal range may affect the SST, salinity and discharge.

The increase in Pardé coefficients reflects the Karun influence during the spring season. The Karun River joins the eastern bank of Shatt Al-Arab about 72 km north of the Arabian\Persian Gulf. The mean annual discharge of Karun River is about 8.5 km3/year, and hence, the flow of Karun into Shatt Al-Arab depends mainly on spring snowmelt in the Iran Mountains which are affected by the change in the climate (Al-Asadi, 2017). Thus, the characteristic of the discharge regime (i.e the Pardé coefficients) was considerably affected by climate change .

Global warming is the main global driver affecting the NAO, DMI and SOI events in the context of climate changes, and hence, affecting the discharge, salinity, air temperature and sea surface temperature at Shatt Al-Arab estuary.

The first looking of this study is to establish and quantify the extent of each event and its impacts on each hydrographic and climatic parameter in Shatt Al-Arab station. The correlation results of NAO illustrate the negative responses may be related to the subtropic–subpolar NAO sea level pressure gradient. The more zonal tracks of the North Atlantic heat and moisture brought anomalously wetter conditions what reflects in the negative S/SST/AT (Cullen and deMenocal, 2000).

The positive correlation with salinity is related to summer rainfall in the Middle East under the influence of NAO. In addition, the positive correlation in winter month and season may reflect the winter rainfall percentage associated with the NAO event.

Many studies investigated the correlation between the climate of the Middle East and El Nin˜o (Cullen and deMenocal, 2000; Al Senafi and Anis, 2015). The negative influence of the SOI represents the impact on the summer monsoon. Thus, the effect of SOI on the regional precipitation and temperature is a result of its influence on the summer monsoon. The positive influence of the SOI on the SST during February and June reflects the variations in SST what related to SOI pattern. Thus, this result presents the possible influence of the far-field large-scale SOI event on the Middle Eastern climate, in which the positive phase of SOI starts to develop during the spring and summer producing warmer SST surface along the central Pacific Ocean. This shift causes disturbances to the Asian summer monsoon and hence the weather condition in the south of Iraq (Al Senafi and Anis, 2015).

Many studies investigated the correlation between the climate of the Middle East and the DMI event (Saji et al., 1999; Saji and Yamagata, 2003; Al Senafi and Anis, 2015). The positive influence of the DMI reflects the influence of the Indian Ocean on the Asian summer monsoon (Saji et al., 1999; Al Senafi and Anis, 2015). The influence of DMI during February and June is associated with the development of the DMI event during these months in the context of climate change. The seasonal variations in the DMI pattern had reflected in the Rd during spring. However, the positive seasonal pattern of the Indian Ocean Mode had reflected in SST/AT during summer .

The unusual temperature conditions during the DMI event affect the Indian summer monsoon and the weather condition in the south of Iraq .

An insignificant relation between NAO/SOI/DMI and each of Rd/S/AT/SST in the results could be related with the fact that the influence of each climate event has spatial and temporal variations on the Middle East climate (Cullen and deMenocal, 2000; Al-Senafi and Anis, 2015.)

In terms of the conclusions, the study region experienced general trends such as:

#Decrease in the discharge of 2.0936 (m^3/sec)

#Increase in salinity of 0.0071(‰)

#Increase in air temperature of 0.0178 (°C)

#Increase in sea surface temperature of 0.0098 (°C)

This general trend of discharge could be explained by the change in: (1) the main discharge of the tributaries in the context of climate change, (2) the climatic and anthropogenic conditions, (3) SOI in the context of climate change.

Next, the general trend of salinity could be explained by the change in: (1) the main discharge of the tributaries in the context of climate change throughout the change in: (1-1) precipitation amount in the drainage basin (1-2) Karun discharge (1-3) Dam construction near the source of the main tributaries, (2) mean sea-level change in the Arabian\Persian Gulf (3) sea surface temperature change in the Gulf, (4) El Nin˜o event which affect the SST/AT changes in the Gulf, (5) wind speed causing turbulence leads to break down the salinity stratification during the water column which caused a homogenous water column (6) the evaporation process in the Gulf (7) the tidal range at Shatt Al-Arab estuary mouth (8) industrial and agricultural activities (9) the NAO in the context of global warming .

While the Air temperature trend can be explained by the change in: (1) climate change, (2) NAO/DMI/SOI in the context of climate changes (3) the anthropogenic resources.

Finally, the sea surface temperature trend may be explained by the change in: (1) climate change, (2) the NAO in the context of climate change (3) the anthropogenic resources.

The variations in discharge, salinity, air temperature and sea surface temperature to the NAO, DMI, and SOI is confirmed by significant (p-value < 0.05) correlations.

Similar implications can be concluded in terms of monthly and seasonal timescales.

This study has shown that climate change affects the hydrographic and climatic characteristics of Shatt Al-Arab estuary.

ACKNOWLEDGEMENTS

The data were provided by the Marine Science Centre - University of Basrah. The Marine Physics Dept. is appreciatively thanked for their assistance.

5. REFERENCES

Al Senafi, F., Anis, A., (2015) Shamals and climate variability in the Northern Arabian/Persian Gulf from 1973 to 2012. *Int. J. Climatol*. 35: 4509–4528, DOI: 10.1002/joc.4302.

Attrill, M.J., (2009). Sea temperature change as an indicator of global change In: “Climate Change”, (T.M. Letcher ed.), Elsevier, Amsterdam pp. 337–347.

Jones, P.D., Jónsson, T., Wheeler, D., (1997). Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and South-West Iceland. *Int. J. Climatol.* 17: 1433-1450.

Jones, P.D. (2003). Global change: surface temperature trends. In: “Encyclopedia of Atmospheric Sciences”, (J.R. Holton ed.), Academic Press, pp. 898–910, Oxford, UK

Naidu, C., Satyanarayana, G., Durgalakshmi, K., Malleswara Rao, L., Jeevana Mounika, G., Raju, A.D., (2012). Changes in the frequencies of northeast monsoon rainy days in the global warming. *Glob. Planet Change* 92–93: 40–47.

Bormann, H., (2010). Runoff Regime Changes in German Rivers due to Climate Chang, *Erdkunde* 64(3): 257-279. DOI: 10.3112/erdkunde.2010.03.04.

Marine Science Center (MSC), (2016). Monthly data measurements. Technical Report (Iraq), Univ. of Basrah, pp. 77.

Climate Research Unit (CRU), (2018a). Jones's NAO Index Data, https://crudata.uea.ac.uk/cru/data/nao/nao.dat/2018, Accessed Date: 11 July 2018.

Saji, N.H., Yamagata, T., (2003). Possible impacts of Indian Ocean Dipole mode events on global climate, *Climate Research* 25: 151-169. https://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Data/dmi.long.data

Ropelewski, C.F., Jones, P.D., (1987). An extension of the Tahiti-Darwin Southern Oscillation Index. *Monthly Weather Review* 115: 2161-2165.

Climate Research Unit (CRU), (2018b). SOI Index Data, https://crudata.uea.ac.uk/cru/data/soi/soi.dat/, Accessed Date: 11 July 2018.

Emery, W.J., Thomson, R.E. (2001). *Data Analysis Methods in Physical Oceanography*, San Diego, USA, Elsevier.

Mahmood, A.B. (2016). The Interrelation Between the North Atlantic Oscillation (NAO) and Regulated River Discharge at the Baltic Sea Drainage Basin as well as Mean Sea Level at the Baltic Sea-North Sea Region, Ph.D. dissertation, University of Szczecin, Szczecin, Poland.

Al-Rashidi, T.B., El-Gamily, H.I., Amos, C.L., Rakha, K.A., (2009). Sea surface temperature trends in Kuwait Bay, *Arabian Gulf Nat Hazards* 50:73–82. DOI: 10.1007/s11069-008-9320-9 .

Abdullah, A.D., Gisen, J.I.A., van de Zaag, P., Savenije, H.H.G., Karim, U.F.A., Masih, I., Popescu, I., (2016). Predicting the saltwater intrusion in the Shatt al-Arab estuary using an analytical approach. *Hydrol. Earth Syst Sci* 20: 4031–4042. DOI:10.5194/hess-20-4031-2016.

Al-Asadi, S.A.R., (2017). The Future of Freshwater in Shatt Al- Arab River (Southern Iraq), *Journal of Geography and Geology* 9(2).

Cullen, H.M., deMenocal, P.B., (2000). North Atlantic Influence on Tigris- historical discharge (ad 622–1470) and climatic implications. *Geophysical Research Letters* 25(16): 3193–3196.

Al-Muhyi, A.H., (2016). The Study of Monthly, Quarterly, and Annual Water Salinity Changes for the river Shatt Al-Arab for the period 2005-2012. *Basra Studies Journal* 21: 39-54.

Abd-El-Mooty M., Kansoh, R., Abdulhadi, A., (2016). Challenges of Water Resources in Iraq. *Hydrol. Current Res* 7: 260. DOI:10.4172/21577587.100026.

Blasing, T.J., (2018). Recent greenhouse gas concentrations, http://cdiac.ornl.gov/pns/current_ghg.html/, Accessed Date: 3 August 2018.

Saji, N.H., Goswami, B.N., Vinayachandran, P.N., Yamagata, T., (1999). A dipole mode in the tropical Indian Ocean. *Nature* 401(6751): 360–363.