Tidal Datum Levels Realization based on observed Sea level data analysis in Port Said, Egypt

Prepared by

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المستخلص:

من الضرورى مراجعة وتحديث جميع البيانات والمعلومات الموجودة على الخرائط البحرية وذلك أمر حيوي للغاية للسلطات المسؤولة لاتخاذ القرار السليم، ويعتبر التحديث المستمر للعلاقة بين المستويين المرجعيين الأرضى والمائى ذو أهمية حيوية لعديد من المستخدمين فى الصناعات البحرية. تظهر أهميه تلك العلاقة عند التحدث عن الحركات الأرضية الرأسية والتغير فى مستوى سطح البحر.

الهدف من البحث الحالي هو حساب جميع المستويات المدارية المتعلقه بحركة المدروالجزر بميناء بورسعيد والمطل على الساحل المصرى لشرق البحر المتوسط. تم استخدام بيانات كل ساعية عن طريق جهاز يقيس مستوى سطح البحرمثبت بميناء بور فؤاد والذى يشترك مع ميناء بورسعيد في نفس الحوض المائي وبالتالي ستكون خصائص المستويات المدارية للمدر والجزر واحده. تم استخدام حزم من البرامج لتطبيق التحليل التوافقى البسيط للبيانات للحصول على خصائص المدر والجزر والتى توضح أن نوع المدر والجزرهو نصف يومى فى ميناء بورسعيد وميناء بورفؤاد. تم حساب المستويات المداريه للمدر والجزر بالنسبه للمستوى المدرى صفر حسب معايير هيئة المساحه المصرية، لتحقيق أحدث تعريف لكل من المد والجزر الفلكي الأعلى والأدنى المعتمد من قبل المنظمة الهيدروجرافية الدولية.

بعد التحاليل والحساب وجد أن المدى ما بين أعلى مدر فكلى واقل مدر فلكى هو 0.4 متر، كم أنه يجب إضافة 0.1 متر كهامش للأمان والذى تم تذكيته من قبل هيئة التجنيد والتدريب البحرى الانجليزية. بعد تطبيق التحاليل الاحصائية على البيانات وجد أنه أعلى مستوى للمياه طبقا للبيانات المرصوده وصل الى 19.012 مترا واقل مستوى هو 17.318 مترا، لتحقق مدى 1.81 مترا طبقا للمستوى المدرى صفر الذى وضع من قبل هيئة المساحة المصرية. كما وجد أن الفرق ما بين أقل مستوى مدرى من عام 1906 لعام 2015 هو 20 سم وذلك بعد تعريف تم نشره من قبل المنظمة الهيدروجرافية الدولية لاقل مستوى مدرى في عام 2011. كما يوصى البحث الحالى بتحديث

أعلى وأقل مستوى مدرى على الخرائط ليكونا 18.72 و 18.01 مترا على التوالى، وبالتالى تغير مدى المدر والجزر ليصل 0.5 مترا منسب للمتسوى المدرى صفرمن قبل هيئه المساحة المصرية.

Abstract:

A continuous revise and validation for all information on nautical charts is very vital for responsible authorities to take the right decision, especially the guidelines about tidal datum connection with the geodetic vertical datum. This data is needed to be updated continuously as a result of sea-level changes beside tectonic plates movements. The current paper's primary objective is to calculate the tidal levels in Port Said (PS) on Eastern Mediterranean Sea. Hourly sea-level dataset was collected inside Port Foad port, which enclosed with Port Said harbor in the same basin. Harmonic analysis was applied using TIDE tool of Delft-3D hydrodynamic mode. Tidal regime ratio was calculated using Form Factor (FF)equation, indicating 0.21 that expresses semidiurnal tidal domain in the area. Tidal datum levels were realized referred to the Egyptian Surveying Authority (ESA) zero datum, as provided by the Suez Canal Research Institute (SCRI). Furthermore, tidal levels were calculated using MATLAB, fulfilling the most recent definition for both lowest (LAT) and highest (HAT) Astronomical Tides accredited by the International Hydrographic Organization (IHO). Based on the results of analysis and calculations, ranges between highest and lowest same expressions (MHWS & MLWS, MHWN & MLWN, HHWL & LLWL, HAT & LAT) were equivalent to (0.368, 0.096, 0.4372, 0.496 m) respectively. According to the Naval Recruiting and Training Agency (NRTA) a safety margin of (± 10 cm) was added to all calculated levels. Moreover, from statistical analysis of observed sea level dataset, it was found that the highest observed water level is (19.128 m), while the lowest recorded water level is (17.318 m), which means a range of (1.81 m) with standard deviation (0.16 m), referred to the (ESA) Zero level. In a nutshell, there is a constant deference in LAT between 1906 - 2015 by 20 cm due to the new definition of LAT level by IHO in 2011, that increased the values. Additionally, HAT and LAT astronomical level values are recommended to be updated in all concerned nautical publications by 18.72 m and 18.01 m respectively, that means astronomical tidal level range equals (0.516 m) referred to the same datum (ESA) zero level.

Keywords: Port Foad; Tidal datum; Sea level analysis; Chart Datum

1- Introduction

Port Foad is a part of Port Said harbor enclosed in the same water basin as shown in Figure (1-1), which means same tidal pattern and characteristics. Port Said is Egypt's most important harbor located on the northern terminal of the largest international waterway (Suez Canal), and one of the major ports on the Egyptian Mediterranean coast. It is also the main port for Egyptian exports such as cotton and rice, as well as a fueling station for ships passing through the Suez Canal. Port Said is meant to attract logistics startups as well as import and export enterprises due to its excellent geographic location (Encyclopedia Britannica, 2017). It is also considered one of the controllable three harbors on Suez Canal, which is essentially made up of two single-lane waterways that converge at the Great Bitter Lake providing a transit place for ships travelling north and south. The Canal's new expansion, which started in July 2015 included a 72-kilometer stretch of work, now leads to continuous passage of more ships, more than doubling the previous channel's capacity (Biton, 2020).

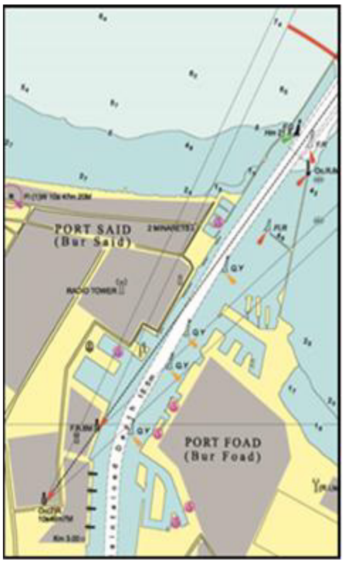

Figure (1): Port Said harbor illustrated on SC-1 Nautical Chart (INT Chart 7159, 2015)

The determination of tidal datum levels from sea level analysis is of importance for many scientific and socio-economic reasons beside nautical chart production. Long-term fluctuations in sea level are primarily influenced by global, regional and local influences. Furthermore, sea level changes (SLR) are mainly due to global climate change besides, local subsidence or uplift, in addition to, the processes of interaction between ocean and atmosphere which are the main reasons (Frihy, 2003).

A rise in sea level will necessitate future plans for coastal protection, as well as the possibility of seawater inundation in the future (Woodworth, 1990). According to the IPCC (2013), the global sea level is rising across all oceans, including the Mediterranean Sea area and over the last 100 years, the global sea level has risen by 10 to 25 cm. Furthermore, for vertical land motions, different averaging systems and/or adjustments have been established, resulting in estimates of absolute global MSL rise ranged from 1.0 to 2.4 mm/yr. (Douglas et al., 2001). In 2007, Alam El-din et al., concluded in their study from 3 years of sea level data analysis that; mean seasonal sea level cycle has an amplitude of 15.4 cm, and have had 0.5 cm standard errors, moreover, the results showed a positive MSL trend at Port Said of about 2.87 mm/y. Land- water movement is mainly described by how water levels alter and how much land moves vertically in both space and time (Kenny et al., 2011).

Concerning maritime industry, especially ships in marine navigation and chart production in hydrographic surveying, chart datum levels are very vital and crucial. Additionally, and according to the annual edition of Admiralty Tide Tables (commonly used by all mariners and published by the United Kingdom Hydrographic Office), all known tidal levels (LAT– HAT – MHWS – MLWS – MHWN – MLWN – MSL) were first determined in Egypt at EL-Suez city as a standard port in the area. In 2015, the Egyptian hydrographic department took over the responsibility of producing nautical charts along all the Egyptian waters, with a new International Chart Number (INT.) at the time of the new Suez Canal re- opening. The Egyptian Navy Hydrographic Department (ENHD) started its production by replacing the GB chart covering the canal by two new INT charts (INT7156, INT 7159), replacing the old Admiralty nautical chart (233). This former nautical chart has an old information of tidal levels as shown in Table (1) These tidal level values were calculated by (UKHO) along with the geodetic survey branch of India in 1906, using seven years of observed sea level data at the period from 1897 until 1904 referred to the LAT as the chart datum, which is the same as the zero of the tidal predictions in the area.(UKHONM, 2018).

Table (1): Old tidal datum levels calculated by the Admiralty Hydrographic Office, shown on former admiralty nautical chart No. (233) (UKHO NP203, 2018).

Tidal Levels referred to Datum of Soundings						
Place	Lat	Long	Heights in metres above datum			
	N	E	MHWS	MHWN	MLWN	MLWS
Port Said (Būr Sa'īd)	31°16'	32°19'	0·6	0·5	0·4	0·3
Suez (As Suways)	29 56	32 33	1·9	1·6	0·7	0·4

For the satisfactory of the newly produced charts, a revise and validation were made for all information on the chart, including tidal datum levels referred to Lowest Astronomical Tide (LAT). The present work aims at studying the sea-level variations for chart tidal datum levels calculations in Port Said harbor .

2. Data and Methods of Analysis

2.1. Data

Hourly sea level data set acquired from Tide Gauge (T.G) pressure sensor was utilized in this paper. T.G is fixed on the pier inside Port Foad (PF) harbor, at the northern tip of the Suez Canal, at the geographical position (31˚ 16′ N, 32 ˚ 19 ′ E) as shown in Figure (2-1). Data is comprised of 44026 records, with 301 missing data tips, which makes it 1846.96 days of data records. Height of tide gauge bench mark is (18.047 m) above ESA zero level as the geodetic datum used to realize sea level measurements in the area, and according to Suez Canal Research Institute (SCRI) documented report. The lowest observed water level at the location of T.G is (17.40 m) above ESA, acquired from historical data analysis of observed sea level, which was measured at the same location using marigraph tide gauge, at the time period from 1980 till 2010. Furthermore, sensor height was adjusted by SCRI to be lower than the lowest observed sea level in the area by fixed value only one meter. In 2010, the old marigraph tide gauge was replaced by a new pressure sensor T.G, for hourly sea level observations.

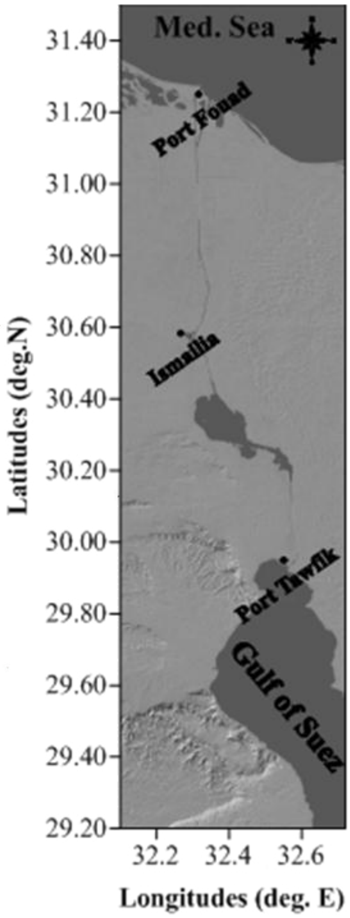

Figure (2): Location of the tide gauge utilized in this investigation in Port Said, Egypt.

2.2. Methods of Analysis

2.2.1. Data arranging

Certain fundamental operations were conducted to the sea level data set in this study. All of data was organized and double-checked for errors, anomalies, and spikes then removed from original raw data. Small gaps in the raw time series (one hour) were linearly interpolated, while for large gaps there was only one extended gap for 13 days, and it was converted into (NAN's) values as shown in Figure (2).

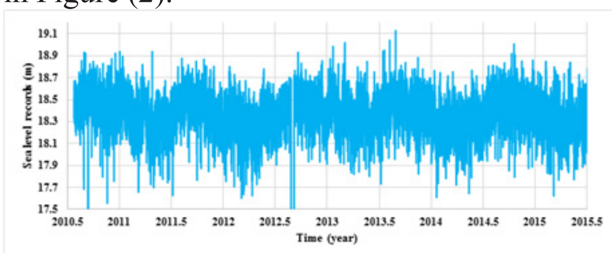

Figure (3): Original observed sea level records in meters, inside Port Foad harbor, (June 2010: July 2015)

2.2.2. Data Harmonic analysis

For tidal datum level calculations, separation between tidal and non-tidal signals was done. So, observed sea level data was subjected to harmonic analysis using the TIDE tool in Delft 3D-hydrodynamic model, which applies the following equation (1), (Pawlowicz et. al., 2002);

$$\eta(t) = \sum_n A_n \cos\left(\frac{2\pi}{T_n} t + \varphi n\right) (1)$$

Where η(t) is the vertical displacement of the sea surface as a function of time (m), A_n is the amplitude of harmonic component (m), T_n is the period of harmonic component (s) and φ_n is the phase of the harmonic component .

2.2.3. Tidal datum calculations

In the present work, the most known vertical tidal datum levels used on nautical charts such as; HAT, LAT, MHWS, MLWS, MHWN, MLWN, HHWL and LLWL, were obtained after harmonic analysis of observed sea level data, then were revised and updated referred to the ESA geodetic vertical datum in (PF) harbor, according to the SCRI report in 2015. Datum levels were calculated based on the amplitude values of the four majors' constituents (M2, S2, K1, O1) acquired from harmonic analysis and based on the following theoretical formulas (Doodson, 1957).

Mean High Water Spring (MHWS) = MSL+ (M2 + S2) (1)
Mean Low Water Spring (MLWS) = MSL- (M2 + S2) (2)
Mean High Water Neaps (MHWN) = MSL + (M2 - S2) (3)
Mean low Water Neaps (MLWN) = MSL - (M2 - S2) (4)
Highest High-Water Level (HHWL) = MSL + (M2+ S2+ K1+ O1) (5)
Lowest Low Water Level (LLWL) = MSL - (M2+ S2+ K1+ O1) (6)
Lowest Astronomical Tide (LAT) = P.F Tide gauge zero level (TGZL) + MSL – Absolute Minimum Tidal level – Absolute Average residuals (7)
Highest Astronomical Tide (HAT) = P.F Tide gauge zero level (TGZL) + MSL + Absolute Minimum Tidal level + Absolute Average residuals (8)

Where MSL is the mean sea level, O1 is the primary lunar diurnal constituent's tidal height, K1 is the luni-solar diurnal constituent's tidal height, M2 is the primary lunar semidiurnal constituent tidal height, and S2 is the major solar semidiurnal constituent's tidal height. According to NRTA a value of + 10 cm will be added as a safety margin.

2.2.4. Statistical analysis

A quantitative measure has been made to describe original data signal individually A descriptive statistics for annually sea level records were calculated using a MATLAB function, for calculating the means, standard deviation, sample variance, minimum and maximum expressed in meters.

3. Results

3.1. Hourly Recorded Sea Level:

The mean value of the hourly observed sea level data set (18.37 m), this value was subtracted (mean removal) from observed data at Port Foad harbor, in the time period from June 2010 to July 2015, as shown in Figure (4). Hourly sea-level records ranged from 17.55 m on June 2010, to 18.316 m on July, 2015., indicating a maximum range of 1.687 m between recorded minimum and maximum values during this period.

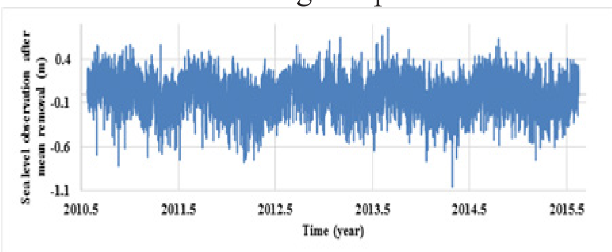

Figure (4): Time series of recorded sea level data set after the mean removal value (18.37).

3.2. Harmonic analysis:

From harmonic analysis, the tide program algorithm identified amplitudes of 69 tidal components, with only 38 significant constituents labelled with ("*"). Amplitudes of significant constituents changed between 0.35 m to -0.37 m referring to range of a tidal range of 0.72 m. Moreover, based on the outputs of the tidal ratio from form factor (0.21), which reflects semi diurnal tidal domain. According to the amplitude values of the major principal diurnal and semi diurnal constituents' tidal datum values were calculated. The three figures below represent the time series of observed sea level components; sea level (Blue), tidal signal (green), and residual signal (red).

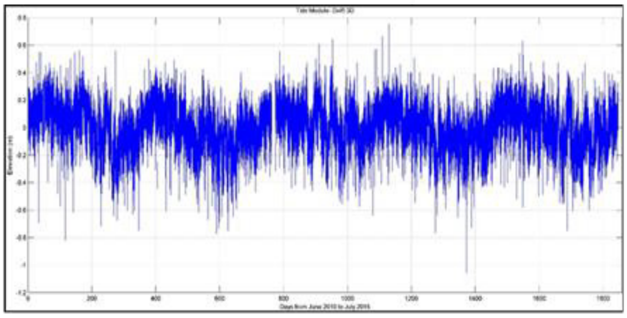

Figure (5): Sea level time series resultant from harmonic analysis by Delft 3D- tide tool.

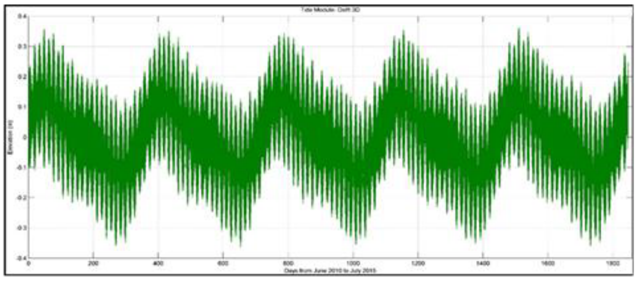

Figure (6): Tidal signal resultant from harmonic analysis by Delft 3D- tide tool.

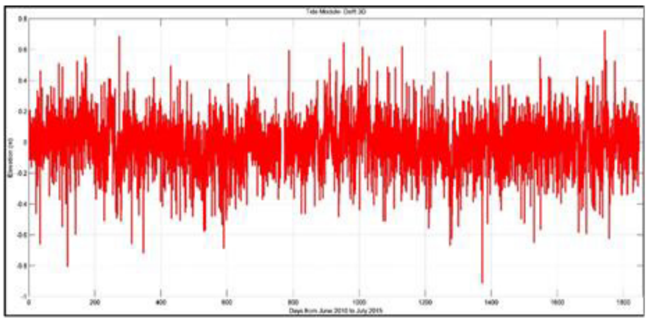

Figure (7): Residual signal resultant from harmonic analysis by Delft 3D- tide tool.

From harmonic analysis tidal constituents' frequencies, amplitudes, and phase angles are represented in Table (2) below.

Table (2): Tidal constituents' frequencies, amplitudes, and phase angles resulted from harmonic analysis.

Frequency (cycle/hr.)	tide	A (m)	Φ (°)	Frequency (cycle/hr.)	tide	A (m)	Φ (°)	Frequency (cycle/hr.)	tide	A (m)	Φ (°)
0.00011	*SA	0.1042	240	0.04329	*J1	0.0017	299	0.11924	*MO3	0.0009	191
0.00023	*SSA	0.0351	244	0.0446	SO1	0.0004	351	0.12077	*M3	0.0034	71
0.00131	MSM	0.0088	247	0.04483	OO1	0.0003	274	0.12206	*SO3	0.0008	171
0.00151	*MM	0.0137	223	0.04634	UPS	0.0006	142	0.12229	*MK3	0.0009	106
0.00282	MSF	0.0061	259	0.07597	*OQ2	0.001	130	0.12511	*SK3	0.0014	358
0.00305	MF	0.0053	78	0.07618	*EPS	0.0012	297	0.15951	MN4	0.0003	21
0.0344	ALP	0.0002	277	0.07749	*2N2	0.0025	312	0.16102	*M4	0.0012	63
0.03571	2Q1	0.0003	199	0.07769	*MU2	0.0031	318	0.16233	SN4	0.0007	43
0.03591	SIG	0.0004	270	0.079	*N2	0.0185	300	0.16384	*MS4	0.0015	115
0.03722	*Q1	0.0019	259	0.0792	*NU2	0.0037	296	0.16407	MK4	0.0003	338
0.03742	RHO	0.0006	300	0.08031	GAM	0.0003	325	0.16667	S4	0.0001	248
0.03873	*O1	0.0166	271	0.0804	H1	0.0003	293	0.16689	SK4	0.0007	154
0.03896	TAU	0.0006	318	0.08051	*M2	0.1124	296	0.2028	2MK	0.0006	200
0.04004	BET	0.0005	15	0.08063	*H2	0.0012	293	0.20845	2SK	0.0002	4
0.04027	*NO1	0.0026	284	0.08074	MKS	0.0005	50	0.24002	*2MN	0.0017	53
0.04047	CHI	0.0004	17	0.08182	*LDA	0.0015	330	0.24153	*M6	0.0018	98
0.04144	*PI1	0.0018	246	0.08202	*L2	0.0037	300	0.24436	*2MS	0.0033	149
0.04155	*P1	0.0071	306	0.08322	*T2	0.0041	324	0.24458	2MK	0.0008	154
0.04167	*S1	0.0139	302	0.08333	*S2	0.0686	309	0.24718	*2SM	0.0019	215
0.04178	*K1	0.0215	299	0.08345	R2	0.0006	87	0.24741	MSK	0.0001	23
0.04189	*PSI	0.0009	164	0.08356	*K2	0.0187	331	0.28331	3MK	0.0004	195
0.04201	PHI	0.0006	18	0.08485	*MSN	0.0008	241	0.32205	M8	0.0005	15
0.04309	THE	0.0006	290	0.08507	*ETA	0.0017	319	0.40256	M10	0.0007	206

It seems from the table, that M2, SA and S2 dominated the constituents in amplitude by 11.2 cm, 10 cm and 6 cm respectively, which reflects semi-diurnal regime besides, the dominance of seasonal changes in the area.

3.3. Tidal datum levels calculations

As mentioned earlier that datum levels were calculated based on the amplitude values of the four major harmonic constituents (M2, S2, K1, O1) acquired from harmonic analysis. In addition to the ellipsoidal height of the mean sea level value as calculated from original observed sea level dataset referred to ESA geodetic datum, as shown in Table (3).

Table (3): Tidal datum levels referred to the ESA- zero level.

Tidal Datum	Port Foad	NRTA (±10)
Highest High-Water Level (HHWL; m)	18.59	18.69
Lowest Low Water Level (LLWL; m)	18.16	18.06
Highest water range (m)	0.437	0.637
Mean High Water Spring (MHWS; m)	18.55	18.65
Mean Low Water Spring (MLWS; m)	18.19	18.09
Mean Spring Range (m)	0.36	0.56
Mean High Water Neap (MHWN; m)	18.41	18.51
Mean Low Water Neap (MLWN; m)	18.33	18.23
Mean Neap Range (m)	0.09	19.29
Lowest astronomical tide (LAT; m)	18.12	18.02
Highest astronomical tide (HAT; m)	18.62	18.72
Astronomical tide range (m)	0.50	0.7

According to the Naval Recruiting and Training Agency, + 10 cm value was added algebraically as a safety margin to all tidal datum levels in the table above. For the purpose of correcting and updating the tidal datum levels information shown on the new Suez Canal charts (INT charts, 7156,7159) datum levels were calculated referred to the LAT as shown in Table (4).

Table (4): New updated tidal datum levels calculated from observed sea level data analysis in the period from 2010 to 2015 referred to the LAT.

Places	MHWS	MHWN	MSL	MLWN	MLWS
Port Foad (2015)	0.4	0.3	0.25	0.2	0.1
Old datum values (1906)	0.6	0.5	-	0.4	0.3

From Table (4), it is clear that tidal datum levels differed from old values by almost a constant value 0.2 m, indicating a difference between the datasets referred to the reference level (LAT), can be justified either by methods of analysis and definition of LAT used in 1906 or a constant change in the reference level by 20 cm during the period (109 year). In a nutshell, there is a constant deference in LAT by 20 cm due to the new definition of LAT level by IHO in 2011, that increased the values.

3.4. Statistical analysis

A descriptive statistical analysis was applied for the annually records, to clarify difference in sea level change each year.

Table (5): Descriptive statistics of the sea level records during (June 2010 to July 2015) for each year.

Month	Mean (m)	Standard Deviation	Sample Variance	Range (m)	Minimum (m)	Maximum (m)
June -2010	18.47965	0.127398	0.01623	1.383	17.555	18.938
2011	18.35237	0.167242	0.02797	1.309	17.626	18.935
2012	18.37006	0.164074	0.02692	1.381	17.603	18.984
2013	18.383	0.156627	0.024532	1.519	17.609	19.128
2014	18.36653	0.158832	0.025227	1.687	17.318	19.005
July- 2015	18.31674	0.163687	0.026794	1.224	17.623	18.847

It is clear that the maximum water level during the period of investigation was in 2013, while the lowest water level was during 2010. The maximum mean sea level was during 2015, and the maximum and minimum water level range were during 2014 and 2015 respectively.

4. Discussion and Conclusions:

Based on the comprehensive analysis of vertical datum levels, it was concluded that؛

Tidal vertical datum level calculated from observed sea level data analysis, in Port Foad harbor are as follow; the lowest LAT and the highest HAT values for chart datum and chart heights are (18.12 m) and (18.62 m) respectively, referred to the ESA. Meanwhile, the other tidal datum levels are 0.43, 0.3, 0.2 and 0.065 as the suggested MHWS, MHWN, MLWN and MLWS respectively. A safety margin value (± 10 cm) should be considered and added to all calculated final vertical datum levels according to (NRTA, 2004). In a nutshell, there is a constant deference in LAT between 1906 - 2015 by 20 cm due to the new definition of LAT level by IHO in 2011, that increased the values. Additionally, HAT and LAT astronomical level values are recommended to be updated in all concerned nautical publications by 18.72 m and 18.01 m respectively, that means astronomical tidal level range equals (0.516 m) referred to the same datum (ESA) zero level.

5. Recommendation :

1-A continuous update is needed for tidal vertical datum realizations referred to the latest international terrestrial reference frame. ITRF or any other new geodetic datum. Additional studies are required for accurate determination and realization of tidal datum levels for at least 18.6 years to account for tidal nodal cycle.

2- An accurate geodetic bench mark is required in the area, to account for subsidence and uplift of land and consequently the absolute sea level. Finally, an offshore observing sensor is required to collect data outside the harbor for future modeling requirements.

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