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Tide Prediction for the Persian Gulf Coasts based on Harmonic Analysis

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Abstract- This study employs two subprograms of the IOS package, including tidal height analysis and tidal height prediction, to predict tidal levels in multiple stations at the coastal area of the Persian Gulf for which the measured data on water levels are available. At first, the data measured in the stations under concern underwent harmonic analyses using the tidal height analysis subprogram of the IOS package. The analyses were performed in different phases for annual, semiyearly, trimonthly, and monthly periods. Next, working with the height prediction subprogram in the IOS package, the tidal levels in the stations were predicted separately for years wherein the measured data were accessible based on the results of various analyzes conducted in the previous phase (i.e., annual, semiyearly, trimonthly, and monthly periods). The investigations affirmed the performance of the method and its subprograms. Furthermore, the accuracy of forecasting made based on the annual harmonic analysis results was much higher than analyses conducted for other periods.

Keywords- Tidal components, Amplitude, Phase, IOS software package.

Introduction

The tidal changes are controlled by the constant earth's rotation around itself (rotation), the moon's rotation around the earth, the moon's rotation around the sun, and the earth's rotation around the sun (revolution). Each factor holds its unique frequency and their combination influences the tidal behavior. Obliquity (change in the axial tilt in relation to the rotation) and the different "plane of the moon's rotation around the earth" further influence tidal behavior characteristics. The water level at a given point could also be influenced by other factors such as atmospheric conditions and the features of the oceans. Sörensen et al. (2006) reported a sensitivity analysis of three well-established Kalman filter approaches for use in water level simulation in a 3D hydrodynamic modeling system. Their study accentuated the efficacy of the Kalman filter when working with these types of systems (Consoli et al, 2014). Based on the field data restrictions, the artificial neural network (ANN) can appropriately calculate the tidal level on an hourly, daily, weekly, or monthly basis.

Deo and Chaudhari (1998) used the neural network model to simulate the tidal curves of a subordinate station based on the data of a standard or reference tidal station. ANNs were first applied to tide forecasting by using the field data of both diurnal (daily) and semi-diurnal (semi-daily) tides by Tsai and Lee (1998). However, their model was only applicable to the prediction of diurnal and semi-diurnal tides. Indeed, mixed tides are more probable to happen in the field than diurnal and semi-diurnal tides (Lee et al., 1998). Lee et al. (2002) and Lee (2004) applied a neural network to predict different types of tides and found that this technique can be efficacious even if the effect of non-astronomical components is important (Consoli et al., 2014). Cox et al. (2002) and Lee (2006) developed an advanced ANN model for tide forecasting using a short-term tidal record and considering all diurnal, semi-diurnal, and mixed tides in their model. The data from three harbors in Taiwan were used as case studies, and the effects of the neural network structure, including training techniques and learning algorithms, were discussed in detail (Consoli et al., 2014).

The tidal changes have long been observed by the residents of coastal areas as a factor that alters the coastline. The residents of these areas have employed such tidal changes in various ways for economic development, such as promoting fishing efficacy, speeding up the moving away from the coast to launch a sea trip, and/or returning to the coast. Concerning the tidal effects on the coastal economy and activities, tidal studies have a history of 4000 years ago (Lefebvre and Stewart, 1996).

By measuring the water level changes in a certain place for a given period, it would be possible to forecast the tidal changes in the same place for other periods using computational methods. This is achieved using various methods, including harmonic and non-harmonic methods and ANNs.

Methods

The steps to this study include data collection and preparation, harmonic analyses on the prepared data, extraction of different tidal components, forecasting of tidal levels using the results of the harmonic analyses, and investigation of the forecasting results.

The main tool in this study is a program for the harmonic analysis and forecasting of tidal levels developed by Foreman et al. (1977), which is known as the Institute of Ocean Science (IOS) software package.

Presently, the tidal data to 6 permanent stations of BANDAR-E EMAM HASAN, BANDAR-E BOSHEHR, KANGAN, BANDAR-E SHAHID RAJAEE, JASK, and CHABAHAR are available in the Ocean Data Center of the Iranian National Institute of Oceanography and Atmospheric Sciences (Table 1).

Table 1. Position of the studied tidal stations

Station	Longitude		Latitude	
	Min	Degree	Min	Degree
BANDAR-E EMAM HASAN	15	50	50	29
BANDAR-E BOSHEHR	50	50	59	28
KANGAN	3	52	50	27
BANDAR-E SHAHID RAJAEE	4	56	6	27
JASK	46	57	39	25
CHABAHAR	37	60	17	25

Table 2. Data on the main harmonic components extracted from tidal tables of the National Cartography Center of Iran (NCC)

ITEM	Places	LAT	LONG	HARMONIC CONSTANT								Z0=MSL
		(N)	(E)	M2		S2		K1		O1		
				g	H.m	g	H.m	g	H.m	g	H.m	
1	BANDAR-E EMAM HASAN	29 50	50 15	278.6	0.40	328.6	0.16	289.9	0.40	244.3	0.23	1.31
2	BANDAR-E BOSHEHR	28 59	50 50	229.6	0.38	293.6	0.15	288.7	0.33	238.9	0.23	1.21
3	KANGAN	27 50	52 03	131.3	0.54	175.9	0.19	179.6	0.24	151.3	0.14	1.23
4	BANDAR-E SHAHID RAJAEE	27 06	56 04	306.2	1.05	341.3	0.41	70.8	0.38	59.33	0.26	2.32
5	JASK	25 39	57 46	257.6	0.66	290.6	0.27	32.8	0.40	30.6	0.20	1.68
6	CHABAHAR	25 17	60 37	267.3	0.62	299.6	0.24	34.5	0.40	35.8	0.20	1.61

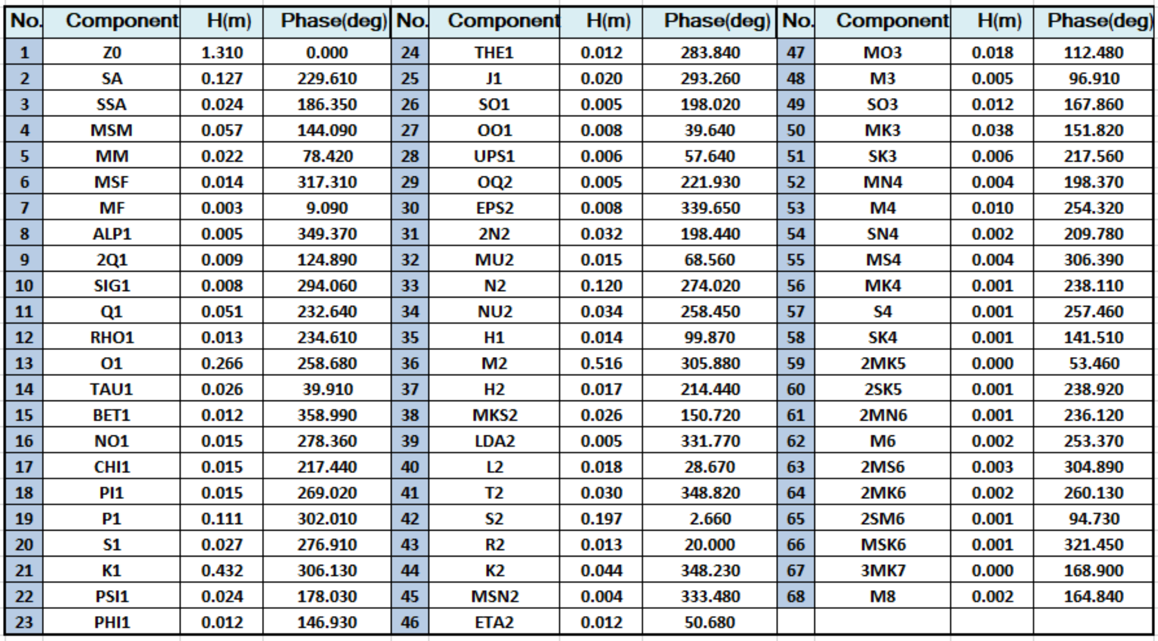
Findings

1. BANDAR-E EMAM HASAN

Data filtering

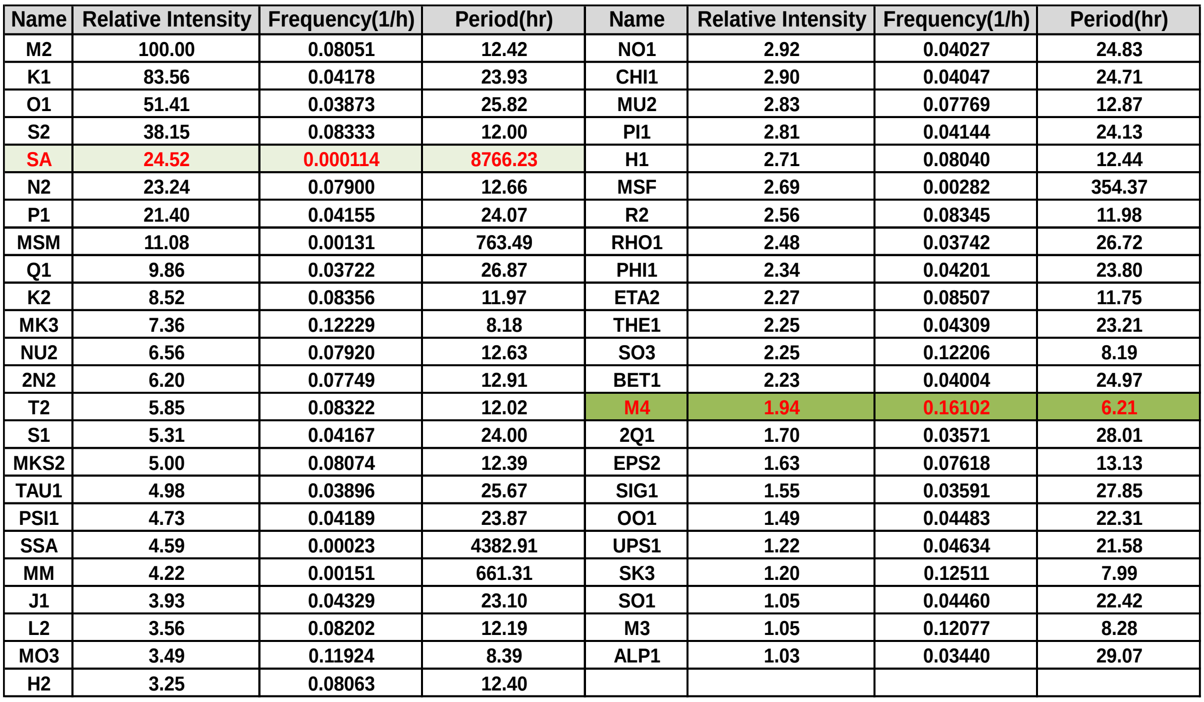
After the investigation and quality control of the recorded data on tidal fluctuations at the BANDAR-E EMAM HASN station, the data from 1992 was chosen for harmonic analysis. Table 3 summarizes the results of this harmonic analysis that has allowed the extraction of 68 components. Of all these extracted components, the components whose amplitude is more than 1% compared to the amplitude of the M2 component are separated and the results are given in Table 4. As shown in this table, the maximum and minimum frequency of these components are 0.16102 (for the M4 component with a period of 6.21 hours) and 0.00011 (for the SA component with a period of 8766.23 hours), respectively.

Table 3. The results of the harmonic analysis of annual data on the tidal fluctuations at the BANDAR-E EMAM HASAN station



No.	Component	H(m)	Phase(deg)	No.	Component	H(m)	Phase(deg)	No.	Component	H(m)	Phase(deg)
1	Z0	1.310	0.000	24	THE1	0.012	283.840	47	MO3	0.018	112.480
2	SA	0.127	229.610	25	J1	0.020	293.260	48	M3	0.005	96.910
3	SSA	0.024	186.350	26	SO1	0.005	198.020	49	SO3	0.012	167.860
4	MSM	0.057	144.090	27	OO1	0.008	39.640	50	MK3	0.038	151.820
5	MM	0.022	78.420	28	UPS1	0.006	57.640	51	SK3	0.006	217.560
6	MSF	0.014	317.310	29	OQ2	0.005	221.930	52	MN4	0.004	198.370
7	MF	0.003	9.090	30	EPS2	0.008	339.650	53	M4	0.010	254.320
8	ALP1	0.005	349.370	31	2N2	0.032	198.440	54	SN4	0.002	209.780
9	2Q1	0.009	124.890	32	MU2	0.015	68.560	55	MS4	0.004	306.390
10	SIG1	0.008	294.060	33	N2	0.120	274.020	56	MK4	0.001	238.110
11	Q1	0.051	232.640	34	NU2	0.034	258.450	57	S4	0.001	257.460
12	RHO1	0.013	234.610	35	H1	0.014	99.870	58	SK4	0.001	141.510
13	O1	0.266	258.680	36	M2	0.516	305.880	59	2MK5	0.000	53.460
14	TAU1	0.026	39.910	37	H2	0.017	214.440	60	2SK5	0.001	238.920
15	BET1	0.012	358.990	38	MKS2	0.026	150.720	61	2MN6	0.001	236.120
16	NO1	0.015	278.360	39	LDA2	0.005	331.770	62	M6	0.002	253.370
17	CHI1	0.015	217.440	40	L2	0.018	28.670	63	2MS6	0.003	304.890
18	PI1	0.015	269.020	41	T2	0.030	348.820	64	2MK6	0.002	260.130
19	P1	0.111	302.010	42	S2	0.197	2.660	65	2SM6	0.001	94.730
20	S1	0.027	276.910	43	R2	0.013	20.000	66	MSK6	0.001	321.450
21	K1	0.432	306.130	44	K2	0.044	348.230	67	3MK7	0.000	168.900
22	PSI1	0.024	178.030	45	MSN2	0.004	333.480	68	M8	0.002	164.840
23	PHI1	0.012	146.930	46	ETA2	0.012	50.680				

Table 4. Tidal components with a power of over 1% compared to the main component (M2) at the BANDAR-E EMAM HASAN station



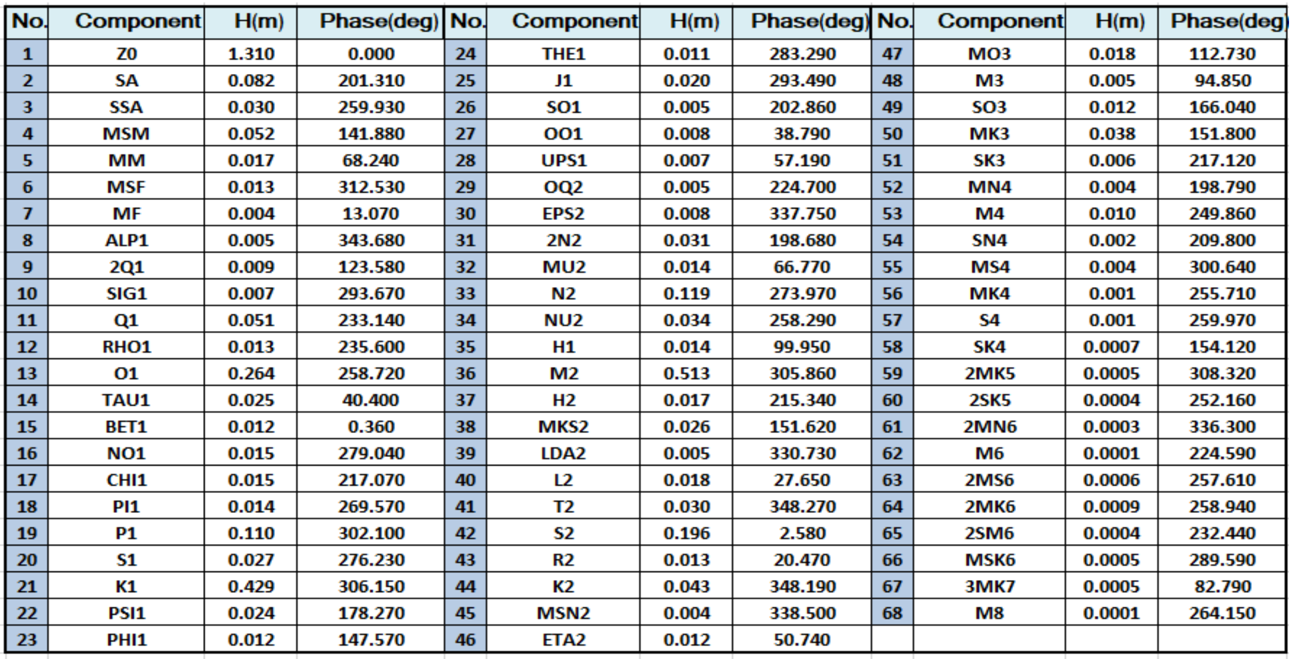
Name	Relative Intensity	Frequency(1/h)	Period(hr)	Name	Relative Intensity	Frequency(1/h)	Period(hr)
M2	100.00	0.08051	12.42	NO1	2.92	0.04027	24.83
K1	83.56	0.04178	23.93	CHI1	2.90	0.04047	24.71
O1	51.41	0.03873	25.82	MU2	2.83	0.07769	12.87
S2	38.15	0.08333	12.00	PI1	2.81	0.04144	24.13
SA	24.52	0.000114	8766.23	H1	2.71	0.08040	12.44
N2	23.24	0.07900	12.66	MSF	2.69	0.00282	354.37
P1	21.40	0.04155	24.07	R2	2.56	0.08345	11.98
MSM	11.08	0.00131	763.49	RHO1	2.48	0.03742	26.72
Q1	9.86	0.03722	26.87	PHI1	2.34	0.04201	23.80
K2	8.52	0.08356	11.97	ETA2	2.27	0.08507	11.75
MK3	7.36	0.12229	8.18	THE1	2.25	0.04309	23.21
NU2	6.56	0.07920	12.63	SO3	2.25	0.12206	8.19
2N2	6.20	0.07749	12.91	BET1	2.23	0.04004	24.97
T2	5.85	0.08322	12.02	M4	1.94	0.16102	6.21
S1	5.31	0.04167	24.00	2Q1	1.70	0.03571	28.01
MKS2	5.00	0.08074	12.39	EPS2	1.63	0.07618	13.13
TAU1	4.98	0.03896	25.67	SIG1	1.55	0.03591	27.85
PSI1	4.73	0.04189	23.87	OO1	1.49	0.04483	22.31
SSA	4.59	0.00023	4382.91	UPS1	1.22	0.04634	21.58
MM	4.22	0.00151	661.31	SK3	1.20	0.12511	7.99
J1	3.93	0.04329	23.10	SO1	1.05	0.04460	22.42
L2	3.56	0.08202	12.19	M3	1.05	0.12077	8.28
MO3	3.49	0.11924	8.39	ALP1	1.03	0.03440	29.07
H2	3.25	0.08063	12.40				

Therefore, using a program in MATLAB, these data are first filtered by a high-pass and low-pass filter corresponding to the identified minimum and maximum frequencies and then prepared for use in the next steps.

Harmonic analysis of filtered data

The harmonic analysis of all this year's data, including 7569 hourly data and 1215 gaps (13.8% of the entire year), allowed for extracting 68 tidal components, whose amplitude and phase values are given in Table 5, where the highest amplitude value is related to the tidal component M2 and is equal to 0.513 meters.

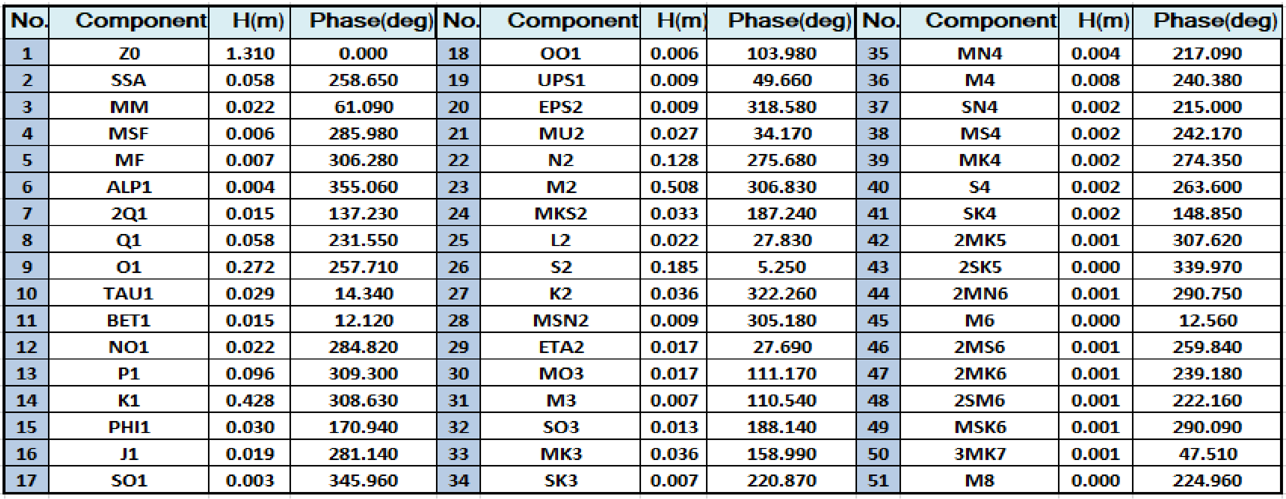
Table 5. The results of the harmonic analysis of annual and filtered data on tidal fluctuations at the BANDAR-E EMAM HASAN station



No.	Component	H(m)	Phase(deg)	No.	Component	H(m)	Phase(deg)	No.	Component	H(m)	Phase(deg)
1	Z0	1.310	0.000	24	THE1	0.011	283.290	47	MO3	0.018	112.730
2	SA	0.082	201.310	25	J1	0.020	293.490	48	M3	0.005	94.850
3	SSA	0.030	259.930	26	SO1	0.005	202.860	49	SO3	0.012	166.040
4	MSM	0.052	141.880	27	OO1	0.008	38.790	50	MK3	0.038	151.800
5	MM	0.017	68.240	28	UPS1	0.007	57.190	51	SK3	0.006	217.120
6	MSF	0.013	312.530	29	OQ2	0.005	224.700	52	MN4	0.004	198.790
7	MF	0.004	13.070	30	EPS2	0.008	337.750	53	M4	0.010	249.860
8	ALP1	0.005	343.680	31	2N2	0.031	198.680	54	SN4	0.002	209.800
9	2Q1	0.009	123.580	32	MU2	0.014	66.770	55	MS4	0.004	300.640
10	SIG1	0.007	293.670	33	N2	0.119	273.970	56	MK4	0.001	255.710
11	Q1	0.051	233.140	34	NU2	0.034	258.290	57	S4	0.001	259.970
12	RHO1	0.013	235.600	35	H1	0.014	99.950	58	SK4	0.0007	154.120
13	O1	0.264	258.720	36	M2	0.513	305.860	59	2MK5	0.0005	308.320
14	TAU1	0.025	40.400	37	H2	0.017	215.340	60	2SK5	0.0004	252.160
15	BET1	0.012	0.360	38	MKS2	0.026	151.620	61	2MN6	0.0003	336.300
16	NO1	0.015	279.040	39	LDA2	0.005	330.730	62	M6	0.0001	224.590
17	CHI1	0.015	217.070	40	L2	0.018	27.650	63	2MS6	0.0006	257.610
18	PI1	0.014	269.570	41	T2	0.030	348.270	64	2MK6	0.0009	258.940
19	P1	0.110	302.100	42	S2	0.196	2.580	65	2SM6	0.0004	232.440
20	S1	0.027	276.230	43	R2	0.013	20.470	66	MSK6	0.0005	289.590
21	K1	0.429	306.150	44	K2	0.043	348.190	67	3MK7	0.0005	82.790
22	PSI1	0.024	178.270	45	MSN2	0.004	338.500	68	M8	0.0001	264.150
23	PHI1	0.012	147.570	46	ETA2	0.012	50.740				

Table 6 presents the results of the harmonic analysis of data from a semiyearly period from this station. This period that contains data recorded from April to September has 4092 hourly data and 300 gaps (6.8% of the entire period). The number of tidal components that are extractable from these data is 51, for which the measured amplitude and phase values are given in Table 6. According to this analysis, the M2 component (with an amplitude of 0.508 meters) is the most important tidal component of this station. Figure 1 illustrates the 10 most important tidal components obtained from this analysis along with their importance compared to the M2 component.

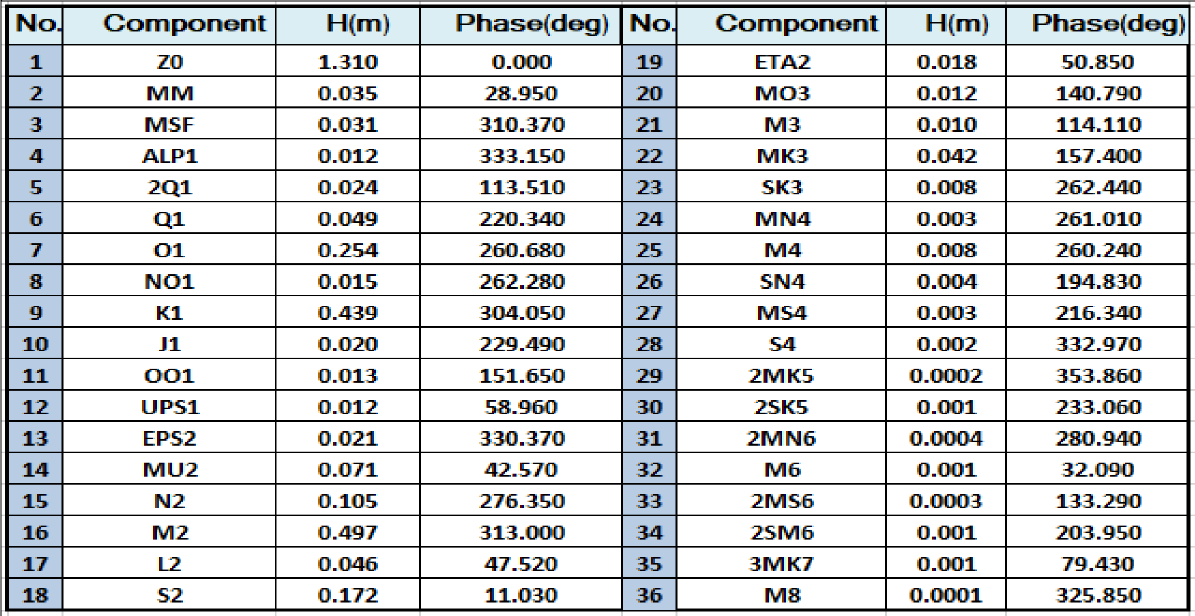
Table 7. The results of the harmonic analysis of semiyearly and filtered data on tidal fluctuations at the BANDAR-E EMAM HASAN station



No.	Component	H(m)	Phase(deg)	No.	Component	H(m)	Phase(deg)	No.	Component	H(m)	Phase(deg)
1	Z0	1.310	0.000	18	OO1	0.006	103.980	35	MN4	0.004	217.090
2	SSA	0.058	258.650	19	UPS1	0.009	49.660	36	M4	0.008	240.380
3	MM	0.022	61.090	20	EPS2	0.009	318.580	37	SN4	0.002	215.000
4	MSF	0.006	285.980	21	MU2	0.027	34.170	38	MS4	0.002	242.170
5	MF	0.007	306.280	22	N2	0.128	275.680	39	MK4	0.002	274.350
6	ALP1	0.004	355.060	23	M2	0.508	306.830	40	S4	0.002	263.600
7	2Q1	0.015	137.230	24	MKS2	0.033	187.240	41	SK4	0.002	148.850
8	Q1	0.058	231.550	25	L2	0.022	27.830	42	2MK5	0.001	307.620
9	O1	0.272	257.710	26	S2	0.185	5.250	43	2SK5	0.000	339.970
10	TAU1	0.029	14.340	27	K2	0.036	322.260	44	2MN6	0.001	290.750
11	BET1	0.015	12.120	28	MSN2	0.009	305.180	45	M6	0.000	12.560
12	NO1	0.022	284.820	29	ETA2	0.017	27.690	46	2MS6	0.001	259.840
13	P1	0.096	309.300	30	MO3	0.017	111.170	47	2MK6	0.001	239.180
14	K1	0.428	308.630	31	M3	0.007	110.540	48	2SM6	0.001	222.160
15	PHI1	0.030	170.940	32	SO3	0.013	188.140	49	MSK6	0.001	290.090
16	J1	0.019	281.140	33	MK3	0.036	158.990	50	3MK7	0.001	47.510
17	SO1	0.003	345.960	34	SK3	0.007	220.870	51	M8	0.000	224.960

Harmonic analysis was then conducted on tidal data recorded over three months in 1992 at the BANDAR-E EMAM HASAN station. This period that contains hourly tidal data recorded from April to June has 2106 data and 78 gaps (3.6% of the entire period). The number of tidal components that are extractable from this data is 38, with the corresponding information given in Table (8).

Table 8. The results of the harmonic analysis of data on tidal fluctuations gathered for three months from the BANDAR-E EMAM HASAN station



No.	Component	H(m)	Phase(deg)	No.	Component	H(m)	Phase(deg)
1	Z0	1.310	0.000	19	ETA2	0.018	50.850
2	MM	0.035	28.950	20	MO3	0.012	140.790
3	MSF	0.031	310.370	21	M3	0.010	114.110
4	ALP1	0.012	333.150	22	MK3	0.042	157.400
5	2Q1	0.024	113.510	23	SK3	0.008	262.440
6	Q1	0.049	220.340	24	MN4	0.003	261.010
7	O1	0.254	260.680	25	M4	0.008	260.240
8	NO1	0.015	262.280	26	SN4	0.004	194.830
9	K1	0.439	304.050	27	MS4	0.003	216.340
10	J1	0.020	229.490	28	S4	0.002	332.970
11	OO1	0.013	151.650	29	2MK5	0.0002	353.860
12	UPS1	0.012	58.960	30	2SK5	0.001	233.060
13	EPS2	0.021	330.370	31	2MN6	0.0004	280.940
14	MU2	0.071	42.570	32	M6	0.001	32.090
15	N2	0.105	276.350	33	2MS6	0.0003	133.290
16	M2	0.497	313.000	34	2SM6	0.001	203.950
17	L2	0.046	47.520	35	3MK7	0.001	79.430
18	S2	0.172	11.030	36	M8	0.0001	325.850

The results of this analysis furthermore introduce the M2 component with an amplitude of 0.497 m as the most important tidal component at the BANDAR-E EMAM HASAN station. Figure 1 illustrates 10 main tidal components obtained from this analysis with their corresponding relative intensity.

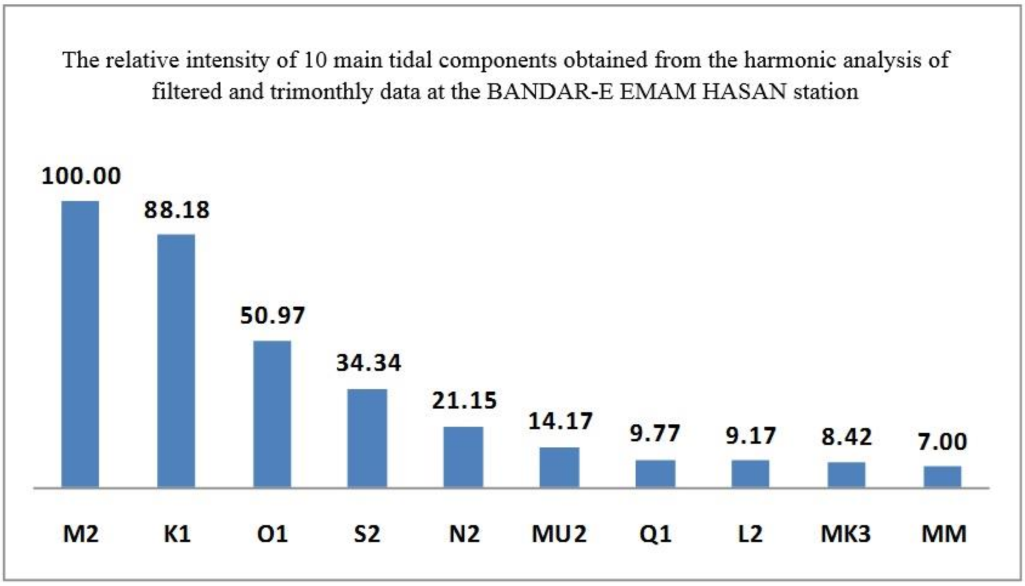
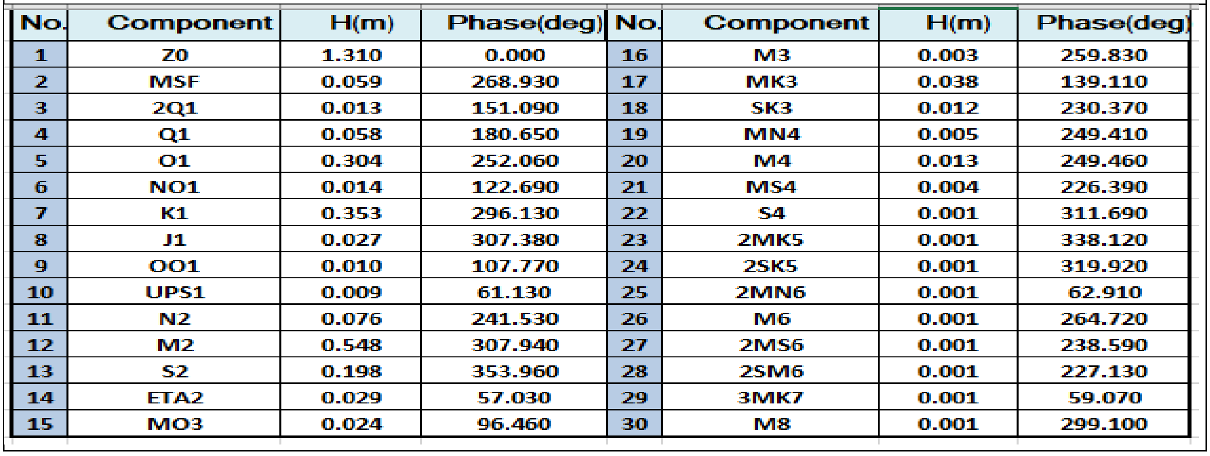


Figure 1. The relative intensity of 10 main tidal components obtained from the harmonic analysis of trimonthly data in 1992 at the BANDAR-E EMAM HASAN station

Ultimately, the harmonic analysis was conducted on tidal data obtained during April 1992 from the BANDAR-E EMAM HASAN station. From this period, which contains 720 hourly data with no gap, a total of 30 tidal components were extracted (Table 9).

Table 9. The results obtained from the harmonic analysis of filtered and monthly data (for April 1992) gathered from the BANDAR-E EMAM HASAN station



No.	Component	H(m)	Phase(deg)	No.	Component	H(m)	Phase(deg)
1	Z0	1.310	0.000	16	M3	0.003	259.830
2	MSF	0.059	268.930	17	MK3	0.038	139.110
3	2Q1	0.013	151.090	18	SK3	0.012	230.370
4	Q1	0.058	180.650	19	MN4	0.005	249.410
5	O1	0.304	252.060	20	M4	0.013	249.460
6	NO1	0.014	122.690	21	MS4	0.004	226.390
7	K1	0.353	296.130	22	S4	0.001	311.690
8	J1	0.027	307.380	23	2MK5	0.001	338.120
9	OO1	0.010	107.770	24	2SK5	0.001	319.920
10	UPS1	0.009	61.130	25	2MN6	0.001	62.910
11	N2	0.076	241.530	26	M6	0.001	264.720
12	M2	0.548	307.940	27	2MS6	0.001	238.590
13	S2	0.198	353.960	28	2SM6	0.001	227.130
14	ETA2	0.029	57.030	29	3MK7	0.001	59.070
15	MO3	0.024	96.460	30	M8	0.001	299.100

Likewise, this analysis revealed the M2 component with an amplitude of 0.497 m as the most important tidal component at the BANDAR-E EMAM HASAN station. Figure 2 illustrates 10 main tidal components obtained from this analysis with their corresponding relative intensity.

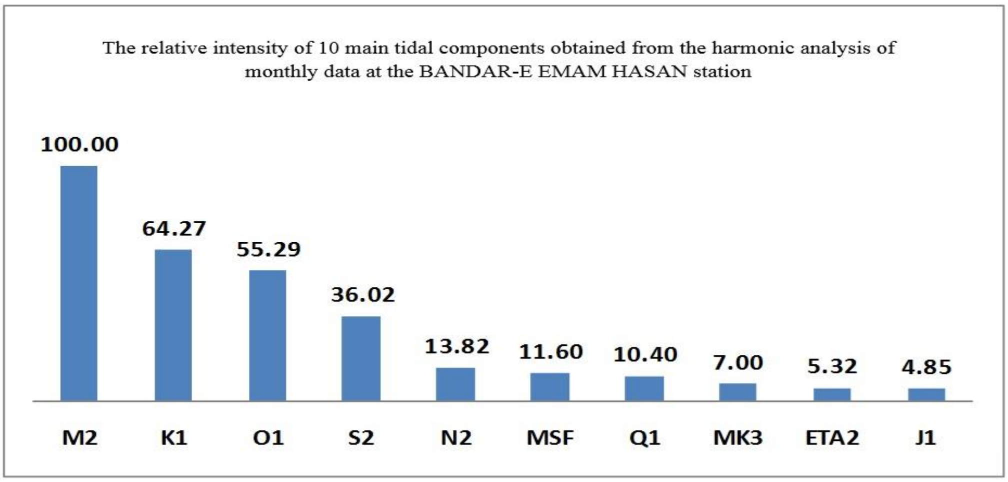


Figure 1. The relative intensity of 10 main tidal components obtained from the harmonic analysis of filtered and monthly data in 1992 at the BANDAR-E EMAM HASAN station

2. BANDAR-E BOSHEHR

According to the results, the maximum and minimum frequencies were 0.24436 (for the 2MS6 component with a period of 4.09 h) and 0.00023 (for the SSA component with a period of 4382.91 h). The filtered data on water level fluctuations at the BANDAR-E BOSHEHR station in 1993 includes 7896 hourly data and 744 gaps (8.61% of the whole year). Out of these data, 60 tidal components are extractable, for which the amplitude and phase values were obtained.

In this station, M2 with an amplitude of 0.375 m was the main tidal component. The results of the harmonic analysis conducted on the tidal data gathered over six months in 2013 (from April to September) at the BANDAR-E BOSHEHR station are presented. A total of 51 tidal components were extracted from 4392 hourly data with no gaps. These results also reveal M2 with a tidal amplitude of 0.388 m as the main tidal component in this station.

Furthermore, similar harmonic analyzes were conducted on trimonthly tidal data (gathered from April to June) and monthly tidal data (gathered in April) from the BANDAR-E BOSHEHR station in 1993. A total of 36 and 30 components were extracted respectively from the trimonthly analysis (with 2184 data) and monthly analysis (with 720 data). It was found that M2 with an amplitude of 0.391 m (for trimonthly data) and 0.388 m (for monthly data) is the main tidal component in this station.

3. KANGAN

The results obtained from the harmonic analysis of these data allowed for the extraction of 68 components, where the components with an amplitude of over 1% compared to that of the M2 component were separated. According to the results given in Table XXX, the maximum and minimum frequency of these components are 0.16102 (for the M4 component with a period of 6.21 h) and 0.000114 (for the SA component with a period of 8766.23 h). As shown, M2 is the main tidal component in this station for all the analyses and its amplitude values are 0.558, 0.559, 0.56, and 0.569 m for annual, semiyearly, trimonthly, and monthly analyses, respectively.

4. BANDAR-E SHAHID RAJAEE

According to the results, the maximum and minimum frequencies are 0.16102 (for the M4 component with a period of 6.21) and 0.000228 (for the SSA component with a period of 4382.91 h). In this station, the harmonic analysis results allowed for the extraction of 60 tidal components (for the annual analysis), 51 tidal components (for the semiyearly analysis), 36 tidal components (for the trimonthly analysis), and 30 components (for the monthly analysis in May). The results revealed that M2 is the main tidal component in this station for all analyses and its amplitude is 1.078, 1.079, 1.076, and 1.082 m, respectively for annual, semiyearly, trimonthly, and monthly anal

5. BANDAR-E JASK

As can be inferred from this table, the maximum and minimum frequencies are 0.12511 (for the SK3 component with a period of 7.99) and 0000228 (for the SSA component with a period of 4382.91 h). The results revealed that M2 is the main tidal component in this station for all analyses and its amplitude is 0.69, 0.559, 0.681, and 0.678 m, respectively for annual, semiyearly, trimonthly, and monthly analyses.

6. CHABAHAR

As can be inferred from this table, the maximum and minimum frequencies are 0.12511 (for the SK3 component with a period of 7.99) and 0000228 (for the SSA component with a period of 4382.91 h). The results revealed that M2 is the main tidal component in this station for all analyses and its amplitude is 0.612, 0.627, 0.637, and 0.639 m, respectively for annual, semiyearly, trimonthly, and monthly analyses.

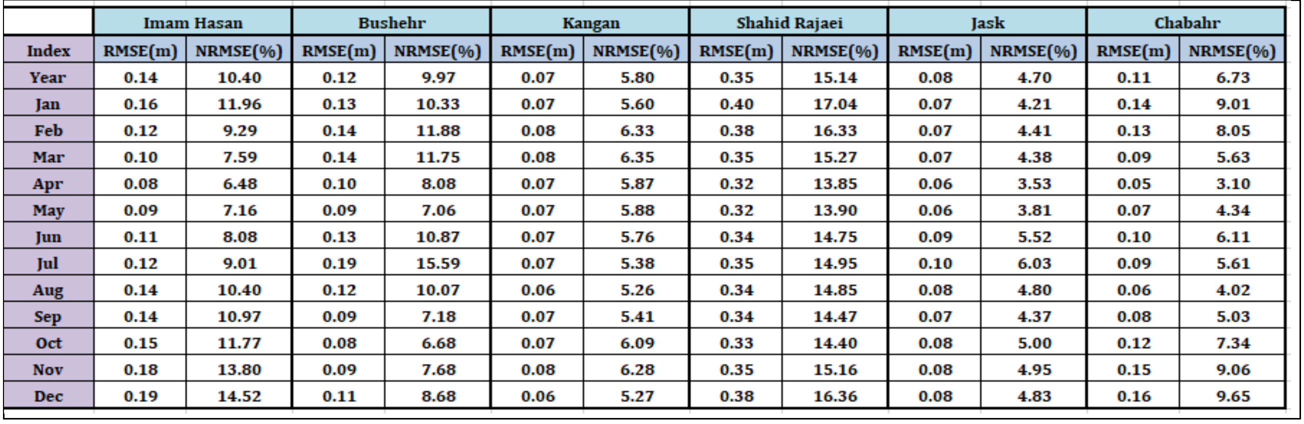
Quantitative evaluation of forecasts

In this section, the RMSE (Root Mean Square Error) and NRMSE (Normalized Root Mean Square Error) indices were calculated to quantitatively evaluate the results of tidal forecasts made in the stations under concern. Next, by comparing the values obtained for different methods, the duration of the statistical period required to extract the tidal components, as well as the adequacy of the IOS package for the tidal height forecasting are determined and investigated. The mathematical equations for these two statistical indicators are as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{model,i})^2}{n}}$$

$$NRMSE = \frac{RMSE}{\overline{X_{obs}}} \times 100$$

Table 10. The RMSE and NRMSE values for the evaluation of the difference between the tidal levels forecasted by the National Cartography Center of Iran (NCC) and those obtained in this study for various stations



	Imam Hasan		Bushehr		Kangan		Shahid Rajaei		Jask		Chabahr	
Index	RMSE(m)	NRMSE(%)	RMSE(m)	NRMSE(%)	RMSE(m)	NRMSE(%)	RMSE(m)	NRMSE(%)	RMSE(m)	NRMSE(%)	RMSE(m)	NRMSE(%)
Year	0.14	10.40	0.12	9.97	0.07	5.80	0.35	15.14	0.08	4.70	0.11	6.73
Jan	0.16	11.96	0.13	10.33	0.07	5.60	0.40	17.04	0.07	4.21	0.14	9.01
Feb	0.12	9.29	0.14	11.88	0.08	6.33	0.38	16.33	0.07	4.41	0.13	8.05
Mar	0.10	7.59	0.14	11.75	0.08	6.35	0.35	15.27	0.07	4.38	0.09	5.63
Apr	0.08	6.48	0.10	8.08	0.07	5.87	0.32	13.85	0.06	3.53	0.05	3.10
May	0.09	7.16	0.09	7.06	0.07	5.88	0.32	13.90	0.06	3.81	0.07	4.34
Jun	0.11	8.08	0.13	10.87	0.07	5.76	0.34	14.75	0.09	5.52	0.10	6.11
Jul	0.12	9.01	0.19	15.59	0.07	5.38	0.35	14.95	0.10	6.03	0.09	5.61
Aug	0.14	10.40	0.12	10.07	0.06	5.26	0.34	14.85	0.08	4.80	0.06	4.02
Sep	0.14	10.97	0.09	7.18	0.07	5.41	0.34	14.47	0.07	4.37	0.08	5.03
Oct	0.15	11.77	0.08	6.68	0.07	6.09	0.33	14.40	0.08	5.00	0.12	7.34
Nov	0.18	13.80	0.09	7.68	0.08	6.28	0.35	15.16	0.08	4.95	0.15	9.06
Dec	0.19	14.52	0.11	8.68	0.06	5.27	0.38	16.36	0.08	4.83	0.16	9.65

Conclusion

The results of this study confirmed the performance of the tidal height analysis and tidal height prediction subprograms of the IOS package in conducting harmonic analysis of the measured water level data, extracting the different tidal components, and forecasting appropriate tidal levels. In all the investigated stations, M2 was the main tidal component, while the relative intensity of other components varies in different stations. The error for forecasting tidal levels in the whole year based on the harmonic analysis of the annual data was less than forecasts made for other periods. However, this trend was not similar in all months of the year. To be more precise, the forecasting accuracy was reduced in cases where the number of data was forecasting. Indeed, this was not correlated with the duration of the statistical periods for data collection and was due to the disturbances caused by adverse climate conditions, such as winds, storms, and atmospheric pressure fluctuations during data recording and their effect on water level changes.

The difference in the accuracy of forecasts made for the annual analysis with those semiyearly, trimonthly, and monthly analyses was about 7%. Therefore, when the annual data are not accessible, the data from shorter periods can be utilized in harmonic analyses and then forecasts. The forecasted tidal levels in the studied stations determined by the values of four tidal components obtained from the tables provided by the National Cartography Center of Iran (NCC) are less accurate than those forecasted via the harmonic analysis of the measured data. The results of the forecasts made by the TMD software in the investigated stations are not of sufficient accuracy except for a few cases.

Future studies are recommended to work with other subprograms of the IOS package for the analysis and forecasting of tidal flows.

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