IOP Conf. Series: Earth and Environmental Science **162** (2018) 012018 doi:10.1088/1755-1315/162/1/012018

Analysis of daily wind circulation toward sea level rise in Semarang

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Abstract. Semarang is one of the coastal areas in Indonesia that frequently occur tidal flood. Tidal flood is a phenomenon where the sea water entering the land area. It can be influenced by astronomical factor that is gravity of moon and sun besides meteorological factor which also play a role in rising the sea level. Sea level rise can cause flood disaster in coastal areas if the height of coastal land is below sea level. At the time of minimum sea wave height, sea level rise is also low, so rising sea level is only played by high tidal fluctuations. Wind data used in this study. The data classified into land breeze, sea breeze and wind transition. From wind data, three classifications of wind speed are determined that is when the wind with minimum, average and maximum speeds. The method of calculating some variables of sea level rise (wave set up) as well as sea tidal observation and measurement. From this research it can be seen that sea level rise in Semarang besides caused by tidal factor is also caused by meteorological factors such as wind speed.

1. Introduction

The coastal area is an area that is highly vulnerable to environmental pressure from land or from the sea. The coastal area is the area between land and sea. One of the recent pressures that threaten the sustainability of coastal areas around the world is the increasing of sea levels. Towards the land of the coastal area includes part of the Mainland, either dry or submerged in water, which is still influenced by oceanic properties such as tides, sea breezes and saltwater permeation. While towards the sea, the coastal area includes part of the ocean which is still influenced by natural processes that occur on land such as sedimentation and freshwater flow or caused by human activities on the ground such as deforestation and pollution (Supriharyono, 2002).

Sea level rise events and the decline of land allegedly resulted in frequent floods in the coastal area of Semarang, during high tide in a period of ± 25 last year. The flood, known as the rob (tidal flood), inundated areas lower than sea level during the highest tide (Mean High Water Level). According Sarbidi (2002) water height due to the flood can reach 20-60 cm rob with the estimated inundation area of 32.6 km^2.

Rob or tidal flood is a phenomenon of overflowing sea water to the mainland[1]. The increase of sea water due to the tide is a natural phenomenon and can be predicted. Tidal events are due to the movement

[1] http://pusatkrisis.kemkes.go.id/what-is-rob-flood

of the sun, earth, moon and other celestial objects. Sea level rise caused by the tides, in addition it is also caused by other factors or external force such as water push, swell (waves caused from a distance), storms and tropical storms which is a phenomenon that frequently occurs at sea.

The movement of the wind caused the sea waves which makes the sea level rises. These are the possible causes for the occurrence of rob in Semarang. Wind conditions in the coastal area of Semarang is dominated by west monsoon winds.. year, the western monsoon blows at an average speed of 14.5 knots and an average maximum speed of 22.9 knots from the west, northwest and north (Prihatno, 2009). Therefore, it is necessary to analyse and calculate the wind velocity and fluctuation of tides to find out how high sea waves and sea level rise caused during the tidal period.

2. Data and method

This research is in the area of Semarang Maritime Meteorological Station , located at coordinate positions 6.95^0 S and 110.42^0 E. The data used in this study is the data direction and wind speed obtained from daily observation based on hourly surface observation. In addition, the data used are hourly tidal observation data with in period of 2012 - 2016. Several stages of data processing in this research, as follows:

- Classification of sea breeze, transition wind and ground wind based on penetration theory
- Determine the dominant wind direction to determine the fetch length.
- Calculation of effective fetch value at research point, fetch calculation is used to determine sea wave height (H) and wave period (T).
- After determining the height and period of wave then also determined the increase of sea level (wave set up) S_w because of waves or sea level rise reaching coastal areas.
- Counting the tides in the research area and then determined the highest tide.
- From the wave height data then accumulated with high during the tide period.
- Calculation of sea level high frequency at high wave and at the highest tide occurs simultaneously.

In the classification of land breeze and sea breeze obtained by using penetration theory that sea breeze can enter up to 100 km to the land area. therefore, the calculation of 100 km distance between Semarang maritime Meteorological Station with the coast and determine the angle of direction by using trigonometric theory, for transition wind is defined as 300 degree angle from sea breeze toward land and the rest is defined as land breeze.

After determining the wind classification, the dominant wind direction in the research area can be known. By calculating the dominant wind direction is used to measure the fetch length, fetch length is one of the factors that determine the wave characteristics generated by the wind (Davis 1991). Fetch is the distance travelled by the wind from the direction of wave generation . To calculate the fetch using the equation as follows:

$$F_{eff}= \frac{\Sigma X_i \text{ Cos a}}{\Sigma \text{ Cos a}} \quad (1)$$

F_{eff} = Effective Fetch (Km)
X_i = Fetch Length / Actual Distance (Km)
a = Angle of deviation on both sides of the dominant wind direction.

The calculation of the effective fetch used to convert wind into a wave, in this case the wave height (H_0) and period of a wave are converted by using the equation according to the SPM (shore protection manual), 1984 vol. 1 as follows:

$$H_0 = 5.112 \times 10^{-4} \times U_A \times F^{0.5} \quad (2)$$

$$T_0 = 6.238 \times 10^{-2} \times (U_A \times F)^{0.33} \quad (3)$$

$$R_L = \frac{U_W}{U_L} \quad (4)$$

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$$U_A = 0.71 \times {U_w}^{1.23} \tag{5}$$

H_o = sea wave height (m)
T_o = period of sea wave (s)
F = Fetch/ Fetch Effective
U_A = voltage factor of wind
R_L = linkages of UL dan UW (velocity of sea breeze and velocity of land breeze)
U_W = wind velocity above sea surface (m)
U_L = wind velocity over land (m)
1 Knot = 0.5144 m/s

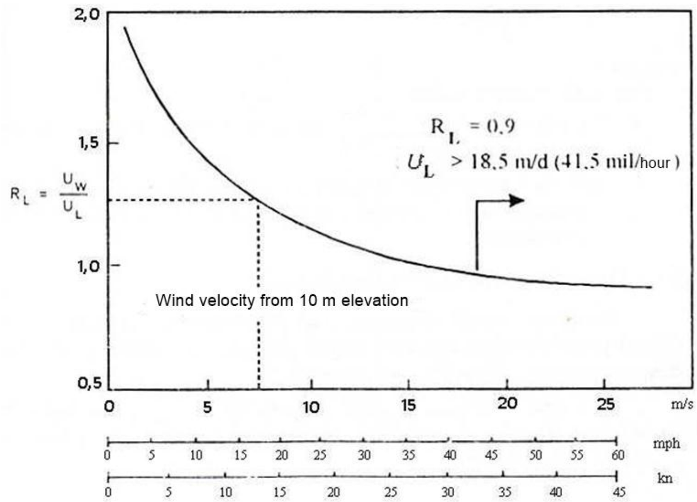

Figure 1. The relationship between wind velocity at sea and shore (Source: Triatmodjo, 1999)

Since the registering station is grounded to get the sea breeze velocity is approximated by the equation $R_L=U_w/U_L$ (Triatmodjo, 1999) as well as utilizing the graph of the relationship between wind speed at sea and land and based on Figure 1. Then the calculation of water level due to wave (S_w) is done by using several variables, like wavelength with equation Lo=1.56T2. Where the depth of the sea (d) is close to the coast of Semarang waters is 9 meters while the slope of the seafloor (m) with 1: 500 is 0.02. The depth of the sea (d) is based on research conducted by Satriadi (2012).

Table 1. Functions of d/L for even increments of d/L_0 (Source: Triatmodjo, 1999)

d/L_o	d/L	2π d/L	TANH 2π d/L	SINH 2π d/L	COSH 2π d/L	H/H'_o	K	4π d/L	SINH 4π d/L	COSH 4π d/L	n	C_G/C_o	M
.006000	.03110	.1954	.1929	.1967	1.0192	1.620	.9812	.3908	.4008	1.077	.9875	.1905	133
.006100	.03136	.1970	.1945	.1983	1.0195	1.614	.9809	.3941	.4044	1.079	.9873	.1920	130
.006200	.03162	.1987	.1961	.2000	1.0198	1.607	.9806	.3973	.4079	1.080	.9871	.1935	128
.006300	.03188	.2003	.1976	.2016	1.0201	1.601	.9803	.4006	.4114	1.081	.9869	.1950	126
.006400	.03213	.2019	.1992	.2033	1.0205	1.595	.9799	.4038	.4148	1.083	.9867	.1965	124
.006500	.03238	.2035	.2007	.2049	1.0208	1.589	.9796	.4070	.4183	1.084	.9865	.1980	123
.006600	.03264	.2051	.2022	.2065	1.0211	1.583	.9793	.4101	.4217	1.085	.9863	.1994	121
.006700	.03289	.2066	.2037	.2081	1.0214	1.578	.9790	.4133	.4251	1.087	.9860	.2009	119
.006800	.03313	.2082	.2052	.2097	1.0217	1.572	.9787	.4164	.4285	1.088	.9858	.2023	117
.006900	.03338	.2097	.2067	.2113	1.0221	1.567	.9784	.4195	.4319	1.089	.9856	.2037	116
.007000	.03362	.2113	.2082	.2128	1.0224	1.561	.9781	.4225	.4352	1.091	.9854	.2051	114
.007100	.03387	.2128	.2096	.2144	1.0227	1.556	.9778	.4256	.4386	1.092	.9852	.2065	112
.007200	.03411	.2143	.2111	.2160	1.0231	1.551	.9774	.4286	.4419	1.093	.9850	.2079	111
.007300	.03435	.2158	.2125	.2175	1.0234	1.546	.9771	.4316	.4452	1.095	.9848	.2093	109
.007400	.03459	.2173	.2139	.2190	1.0237	1.541	.9768	.4346	.4484	1.096	.9846	.2106	108

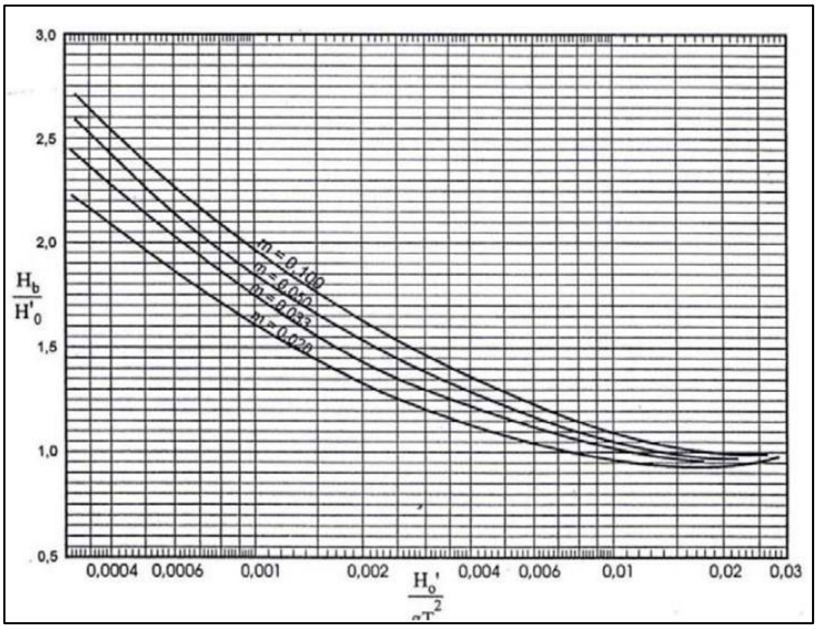

Figure 2. Graph of height of breaking wave (Triatmodjo,1999)

Table 1 is used to determine the value of L and n to determining the wavelength. after that rapid wave propagation has determinated by using the equation $C_0 = L_o / T$ (Keand $C = L / T$ the calculation of Rapid wave propagation is used to calculate the value of shoaling coefficient with the following equation:

$$K_s = \sqrt{\frac{1}{2} \times \frac{1}{n} \times \frac{1}{\frac{C}{C_o}}} \quad (6)$$

K_s = Shoaling Coefficient
n = the fraction of wave energy that travels forward with the wavefrom
C = Wave Speed (m/s)
C_0 = Depth water wave speed (m/s)
L = wavelenght(m)
L_0 = Depth water wavelength (m)

To determine the height of the breaking wave (H_b) in this case is done using the graph of the relationship between H'_0 / gT^2 and H_b / H_0 where to find the value of H'0 with the equation $H'_0 = H_0 / K_s$, after getting the breaking wave value then determined The value of wave set up in the coast because of the wave with the equation:

$$S_w = 0.19[\,1 - 2.82\sqrt{\frac{H_b}{gT^2}}]H_b \quad (7)$$

In general, the tides in various regions in Indonesia can be divided into 4 types (Triatmodjo, 1999), namely Semi diurnal tide, diurnal tide, mixed prevailing semidiurnal and mixed prevailing diurnal. In this study tidal data were obtained from observations and measurements in the period 2012 - 2016 observed and recorded hourly on a tidal observation form. The calculation is done by determining the value of Mean Sea Level (MSL), Mean High Water Level (MHWL) and Highest High Water Level (HHWL).

Frequency calculation is done by calculating of sea level in the coast at the high tidal wave along with the highest average tide. This is done to analyse sea water level in Semarang waters most often due to wind speed factor or high wind speed factor that occurs simultaneously at the highest tide.

3. Result and discussion

Based on the penetration theory that sea breeze can enter up to 100 km to the mainland. Thus, the point taken to classify the sea breeze in this study is the coastal point 100 km from the Semarang Maritime Meteorology station.

Measuring the distance of sea breeze into the mainland is calculated using Google Earth. After determining the direction of the sea breeze then classified land breeze and transition wind, where the transition wind is a wind that is calculated 30^0 from the direction of the sea breeze.

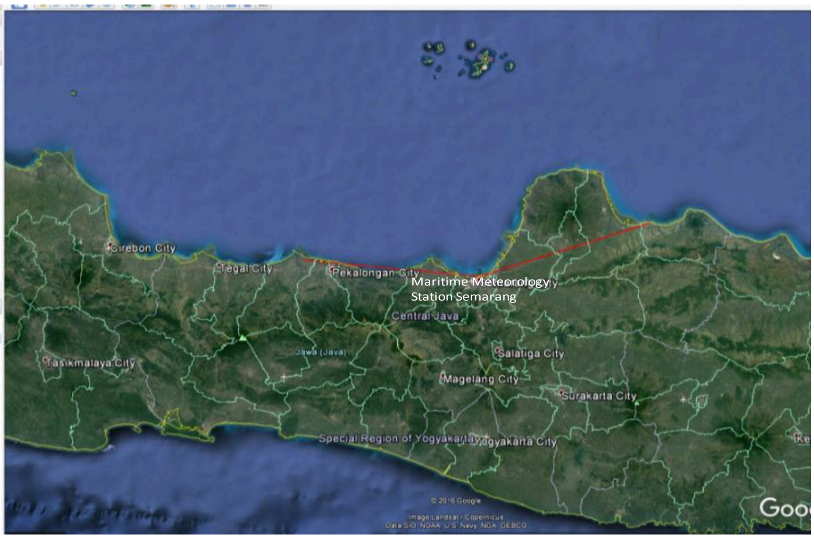

Figure 3. Maritime Meteorology Station Semarang Position (-6.95°S,110.41°E) In Google Earth.

Figure 4. Classification of Wind Direction by Penetration Theory

Based on Figure 4, the sea breeze is a wind that blows from 270^0 - 70^0 (West to East), for transition wind 1 of the wind direction from the direction of 70^0-100^0 (East), transition wind 2 comes from the direction of 240^0-270^0, while for the land breeze is the direction wind from 100^0 - 240^0(East to South

West). From the classification is obtained that the land breeze is the direction of wind blowing from the direction from west to northeast

Sea breeze is the wind that blows from the sea towards the mainland and generally occurs during the day, based on the wind penetration theory, the sea breeze in figure 5 occurs at 06.00 - 12.00 am. From the windrose diagram, we obtained that the dominant wind sea direction every 3 hours comes from the North-West wind direction.

Calculation of effective fetch that is by using the direction of the dominant wind that is northwest further the northwest direction we assume as 0^0 in the cartesiancoordinat. From the lines were made another line from the same point but with the angle from the previous line by 5^0 respectively. Then do as much as 4 times until you reach the corner of 20^0 as seen in Figure 6.

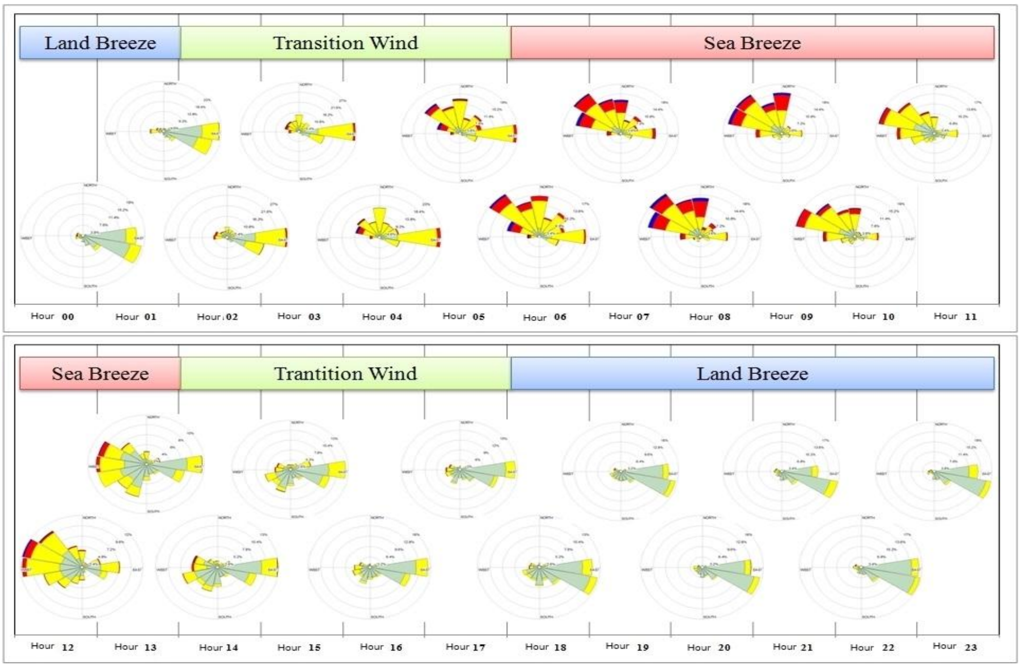

Figure 5. Windrose at 00 – 23 in June 2000 until June 2011

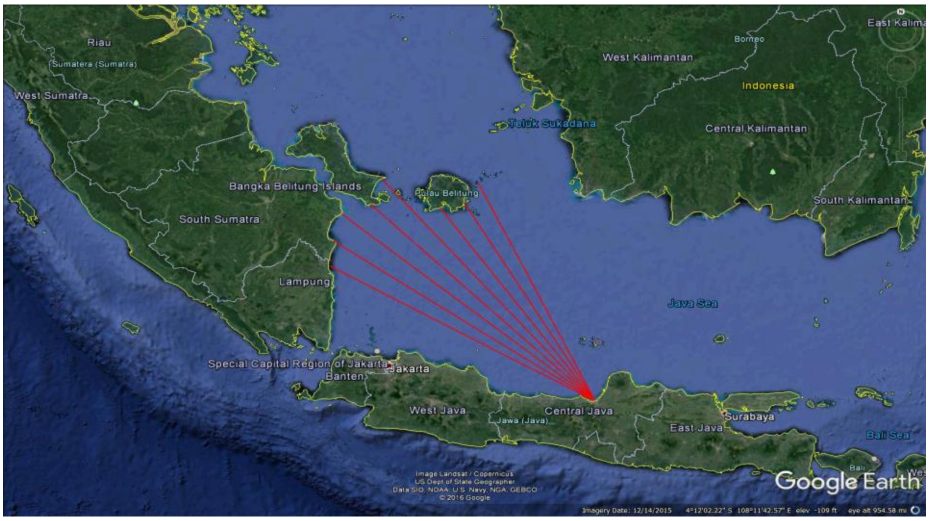

Figure 6. Map of fetch area of Semarang

Table 2. Fetch Distance Calculation

a (˚)	Cos a	Xi (km)	Xi.Cos a
20	0.408	517	211
15	0.760	493	375
10	0.839	510	428
5	0.284	629	178
0	1.000	603	603
5	0.284	630	179
10	0.839	609	511
15	0.760	587	446
20	0.408	30	12
Sum	5.581		2942.7

$$F_{eff} = \frac{\sum Xi.cosa}{\sum cosa} = \frac{2942.736}{5.581} = 527.276\ km \quad (8)$$

Based on Table 2 the fetch effective of Semarang coast is 527.276 km.

Table 3. Ocean Waves Height Approach from observation wind data to Sea Surface Wind

Wind Speed	Land Breeze Speed (UL)	RL=Uw/UL	Sea Breeze Speed(UW)	Wave Height H (meter)	Wave Period (T)
1-10	0.5 - 5.1	1.9 - 1.4	0.98 - 7.20	0.26 - 2.99	4.27 - 9.60
11-20	5.1 - 10.3	1.4 -1.1	7.20 - 11.32	2.99 - 5.21	9.60 - 11.53
>20	>10.3	<1.1	>11.32	>5.21	>11.53

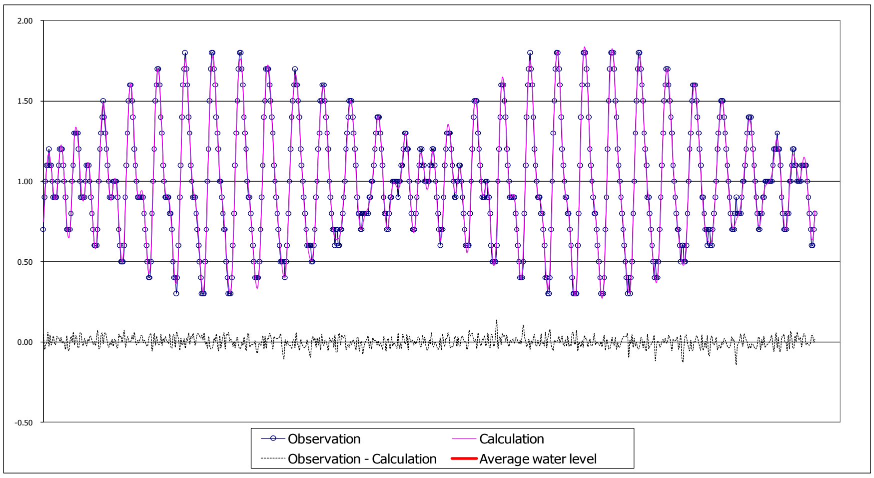

Figure 7. Tidal Waters Levels in Semarang

In Table 3 shows the value of wind speed of land breeze which is divided into 3 classes which are then converted into the sea surface wind approach, the wind speed in knots (kts) must be converted first into the unit m / s then obtained U_w to find the wave height and wave period. From the table obtained that if wind speeds range between 1 – 10 kts the result of wave height will be 0.26 – 2.99 m, wind speeds between 10 – 20 kts will result waves height of 2.99 – 5.21 m, meanwhile for a wind speed of 20 kts will result waves height over 5.21 m.

These values are used to determine the sea level rise (wave set up) that occurs on the coast as seenin Table 1 and Graph1. The result of the calculation of the wave set up 0.26 - 2.99 m after a silting process, sea level in coastal areas rising by 0.01 - 0.56 m, for sea wave height of 2.99 - 5.21 will causing sea level rise in coastal area of 0.56 - 0.87 m and for sea wave height> 5.21 will result in rising > 0.87 m in the coastal area.the result is obtained based on the calculation equation S_w and can be describe by Table 5.

Based on the data analysis of tidal wave in the period 2012 – 2016 which is done each hour, according to the calculations of Least Square then it can be noted that the type of tidal waters in Semarang is mixed, predominantly diurnal tide as indicated by the Figure 5 in addition to the average value of F for tidal in Semarang is 1.1. The results of this research also reinforced by research results from Adhitya (2003) and Darmono (2003) who also get the type of tide of semarang is a mixed, predominantly diurnal tide through the calculation of admiralty. This means that Semarang waters occur twice high and low tide receded during the day but different in high and time.

Based on table 4 obtained the value of HHWL, MHWL, E.G., MLWL and LLWL, but in this study used the value of the MHWL to see the condition of the average increase the sea level water at the time of the highest tide period on average. In the table 4 shows the results of the calculation of the mean sea level obtained 0.597 m while the value of the MHWL is 0.974 so the value of the tide will range from 0.38m above mean sea level.

Table 4. Calculations of Tide in Semarang's waters (2012-2016)

Symbol	Calculation	
HHWL	Z0+(M2+S2+K2+K1+O1+P1)	1.160
MHWL	Z0+(M2+K1+O1)	0.974
MSL	Z0	0.597
MLWL	Z0-(M2+K1+O1)	0.220
CDL	Z0-(M2+S2+K1+O1)	0.140
LLWL	Z0-(M2+S2+K2+K1+O1+P1)	0.034
LAT	Z0-(all constituents)	-0.024

Tides and sea level rise can occur concurrently when a tidal wave propagate to the shore. Therefore, doing the calculation of the total increase sea level rise which occur in conditions period of highest average tides. The calculation results show that when the sea level of 0.01 - 0.56 m occurs along with the highest tide, the sea level in the coast increases to 0.38 - 0.93 m. For sea level rise of 0.56 - 0.87 m and occurring at the highest tide will increasing in a sea level of 0.93 - 1.25 m in sea level while for sea water > 0.87 m and occur along with the highest tide will increase sea level in Coastline above 1.25 as presented in Table 5.

To know the influence of tidal wave events that caused by wind and conditions that occur simultaneously with the highest tide is done by calculating the frequency. On the frequency calculations carried out by using the sea breeze events with wind flow velocity based on 3 classes according to this study with wind speed and tidal conditions can be divided into 3 classes i.e. conditions at altitude <0.6m (MSL = 0.6) which means no tidal , Condition 0.6 - 1 m (MSL - MHWL) and condition> 1m (above MHWL).

Tabel 5. Sea level rise of coastal area at highest tide period

Wave Height H (meter)	Wave Set Up Sw	MHWL	Height Accumulation (Sw+MHWL) m
0.26 - 2.99	0.01 - 0.56	0.38	0.38 - 0.93
2.99 - 5.21	0.56 - 0.87	0.38	0.93 - 1.25
>5.21	>0.87	0.38	>1.25

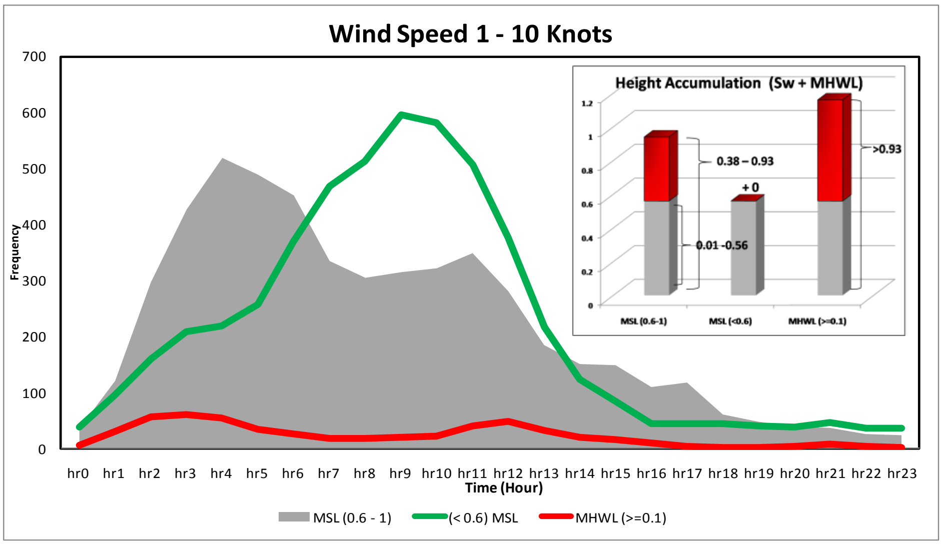

Figure 8. Frequency of Wind Speed (1-10), which occurred simultaneously with each tide height

Based on graph 3.it can be seen that the frequency of wind events from 270^0 - 70^0 (sea breeze) with wind speeds between from 1-10 knots occurring along with the highest average tide (0.6-1) is quite high at dawn (4 a.m – 6 a,m) which causes sea level in coastal area will ranging from 0.38 to 0.93 mthen the frequency of wind occurrence with same speed but not occur simultaneously with the highest tide (<0.6 MSL) are frequently occur in the morning (7 a.m – 12 a.m) with seal level in the coastal area still ranging from 0.01 m to 0.56 m (there is no addition of high tidal)) whereas the wind events with the same velocity that occurs along with the highest tide (> = 0.1 MHWL) has a fairly low incidence when compared to the previous two criteria, but if it happens will raise the sea level in the coastal area as much as> 0.93 m.

It can be seen in graph 4. that the frequency of wind occurrence from direction 270^0 - 70^0(sea breeze) with wind speeds between 10-20 knots that coincides with the highest average tide (0.6-1) is quite high in the morning (5 a.m – 9 a.m) causes sea level in the coastal area ranging from 0.93 to 1.25 m then the frequency of wind occurrence with same speed but not occur simultaneously with the highest tide (<0.6 MSL) are frequently occur in the morning (5 a.m – 11 a.m) with seal level in the coastal area still ranging from 0.56 m to 0.87 m (there is no addition of tidal) whereas the wind events with the same velocity that occurs along with the highest tide (> = 0.1 MHWL) has a fairly low incidence even almost no events but if it happens will raise the sea level in the coastal area as much as> 0.93 m.

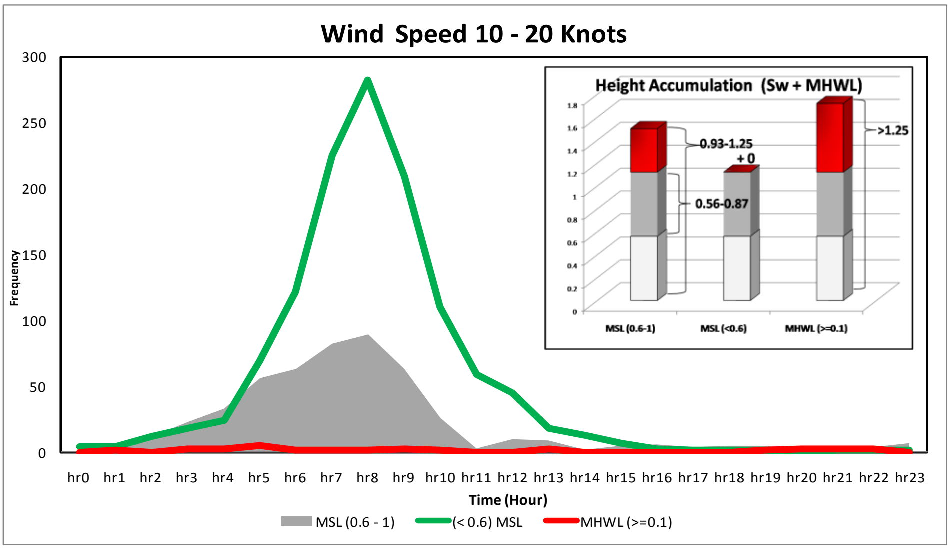

Figure 9. Frequency of Wind Speed (10-20), which occurred simultaneously with each tide height

Based on graph 5. it can be seen that the frequency of wind occurrence from direction 270^0 - 70^0(sea breeze) with wind speeds > 20 knots that coincides with the highest average tide (0.6-1) is very rare if it happens will cause sea level in the coastal area >1.25 m then the frequency of wind occurrence with same speed but not occur simultaneously with the highest tide (<0.6 MSL) are frequently occur compared by other criteria, the wind velocity >20knots will cause seal level in the coastal area >0.87m, whereas the wind events with the same velocity that occurs along with the highest tide (> = 0.1 MHWL) has never happened yet if it happens will raise the sea level in the coastal area much higher than 1.25m .

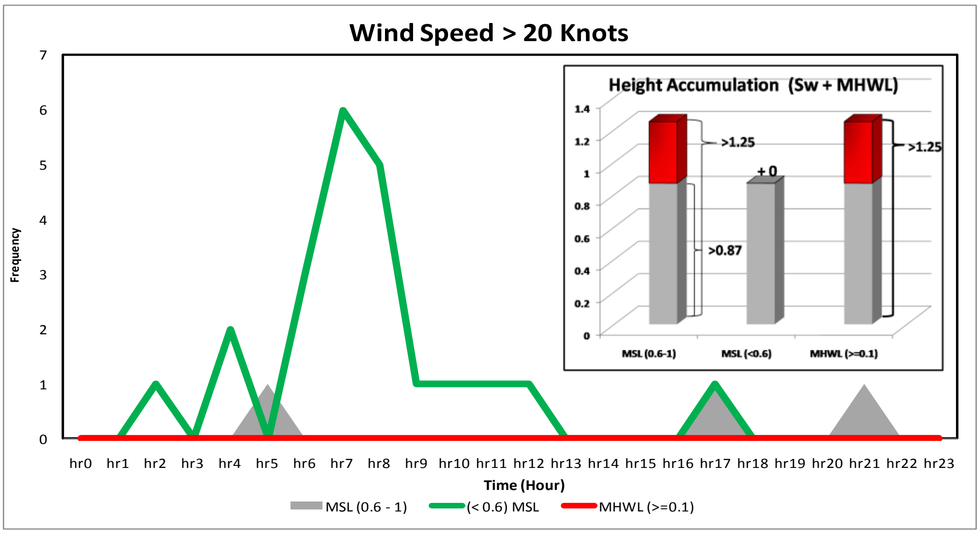

Figure 10. Frequency of Wind Speed (> 20), which occurred simultaneously with each tide height

Sea level rise can cause flood disaster in coastal areas if the height of coastal area below sea level. Ocean waves parameters caused by wind and tidal are dominant factors that influence sea level rise, in this study it is found that the highest sea level rise not only occurs when the wind blows tight that occurs along with the highest tide but the high waves that occur due to strong winds (not coinciding with tides) will also affect sea level rise that will impact on coastal flooding in Semarang.

4. Conclusion

From the research it is found that sea level rise which occurred in Semarang area is the local dynamics with each dominant factor influenced it (Ocean waves and tidal). In the above results obtained that the frequency of wind events 1-10 kts very frequent in Semarang region, this is causing tides on the coastal areas, especially at the highest tide occurs. For 10 - 20 kts wind speed is quite common but this can be a significant when it occurs at the highest tide. while for the frequency of high wind events> 20 kts is very rare in the area of Semarang but if it occurs at the time of maximum tide will cause a significant flood of rob. The results of this study is expected to be a representation related to high sea wave information and become a reference on the influence of meteorological factors to the rising water level.

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