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VARIABILITY OF EQUIVALENT WATER HEIGHT (EWH) IN INDONESIA DURING 14 YEARS OF GRACE GRAVITY SATELLITE MISSION

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Abstract. GRACE Satellite (Gravity Recovery and Climate Experiment) is a gravity monitoring satellite, that is very sensitive to mass changes, especially the signals that produce by redistribution of water masses. Data from this satellite can be used to observe water distribution in the form of spherical harmonic coefficients. Water mass variations are presented as Equivalent Water Height (EWH). The results of GRACE processing showed that the largest EWH was 27.298 cm in January 2015 and the smallest EWH was 29.816 cm in June 2004 in Sumatera Island. The positive trend occurred in Sumatra island and the negative trend occurred in eastern Indonesia. Generally, the trend of Indonesian rainfall throughout 2002 to 2016 was constant. However, there was a change in seasonal patterns in 2014. This research also use Mascon data from GRACE satellite to determine the radius of the gaussian filter and TRMM satellite's data to observe rainfall data to be compared with the EWH variability from GRACE.

Keywords: GRACE, Equivalent Water Height (EWH), TRMM, trend, spherical harmonic, MASCON.

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1. Introduction

Waters are underlying necessary on the life process in the earth (Susana, 2003). Specifically in consequence of the impact of climate changes as the case in Indonesia (Awange et al., 2011; Khaki & Awange, 2019). Much of the water supply on earth is stored in "storage" or can be called "groundwater storage". The availability of water in groundwater storage is a short-term storage such as a lake and there is also storage for thousands of years or even longer, such as storage of water in the form of ice in Greenland (Şen, 2015). According to Tapley et al. (2004), water storage is very important for economic and political implications for understanding and predicting climate change, weather, agricultural productivity, floods and other natural disasters.

Indonesia is an archipelago that has a vast forest, many cultures. Besides, Indonesia is a country that is very often hit by natural disasters. This is absolutely related to the need for water so that we must consider the availability of water in Indonesia.

GRACE satellites to monitor gravity data can be used to observe water distribution in the form of spherical harmonic coefficients (Awange et al., 2011). The latest version of the GRACE satellite monthly gravity model can be used to determine seasonal components that dominate the continental water cycle. This model shows the spatial correlation of the models issued and the global hydrological simulation model is very good (Schmidt et al., 2008). GRACE data is provided through measurements of temporal mass variations which are mostly variations in water volume such as surface water and groundwater (Ahmed et al., 2011). Water mass variations obtained from GRACE Satellite data are declared in the form of Equivalent Water Height/Thickness (EWH/EWT) (Wahr et al., 1998).

EWH is a monthly solution difference (such as a potential interference, geoid undulation), caused by mass redistribution in gravity measurements, there are measurement effects (such as air pressure and tides) that can be modeled and eliminated from measurement data. The remaining difference produced after removing the effect is caused by the redistribution of water masses (ICGEM, 2017).

Research related to analysis of the GRACE satellite EWH of previously been done with the title *Spatio-Temporal Analysis of GRACE Gravity Field Variations Using the Principal Component Analysis* (Anjasmara, 2008). This study discusses the gravity variations of the GRACE satellites which are analyzed using a combination of analytical and statistical methods namely Harmonic Analysis (HA) and Principal Component Analysis (PCA). HA is used to obtain general information on variability while PCA is used to find variability components that are dominantly spatially and temporally. This research analyzes several regions, namely Sumatra-Andaman, Australia, Africa, Antarctica, South America, Arctic, Greenland, South Asia, North America and Central Europe. The results of this analysis show that globally, the strongest signal of variability shows a trend signal. The method used in this study is the analysis of Water Structure Variations (WSV) using GRACE and GLDAS data. The results shown in this study are that WSV from GRACE and GLDAS data tends to decrease. While the CRU data shows a warming trend. Poor water availability in Central Asia. In addition, the mass of water in the Tibetan Plateau and the Tarim basin has increased, possibly due to melting glaciers in Pamirs and the Himalayas. Rainfall Contribution to Changes in water reserves is only the following. However, on the watershed scale, rainfall anomalies are very similar to GRACE and GLDAS data, which can be seen as WSV indicators.

However, related research EWH satellites GRACE satellite data in Indonesia is still very rare. whereas Indonesia is in the zone of subducion that can cause changes in the variation of EWH very quickly when natural disasters occur, such as earthquakes.

2. Data and methods

2.1. Data

The data used in this study are GRACE level 2 satellite data in the form of a spherical harmonic which can be downloaded at The NASA PO.DAAC (The Physical Oceanography Distributed Active Archive Center) website (https://podaac.jpl.nasa.gov) with a time span from 2002 until 2016, in GRACE level 2 satellite data processing needed some supporting data (Feng, 2019), those are the C20 spherical harmonic data coefficient, the 1 degree spherical harmonic coefficient data, and Glacial Isostatic Adjustments (GIA) correction data. The C20 spherical harmonic coefficient data is needed because the coefficient C20 (degree 2 order 0) has an uncertain value, so it is estimated from Satellite Laser Ranging (SLR) to replace the original data, this data can be downloaded at (https://podaac.jpl.nasa.gov/gravity/grace-documentation#TechnicalNotes). Next one is the 1 degree spherical harmonic coefficient data that can be used to estimate degree 1 which is at the center of the earth's mass, this data can be downloaded at (https://podaac.jpl.nasa.gov/gravity/grace-documentation#TechnicalNotes), then Glacial Isostatic Adjustments (GIA) correction data which can be downloaded at (https://podaac.jpl.nasa.gov).

In addition, the data that used in this study is Mascon data in grid form which can be downloaded at (https://podaac.jpl.nasa.gov) and TRMM 3B43 satellite data which is already in the form of monthly rainfall. This data is used as a comparison of EWH values obtained from processing results.

2.2. Method

The data that will be used in this study are GRACE level 2, mass concentration, which is GRACE level 3 and TRMM data as comparison data. The study area will be determined to be the division of Indonesia into grids per 10°, this is done to speed up calculations and must be done before processing the GRACE level 2 satellite data which is in the form of a spherical harmonic coefficient (Joodaki, 2014). The harmonic coefficient in question shows the integral mass given a symbol C_{lm} and S_{lm} (Torge, 1991). The gravitational potential measured by the GRACE satellite is represented by $\Delta\bar{C}_{lm}$ and $\Delta\bar{S}_{lm}$. To change spherical harmonic to surface mass density can be used Equation (1) (Wahr et al., 1998):

$$\Delta\bar{\sigma}(\phi,\lambda) = \frac{2\pi a\rho_{ave}}{3}\sum_{l=0}^{L}\frac{2l+1}{1+k_l}W_1\sum_{m=0}^{l}\bar{P}_{lm}(\sin\phi)\times \left(\Delta\bar{C}_{lm}\cos(m\lambda)+\Delta\bar{S}_{lm}\sin(m\lambda)\right), \quad (1)$$

ϕ shows the latitude of the earth, λ shows the longitude of the earth, a is the spherical radius of the earth, $\bar{P}_{lm}$ is the Legendre function, k_l is love number, W_1, the weight of the frequency error at a high degree, l shows the degree, m shows the order, C_{lm} shows the cosine coefficient, S_{lm} shows the sine harmonic coefficient (Anjasmara, 2008). $\Delta\bar{\sigma}/\rho_w$ is a change in surface mass expressed in EWH (Wahr et al., 1998).

While EWH was extracted, a Gausian filter is used to reduce high-frequency noise in the spherical harmonic coefficient (Feng, 2019). Gaussian Filtering which is done by applying a 300 km radius on level 2 data processing is then matched with MASCON data to see a visual match. in addition to the EWH, extraction TRMM also performed on the data to obtain added value which can be analyzed and compared with the time seriesnya EWH value.

3. Results

3.1. The division of Indonesia

The coordinates of the midpoint of the division of Indonesia are per 10° so that the 18 parts are visualized in Figure 1.

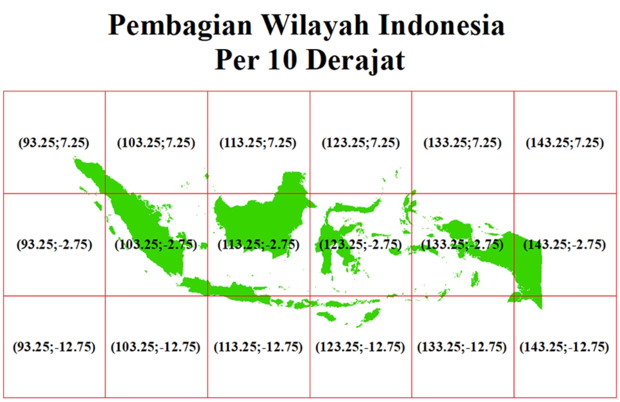


Figure 1. The division of Indonesia

Table 1. The linear equation of the EWH trend

Division	Equations
1	$y = -5867 + 0.09942x$
2	$y = 4.611 - 0.0783x$
3	$y = -0.521 + 0.0054x$
4	$y = -1.500 + 0.02517x$
5	$y = 0.536 - 0.00943x$
6	$y = -1.185 + 0.01999x$
7	$y = -0.184 + 0.00289x$
8	$y = -0.981 + 0.01689x$
9	$y = 1.325 - 0.02235x$
10	$y = -1.443 + 0.02444x$
11	$y = -0.617 + 0.01028x$
12	$y = -0.838 + 0.0142x$
13	$y = 0.031 - 0.00080x$
14	$y = -0.767 + 0.01295x$
15	$y = 0.701 - 0.01192x$
16	$y = -0.385 + 0.00652x$
17	$y = -0.84 + 0.0153x$
18	$y = -0.787 + 0.0140x$

3.2. EWH from Mascon

EWH data from mascon is only used to determine the gaussian filter radius that best matches the GRACE level 2 satellite data in the Indonesian region. the most suitable radius for Indonesia is 300 km. It can be proven by the similarity of visualization of EWH values from mascon and GRACE level 2. This can be seen in Figures 2 and 3 below.

3.3. EWH trend

The trend and time series of EWH are plotted based on the division of the territory of Indonesia (per 10°). Table 1 contains the linear equation of the EWH trend of each region, which is composed of y elements which are EWH values and x which indicate time.

EWH trend values that have been extracted will show the rate of change in the water column in each division in Indonesia, it also can be seen in Figure 4.

3.4. EWH and precipitation's comparisons

Changes in the EWH Value and its comparison with the precipitation value can be seen in the Figure 5.

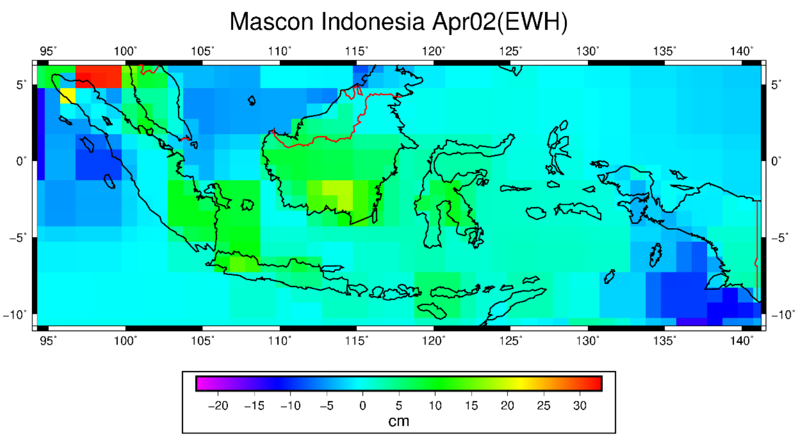


Figure 2. EWH from Mascon

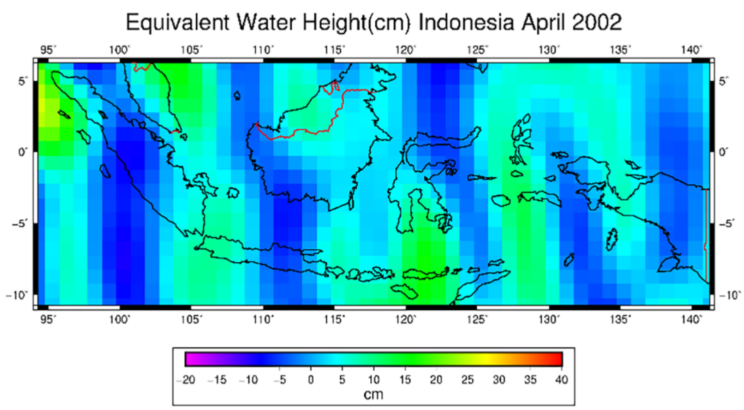


Figure 3. EWH from GRACE Level 2

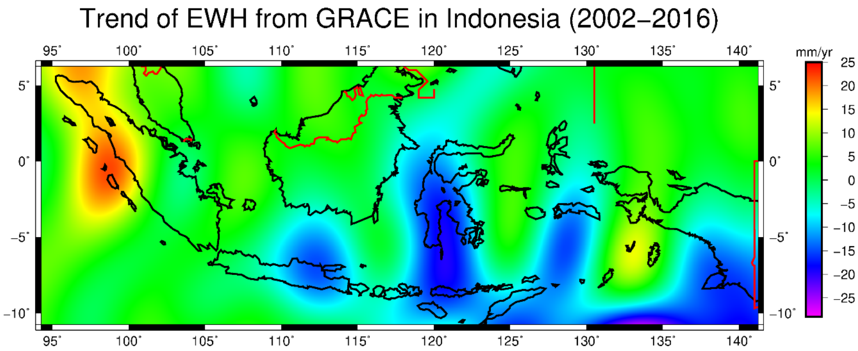
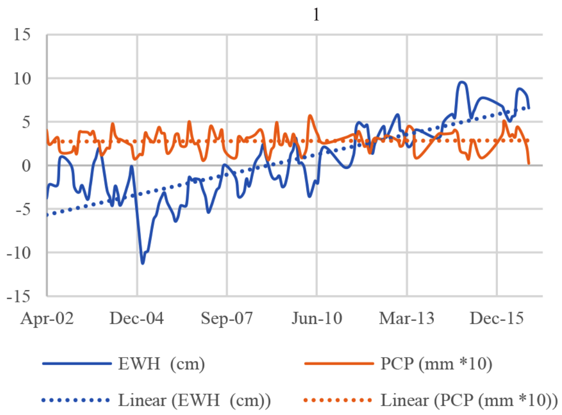
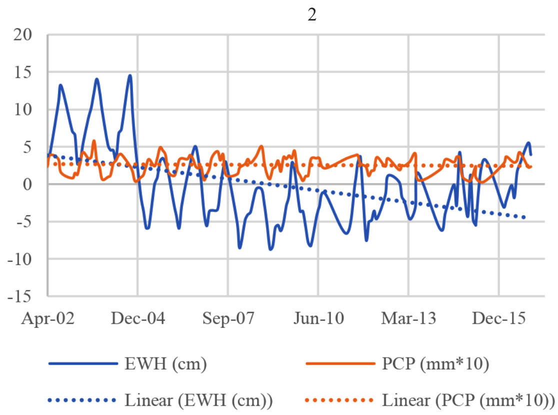


Figure 4. Trend EWH in Indonesia during 14 years



a)



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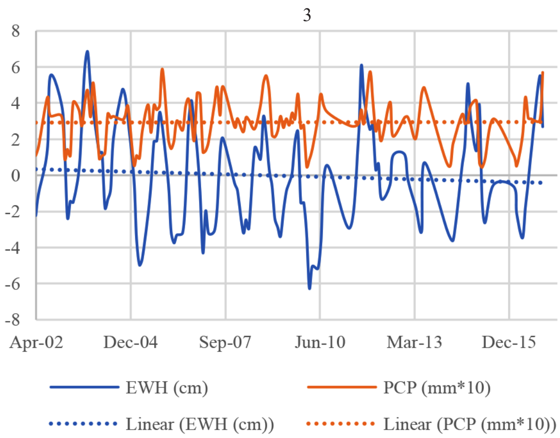

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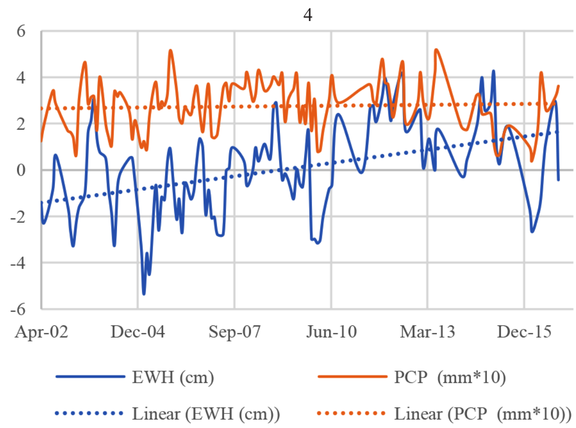

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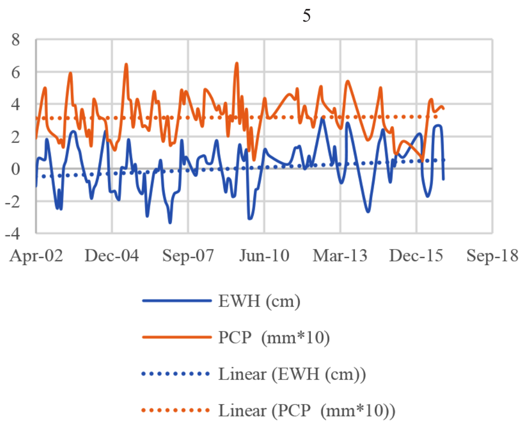

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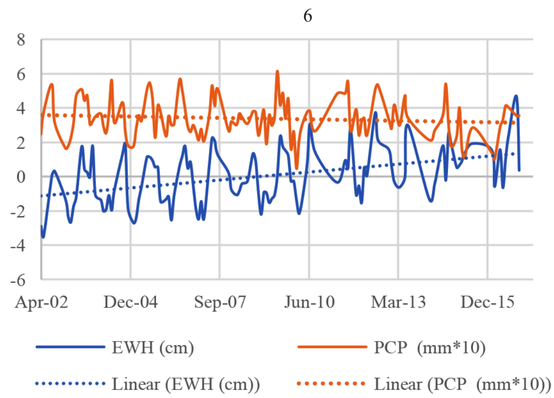
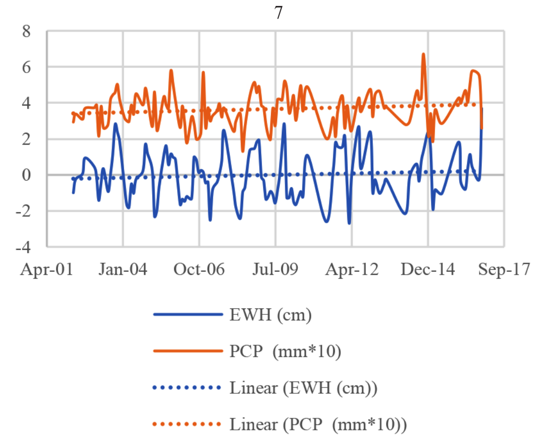
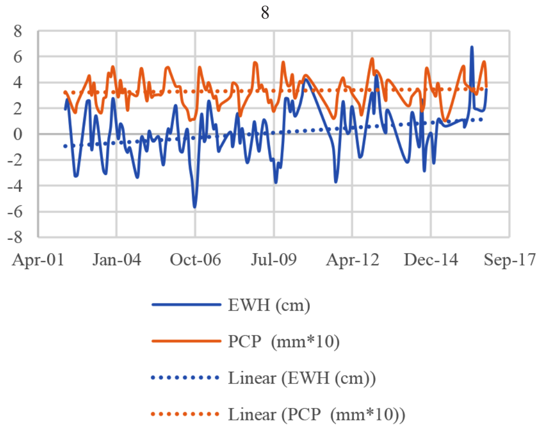


f)

Figure 5. *To be continued*



g)



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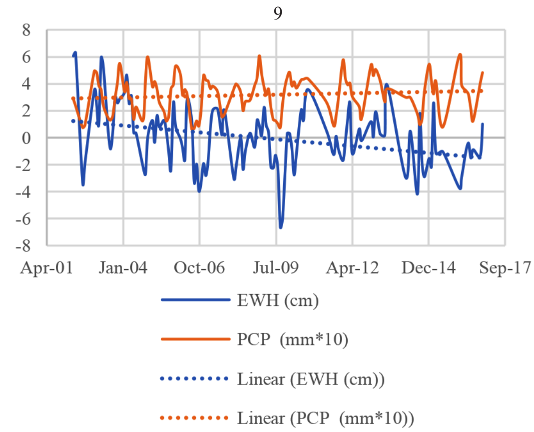

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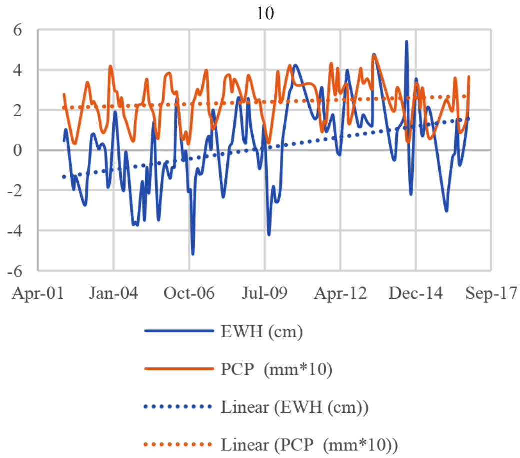

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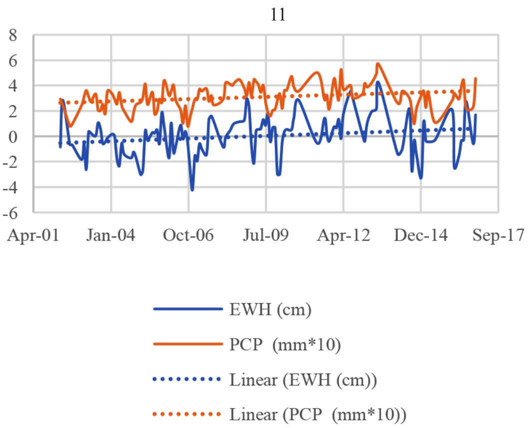
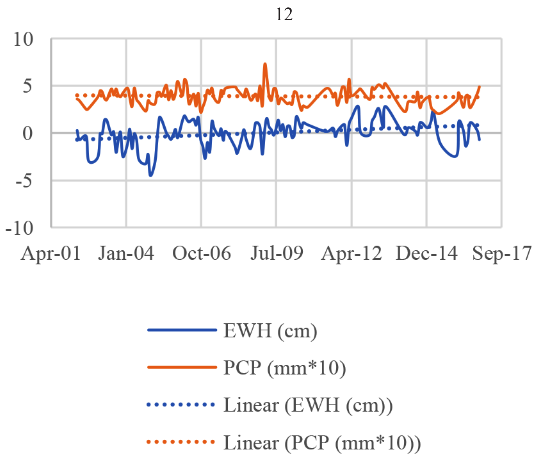
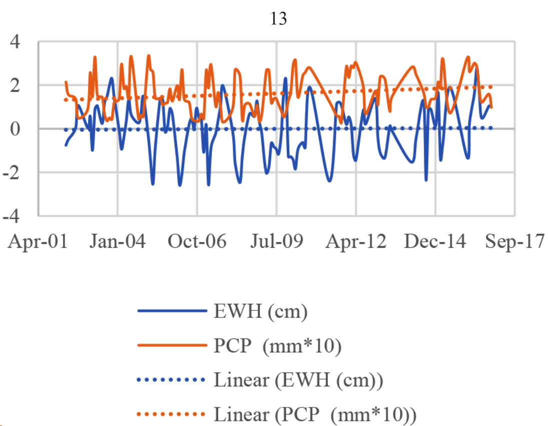


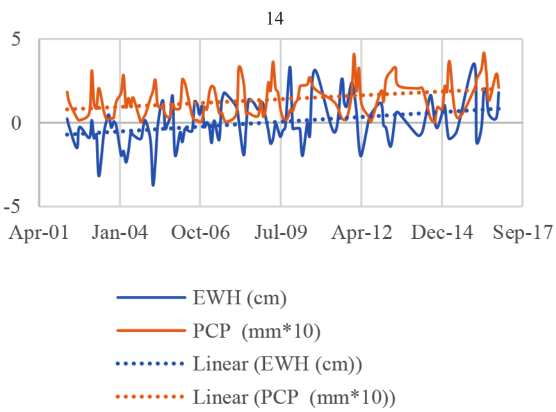
k)



l)

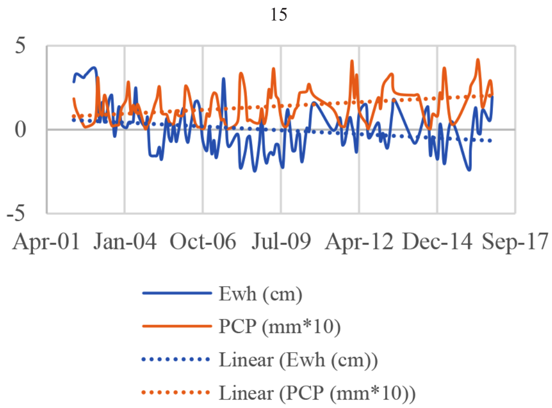


m)

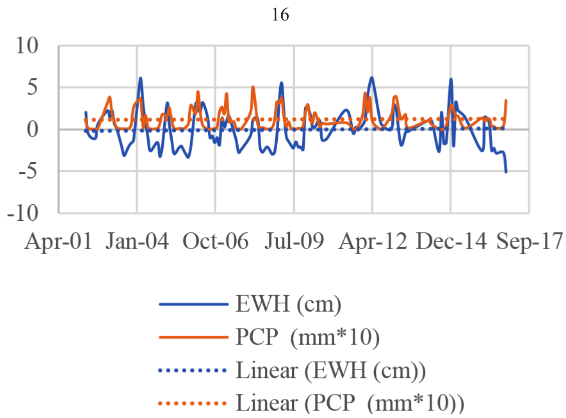


n)

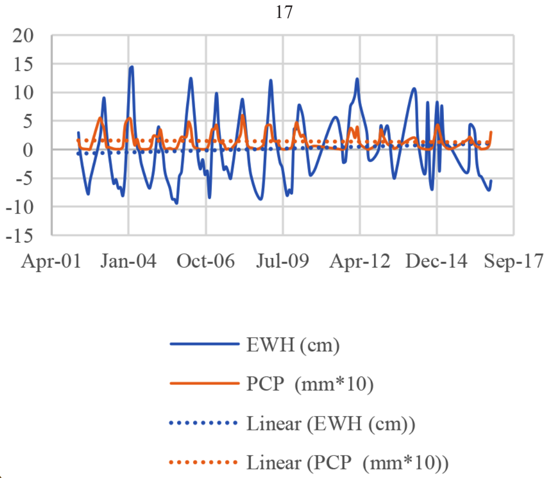
Figure 5. *To be continued*



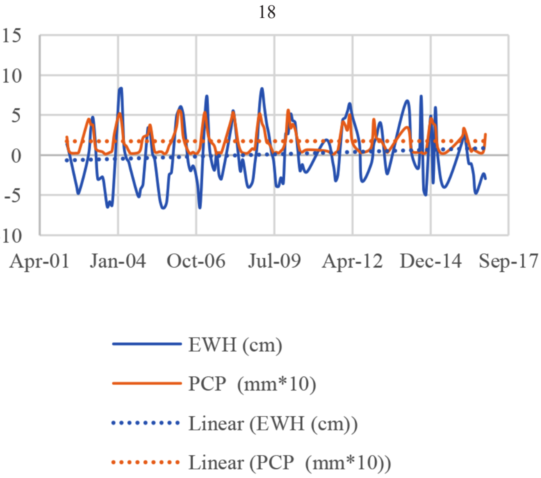
o)



p)



q)



r)

Figure 5. Time series and trend division: a – 1; b – 2; c – 3; d – 4; e – 5; f – 6; g – 7; h – 8; h – 9; j – 10; k – 11; l – 12; m – 13; n – 14; o – 15; p – 16; q – 17; r –18

3.5. Discussion

In Figure 4 it can be seen that in the western islands of Sumatra, East Java and Sulawesi, there have been significant changes in EWH. Sumatra Island is an area that has the largest change in EWH variation rate of ± 20 mm/year (Figure 4), precisely in the eighth region, namely on the island of Sumatra. and eastern Indonesia is the region with the smallest speed ± −26.36 mm/year. This is likely to occur because of the terrible natural phenomena around that in the period of 2002 to 2016 such as the earthquake that occurred in the West Sumatra earthquake in September 2009 so that there was a mass redistribution in large numbers due to the phenomenon .The increase in EWH rate in Sumatra also can be caused by natural disasters that have occurred in 2004 and 2012. earthquakes with magnitudes of 9.2 Mw and 8.6 Mw have changed the gravy field and geoid altitude irreversibly (as opposed to cycles) (Tanaka et al., 2019). It made a significant change in the value of EWH.

A significant increase in the value of EWH also occurred in Region 4, namely the northern part of the island of Sulawesi in 2009 to 2012. Rainfall data from the TRMM satellite also shows a fairly upward trend. Those figures (Figure 5) show that EWH's value in Indonesia for 14 years has increased in all divisions, except for Division 2, 9 and 15 this is also supported by increasing rainfall in the region. According to BMKG (Badan Meteorologi, Klimatologi, dan Geofisika, 2010), since the end of 2014, the conditions at the Central Pacific Equator (Nino 3.4 Index) were in conditions that tended to be warm, this condition continued until July 2015. At the end of July 2015, the Nino 3.4 index was in El Nino Moderate, it causes the 2015 Rainy Season in the Indonesian Region to decline until 10 days from normal.

4. Conclusions

The conclutions of this study are the largest EWH value is 27,298 cm in January 2015 with the position (3.25°; 94.25°) precisely in the eighth part of the region on Sumatra Island, the smallest EWH value of –29.816 cm is in June 2004 with the position (1.25°; 95.25°) precisely in the eighth part of the region on Sumatra Island, the maximum speed of EWH change occurs in the region with the position (–0.75°; 98.25°) which is in the southern sea of Sumatra Island with a speed of 21.71 mm/year, the maximum speed of change in EWH occurs in areas with positions (–10.5°; 133.25°), namely in the southern sea of Irian Jaya Island at a speed of −26.36 mm/year, the part that shows the biggest positive trend is the part of Sumatra, and the part that shows the biggest negative trend is eastern Indonesia.

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