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Estimation of Atmospheric Water Vapor from ANFIS Technique and Its Validation with GPS Data

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Abstract — Adaptive neuro-fuzzy inference system (ANFIS) is a prospective approach in modeling weather parameters based on learning from historical data used. This study presented the comparison of tropospheric precipitable water vapor (PWV) between ANFIS and Global Positioning System (GPS) for areas in Pekan, Pahang, Malaysia. The PWV value was estimated with the ANFIS model with the surface meteorological data as inputs. The accuracy of PWV from ANFIS has been validated with PWV from GPS measurements for the period of 2010. The result showed that the ANFIS PWV has a similar trend with the GPS PWV (r = 0.999 at the 99% confidence level) and found a difference of 0.024%. The PWV from ANFIS was calculated 0.035% higher compared to GPS PWV and found a similar character in two seasonal monsoons. This indicates that the PWV obtained with ANFIS model agreed very well with GPS measurements and it can be implemented to monitor atmospheric variability as well as climate change studies in the absence of GPS data.

Keywords – estimation and validation, ANFIS PWV, GPS PWV, weather forecast

I. INTRODUCTION

Water vapor is one of the essential components in our atmosphere, which has a crucial role in meteorology processes and environmental control especially in understand the behavior of weather and climate change in our Earth. For example, the dynamics of circulation and changes in atmosphere radiation is influenced by the water vapor. This process will affect the transfer and energy formation in the atmosphere [1]. In addition, the water vapor content in our atmosphere is more contributed to generate greenhouse gasses as compared with the other element of greenhouse gasses such as carbon dioxide, nitrous oxide, etc. Although this component is very small, it determines the motion of evaporation and condensation. Understanding of amount, variety, and distribution of water vapor in our atmosphere will help to improve the accuracy of weather forecasts. Due to this importance, several techniques have been developed to measure water vapor content in the atmosphere such as Radiosonde [2] and Global Positioning System (GPS) meteorology [3].

Radiosonde network is one of the tools that can be used to measure the water vapor in terms of precipitable water vapor (PWV). It usually uses a balloon-borne instrument package and sends the package data to Earth via a radio signal through a radio transmitter that is supplied to the instrument. The tool package consists of sensors measuring of temperature, pressure, relative humidity, and wind speed profiles of the atmosphere from the Earth's surface to a height of 30 km. Although it is one of the major networks and excellent instrument to measure PWV vertically, it has some drawbacks for short-term studies in covering temporal and spatial variability as the device restricts the number of launches to twice per day (00:00 UTC and 12:00 UTC) [4]. The PWV estimated from GPS has been applied such as for study the El Niño-Southern Oscillation (ENSO) activity [5, 6], flash floods [7], lightning activity [8], climate change [9,10], etc.

To overcome the limitation of radiosonde, Bevis *et al*. [3] has proposed the principle of estimating tropospheric PWV by using ground-based GPS. This method was updated and evaluated by several authors (e.g., [11,12]). Compared to the radiosonde technique, this method has the capability to measure water vapor in real time with high spatial and temporal resolution, high accuracy, large capacity, and quick variation. However, the availability of GPS data is still lacking which is not available fully 24 hours, particularly for the remote area or area where no GPS receiver provided. Thus, Suparta and Alhasa [13] has been developed a new technique for estimation of PWV without GPS data, which is only needs the surface meteorological data as inputs. The model was developed using adaptive neuro-fuzzy inference system (ANFIS). This model for weather forecasts as of now only developed for the Peninsular Malaysia and Sabah region.

This work primarily studies the greenhouse gasses monitoring system in Pekan, Pahang peatland. The ANFIS PWV model that has been developed will be planted into the microcontroller in order to estimate PWV directly for the next research purpose. Thus, this paper examines the potential use of the ANFIS model to estimate PWV in the Pahang area before it is realized into embedded systems. The result is then validated with other techniques such as GPS meteorology.

II. RESEARCH METHOD

This section gives a brief description of the material, a set of data, and the location of the research. It also describes a brief overview of models, which are used to compute PWV.

A. Dataset and Location

Pekan is a town in Pekan District, Pahang, Malaysia. It is located approximately 50 km from Kuantan as the capital of Pahang State in Peninsular Malaysia. This area was chosen as the location of the study because there are still many native forests which during the summer it can potentially produce burning forests. Burned forests are not only caused by human activity but it can also by the presence of carbon elements in the soil that evaporate into the air. In the tropical region, dry soil can trigger a fire. Another reason to choose the Pekan District is ease of access to the forest. It also has assisted by the Pekan Daerah Forestry Service which gave cooperation to determine the location points of measurement.

For preliminary studies, the main parameters used in this study are the surface meteorology and GPS data. GPS data were obtained from the Department of Survey and Mapping Malaysia (DSMM) via www.rtknet.gov.my. The resolution of downloaded GPS data was 15 seconds daily. The GPS station selected at Pekan, Pahang (PEKN) is geographically located at 03°29'33.36"N, 103°23'22.92"E with ellipsoidal height 26.037 m, as depicted in Fig. 1. The surface meteorological data was obtained from the Weather Underground website, which consisted of pressure, **P** (mbar), temperature, **T** (°C), and relative humidity, **H** (%) with an interval of one-hour. The P, T, H and GPS data are later to be used to compute PWV, which so-called GPS PWV. On the other hand, GPS PWV is weather and climate parameters determined from GPS signals that capable to quantify the water vapor in the atmosphere.

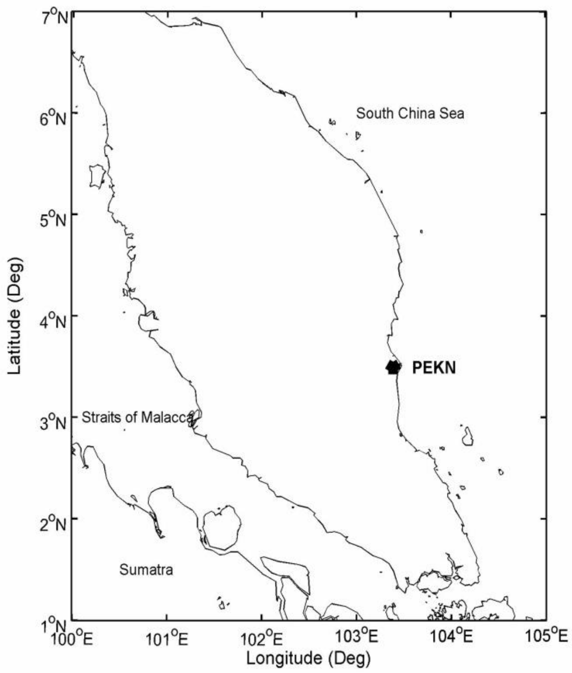

Fig.1. Location of GPS Station at Pekan, Pahang

B. GPS PWV

The tropospheric water vapor program (*TroWav*) which has been written in Matlab by Suparta [14] was used to process PWV from GPS and meteorology data. GPS data is set into a 30 second interval on a daily basis The first procedure in data processing is checking the data quality including cleaning and editing of RINEX data from noise or missing by using a freeware software known as the Translate/Edit/Quality Check (TEQC). TEQC was developed by UNAVCO [15]. In this work, the PWV data was produced with a one-hour interval, due to the surface meteorology data that was obtained is provided in one-hour. The meteorological data was also cleaned for a one-hour resolution. Since the surface meteorology data obtained in this work is not co-located with the GPS station, the interpolation method to obtain high accuracy of PWV should be performed before computation of PWV. The method of interpolating position between GPS and meteorological sensors is handled by applying the concept as proposed by Bai and Feng [16].

PWV total (in mm) from a GPS receiver to the top of the atmosphere was calculated based on the formula proposed by Bevis et al. [3].

$$PWV = \pi(T_m)\ ZWD \tag{1}$$

where ZWD is component wet delay of the atmosphere and the dimensionless $\pi(T_m)$ is a conversion factor that varies with local climates such as location, elevation, season and weather.

$$\pi(T_m) = \left[\rho_{lw} R_v \left(\frac{k_3}{T_m} + k_2^{'}\right)\right]^{-1} 10^6 \tag{2}$$

where ρ_{lw} and R_v are the density of the liquid water and specific gas constant for water vapour, the refraction constants k_1, k_2, and k_3 can be found in Bevis *et al*. [11]. Detailed concept on the GPS processing to compute PWV employed in this work can be referred to Suparta *et al*. [12].

C. ANFIS PWV

The ANFIS PWV model that was developed by Suparta and Alhasa [13] has functions such as the fuzzy inference system (FIS). The ANFIS PWV was constructed in five layers consisted of input layer, fuzzification layer, inferences process, defuzzification layer, and the final output layer. The ANFIS structure that was developed is with three membership functions and rules in layer 1 and layer 4 as adaptive layers. In this process, the layer 1 is act as input to be fuzzified. Inference process and rules are applied in layer 2 and 3. Computation of output for each corresponding rules are carried out in layer 4 and then in layer 5 shows all outputs from layer 4 are combined to get one final output. Figure 2 shows the construction of ANFIS for estimation of PWV value. This model has been trained with the hybrid-learning algorithm.

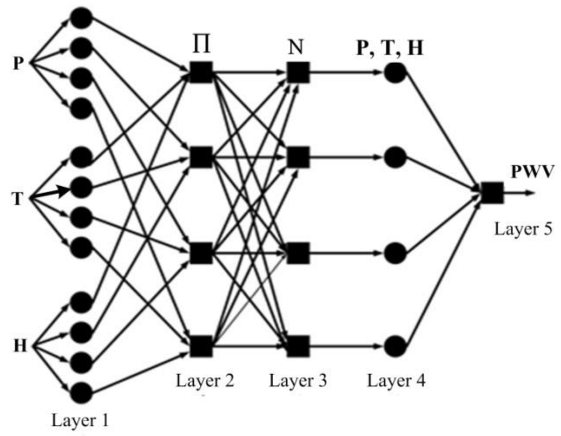

Fig.2. A Structure of ANFIS Model for Estimation of PWV

The entire of the system architecture in each layer of Fig.2 is explained as below [17].

Layer 1: We have three inputs (**P, T, H**). Each input is designed with four nodes as a degree of membership functions. In this work, we used a Gaussian membership function (3).

$$\mu_{Pi}(x) = exp\left[-\left(\frac{x-c_i}{2a_i}\right)^2\right] \tag{3}$$

$$O_{1,i} = \mu_{Pi}(x), \quad i = 1,2 \tag{4}$$

$$O_{1,i} = \mu_{Ti}(y), \quad i = 3,4 \tag{5}$$

$$O_{1,i} = \mu_{Hi}(z), \quad i = 5,6 \tag{6}$$

where μ_{Pi}, μ_{Ti}, and μ_{Hi} are the degree of membership functions for the fuzzy sets P_i, T_i, and H_i, respectively, and $\{a_i,b_i,c_i\}$ is the parameter of a membership function that can change the shape of the function. $O_{1,i}$ is the output of layer 1.

Layer 2: Each node in this layer represents the firing strength for each rule. In the second layer, the T-norm operator (Π) with general performance is applied to obtain the output:

$$O_{2i} = \mu_{Pi}(x) * \mu_{Ti}(y) * \mu_{Hi}(z), i = 1,2 \tag{7}$$

where O_{2i} is the output that represents the firing strength of each rule (w_i).

Layer 3: Each node in this layer is a computation of the ratio between the i[th] rules firing strength and the sum of all rules' firing strengths, or known as the normalized firing strength (N) with the output O_{3i}.

$$O_{3i} = \bar{w}_i = \frac{w_i}{\sum_i w_i} \tag{8}$$

Layer 4: Every node in this layer is a square node with a function (as consequent parameters):

$$O_{4i} = \bar{w}_i f_i = \bar{w}_i(p_i x + q_i y + r_i z + t_i) \tag{9}$$

where $\bar{w}_i$ is the normalized firing strength from the previous layer (third layer) and $(p_i x + q_i y + r_i y + t_i)$ is a parameter in the node.

Layer 5: The single node in this layer is overall output as the summation of all incoming signals from the previous node. In this layer, a circle node is labeled as $\sum$.

$$O_{5i} = \sum_i \bar{w}_i f_i = \frac{\sum_i w_i f_i}{\sum_i w_i} \tag{10}$$

Before the inputs entering in to the first layer of the ANFIS PWV model, it values should be normalized with the scale of -1 to 1 [18]. Normalization is variable scaling to a value between 0 and 1 or between -1 and 1 to minimize the gap in data range when it has extreme values by transforming the data to have a mean of zero and a standard deviation of ±1. In addition, the normalized input and output can accelerate the convergence process during the model training. The process of normalization to fuzzy values is called the fuzzification process [17]. A simple equation to normalize the data as in (11):

$$Y_i = \left(2\left(\frac{X_i - X_{min}}{X_{max} - X_{min}}\right) - 0.5\right) \tag{11}$$

where X_i dan Y_i are represent true and normalized values respectively, and X_{max} and X_{min} are maximum and minimum values of the actual data, respectively.

The next step, fuzzy value as called the degree of membership function (mf) will be evaluated by rule base in layer 2 and layer 3. The first-Sugeno model or TSK (Takagi, Sugeno, and Kang) fuzzy model in the form of a linear equation was used to calculate the PWV value, which known as the defuzzification process. This model is considered popular for data-based fuzzy modeling because it is mathematically simple and has low-consuming computational time [19]. The workflow in estimation of PWV by using ANFIS model is shown in Fig.3.

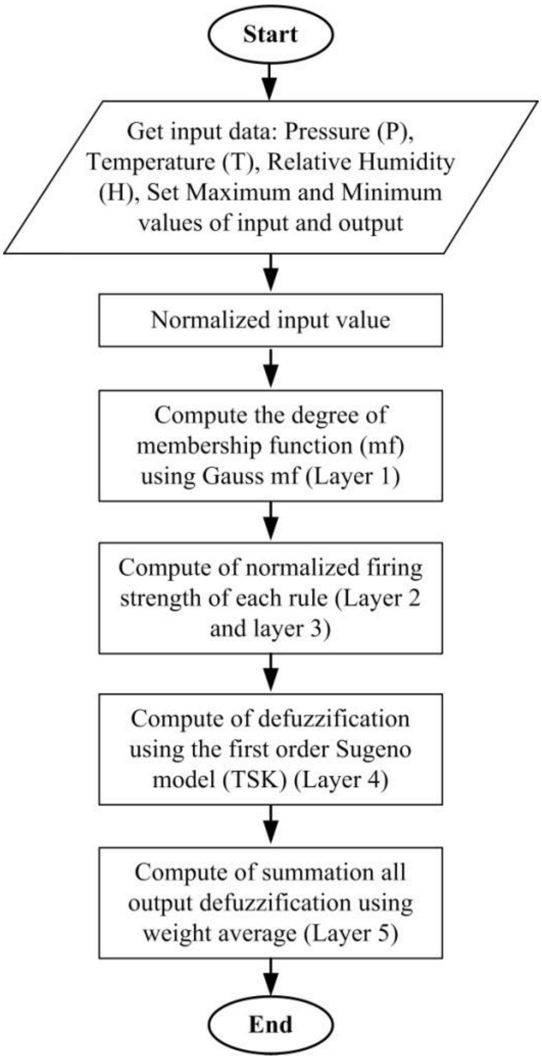

Fig.3. A Workflow For Estimating PWV Using ANFIS

Finally, the PWV value that was estimated by ANFIS PWV model has a one-hour interval. This interval is corresponded to the interval provided in the surface meteorological data (**P**, **T**, and **H**).

III. RESULT

Figure 4a shows the comparison of PWV variation from the ANFIS model and GPS meteorology for the period of 2010 on a daily basis. It can be noticed from this figure that the trend of ANFIS PWV is closely correlated with the GPS PWV. However, the figure shows that GPS data recorded in the half of June and August was nonexistent. However, as seen in the figure, the ANFIS model was capable to estimate the PWV gap occurred in these months. The range for GPS PWV for this area is varying from 38.01 mm to 59.69 mm, while for the ANFIS PWV is from 37.12 mm to 59.70 mm. The average of GPS PWV was 0.035% lower as compared to the ANFIS PWV. On the other hand, the ANFIS model has successful in estimating PWV value when the GPS data is not available.

Figure 4b shows the comparison of time series of PWV average between ANFIS and GPS based on a monthly basis. From this figure, it can be seen that PWV from ANFIS is higher than GPS observation and this is occurred in May and October. While the lowest PWV is recorded in December and is followed in November, January, and February. It indicates that the higher PWV has occurred during the southwest monsoon and the lowest PWV has occurred during the northeast monsoon; wherein the northeast monsoon and the southwest monsoon have maximum and minimum rainfall period, respectively. The trend from PWV variability is likely in the form of a bimodal pattern. On the other hand, during the maximum rainfall period, the PWV will be decreased due to all the water vapor become water droplets.

To clarify the capabilities of ANFIS model, the relationship between ANFIS PWV and GPS PVV is plotted as in Fig.5. Both of methods have a strong linear correlation with r = 0.999, statistically significant at the 99% confidence level. The PWV difference between GPS and ANFIS is about 0.024% where PWV from GPS in computed 0.035% lower than the PWV from ANFIS. This result indicates that the ANFIS PWV have successfully to capture the entire PWV characteristics in the area of Pahang, especially in Pekan District although the location point used in this validation is only one.

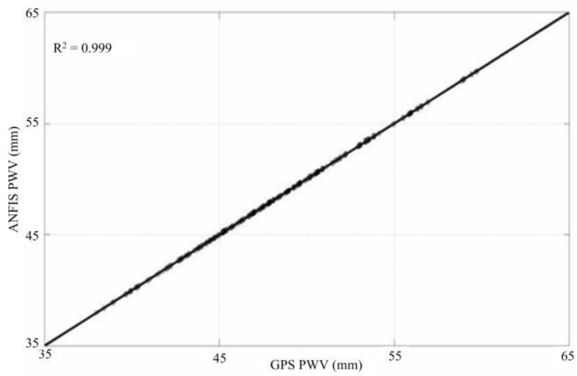

Fig.5. Relationship Between ANFIS PWV and GPS PWV in The Area of Pekan, Pahang for The Period 2010

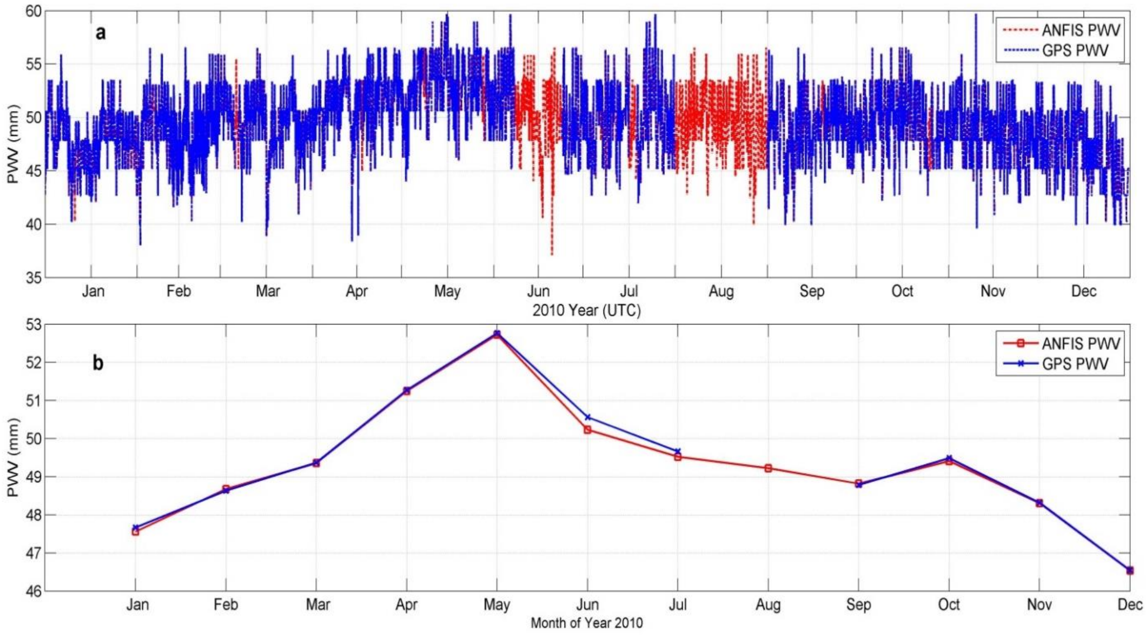

Fig. 4. Validation of PWV Between ANFIS and GPS for The Period of 2010 for (a) Daily Basis and (b) Monthly Average

IV. DISCUSSION

The acquiring information on variations in water vapor variation with a high temporal resolution is important for increasing the accuracy of weather forecasting. The ANFIS PWV can provide alternative and effective techniques for estimating PWV value with a higher time resolution. In this case, the examination of the diurnal cycle of PWV estimated by ANFIS during the two different seasonal monsoons in Peninsular Malaysia will be addressed. For this purpose, the PWV data are processed in daily average during the monsoon period of Southeast monsoon (June-September) and Northeast monsoon (November-December), respectively.

Figure 6 depicts the monthly mean of the diurnal cycle of PWV in Pekan, Pahang area for Southwest monsoon and Northeast monsoon. The red dot is presented for Southwest monsoon, while the blue dot is presented for the Northeast monsoon. In Pekan area, the PWV trend during the Southwest monsoon is starts minima in the morning from 06:00 until 07:00 LT, increasing in 09:00 LT until the late of the afternoon, maxima between 12:00 and 16:00 LT and slow down until the sunset. A similar trend was also shown during the Northeast monsoon, where minima in the morning from 06:00 until 08:00 LT and increasing in 09:00 LT until the late afternoon, maximum between 13:00 and 14:00 LT, and slowly decrease until 19:00 LT. Both of seasonal variations, the second peak of PWV has occurred in the night time before 21:00 LT. This kind of peak occurrence is possibly due to a local circulation such as land breezes. In addition, a large amount of PWV in both of seasons can be observed ranging from 45 mm to 51 mm. The Southwest monsoon in Pekan, Pahang area encounters quite stronger effects than the Northeast monsoon with PWV was higher by 2 mm.

V. CONCLUSSION

For the first time, this study reports the successful of estimation of PWV using ANFIS method in the area of Pekan, Pahang. The ANFIS PWV data was validated with GPS PWV and found that the ANFIS PWV was correlated well with the GPS PWV with a difference of 0.024%. Both of PWVs found to be higher during the Southwest monsoon and lowest during the Northeast monsoon where the diurnal variation is strongly influenced by radiation from the Sun. By this finding, the future work will implement the ANFIS PWV model to monitor the greenhouse gasses variation in Pekan, Pahang peatland. The ANFIS PWV model will then be embedded into a microcontroller to directly estimate the PWV with the meteorology sensors as input.

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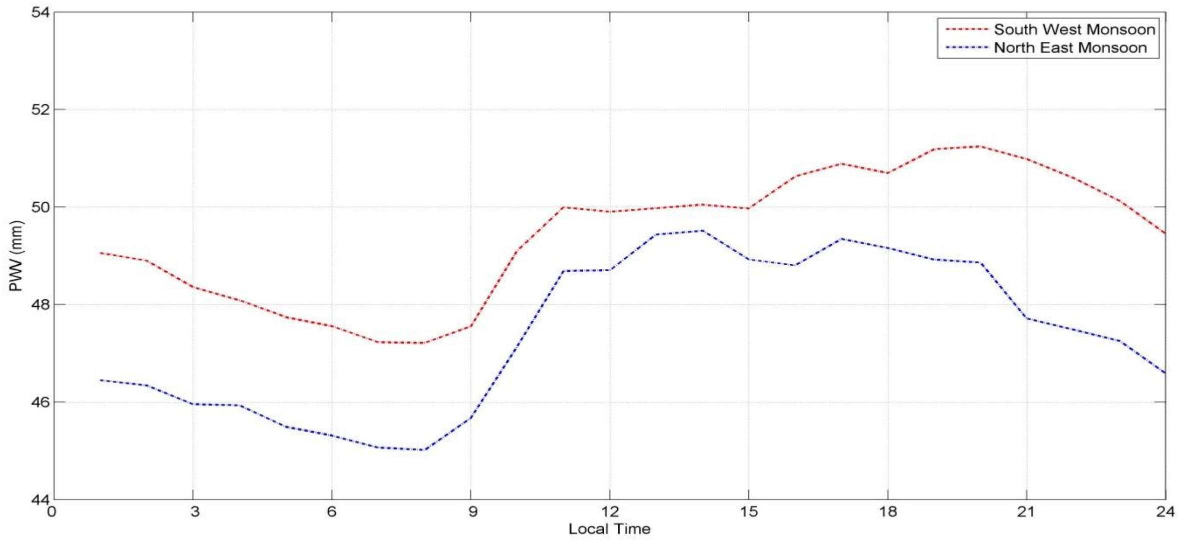

Fig.6. Monthly Mean of Diurnal PWV Cycle Estimated by ANFIS Model During The Southwest Monsoon (June-September) and The Northeast Monsoon (November-December)

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