

## **Anonyms Referee # 2**

Responses to interactive comments of anonymous referee (#2) about our study “**Modeling the Changes in Water Balance Components of Highly Irrigated Western Part of Bangladesh**”

### **General Comments:**

This paper investigates changes in water balance components between 1981-82 to 2012-13 in an area of Bangladesh that is intensively irrigated. First, historical trends are examined using the Mann-Kendal test and discrete wavelet transformation. Then, ARIMA models are developed in order to forecast changes in water balance components. The paper produces some interesting results; particularly around the use of ARIMA models that are fitted to wavelet denoised time series data.

The paper is well organised and about the right length for a study of this kind. Generally speaking the equations are well laid out and easy to follow. However, as it stands the level of English used in the paper is poor, which makes some sections very difficult to follow. I would strongly advise the authors to consult a proofreader who has full professional proficiency in written English. Nevertheless in my judgement the scientific content is sound and represents an interesting approach to analysing and forecasting changes in the water balance. Thus, I would reconsider this paper for publication following a major revision to improve the quality of English as well as addressing the specific points mentioned below.

### **Reply to general comments:**

*We are very much grateful to you for your valuable comments about our study ‘Modeling the Changes in Water Balance Components of Highly Irrigated Western Part of Bangladesh’. We have already gone through your comments and we will incorporate the necessary corrections in the relevant sections. We are also doing necessary corrections in language which is your main concern regarding the manuscript. Actually, we will receive help from two professors of English for doing the corrections in our manuscript. Thank you very much for your suggestions that will help us to prepare a well-organized paper. Yes, the paper is methodological in nature; we have tried to forecast water balance components (WBCs) more precisely after denoising the time series by discrete wavelet transformation. We also expect that there is a scope for further improvement of the methodology by different combinations of wavelet techniques. We will add a discussion section following your suggestions.*

**Action:** *We have written a discussion section (3.4). Please go to reply 11.*

The responses to the specific comments are also presented as follows:

### **Reply to the Specific comments**

**Comment 1:** The Introduction lacks focus, does not provide much critical analysis and does not place the work in the broader context of water resources management. I would like to see the aim of the paper clearly stated in the first paragraph of the paper, so that readers know what the paper is setting out to achieve. The paper is methodological in nature, so the Introduction must make clear to the reader the state-of-the-art in time series analysis for water resources management. Line 82 onwards does include some critical analysis but, in my opinion, it is insufficient to persuade the reader of the approach and its relevance to hydrology more generally. Focus less on the results of studies and instead examine and compare the different ways that previous researchers have tackled the problem.

**Reply 1:** *We also agree with your comments that we need to give more emphasis on the state-of-the-art in time series analysis for water resources management in the introduction section. Thus, we will revise the introduction section following your suggestions.*

**Action:** *We have rewritten the introduction section (1) following the reviewers suggestions.*

## ***1. Introduction***

After introducing the monthly water balance model by Thornthwaite (1948) and afterward followed by Thornthwaite and Mather (1957), this model is going through modifications for adaptation in the different areas of the world and development of the new model is still ongoing (Xu and Singh, 1998) as the water balance model is significantly important in water resources management, irrigation scheduling and crop pattern designing (Kang et al., 2003; Valipour, 2012). Moreover, it can be used for the reconstruction of catchment hydrology, climate change impact assessment and streamflow forecasting (e.g. Alley, 1985; Arnall, 1992, Xu and Halldin, 1996; Molden and Sakthivadivel, 1999; Boughton, 2004; Anderson et al., 2006; Healy et al., 2007; Moriarty et al., 2007; Karimi et al., 2013). Therefore, detecting the changes in WBCs and more accurate forecasting of WBCs are important for achieving the sustainability of water resources management. However, hydro-meteorological time series are contaminated by noises from hydro-physical processes that affect the accuracy of analysis, simulation and forecasting (Sang et al., 2013 and Wang et al., 2014). Hence, it is necessary to denoise the time series for improving the accuracy of the obtained results. In the present study, wavelet denoising technique has been coupled with ARIMA models for forecasting the WBCs after detecting the changes in WBCs by different forms of MK tests and identifying the time period responsible for trends in WBCs time series using DWT time series data.

Generally, physics based numerical models are used for understanding a particular hydrological system and forecasting the water balance or budget (e.g. Fulton et al., 2015, Leta et al., 2016) components. In this method, for reliable forecasting, a large amount of hydrological data is required to assign physical properties of the grid and model parameters and to calibrate the model simulation. However, they have a number of limitations in practice including the cost, time and availability of the data (Yoon et al., 2011; Adamowski and Chan, 2011). Data based forecasting models, statistical models, are suitable alternatives to overcome these problems. The most common statistical methods for hydrological forecasting are ARIMA models and multiple linear regression (Young, 1999; Adamowski, 2007). Many studies use ARIMA model to predict water balance input parameters like rainfall (e.g., Rahman et al., 2015; Rahman et al., 2016), temperature (e.g. Nury et al., 2016) and  $P_{ET}$  (e.g., Valipour, 2012). However, ARIMA model cannot handle non-stationary hydrological data without pre-processing of the input time series data (Tiwari and Chatterjee, 2010; Adamowski and Chan, 2011). Wavelet analysis, a new method in the area of hydrological research, is such a method that is able to handle non-stationary data effectively (Adamowski and Chan, 2011). However, over the course of time some research works have already been done. For example, Adamowski and Chan (2011) coupled wavelet analysis with ANN models for forecasting the hydrological variables like groundwater level in Quebec, Canada. Kisi (2008) and Partal (2009) and Santos & da Silva (2014) develop a hybrid wavelet ANN models for monthly and daily streamflow forecasting respectively. A study conducted by Rahman and Hasan (2014) also finds that the performance of the wavelet-based ARIMA models is better than the classical ARIMA model for forecasting the humidity of Rajshahi meteorological station in Bangladesh. A comparative study of wavelet ARIMA models and wavelet ANN models has been conducted by Nury et al. (2017). The study shows that the wavelet ARIMA models are more effective than the wavelet ANN for temperature forecasting. Khalek and Ali, 2016 develops W-SARIMA and neural network autoregressive model for forecasting the groundwater level. The study also finds that the performance of W-SARIMA model is better than the performance of W-NNAR models. All of these studies mentioned above find that the performance of wavelet aided

model is better than classical ARIMA models and ANN models. Moreover, the analysis of periodicity using wavelet transformed details, and approximation components of hydro-meteorological time series data can better provide insight into trends and effects of time period on trend (e.g. Nalley et al., 2013; Araghi et al., 2014; Pathak et al., 2016). As a result, wavelet transformation of hydro-meteorological time series is gaining popularity in recent years to detect periodicity (e.g. Partal and Küçük, 2006; Partal, 2009; Nalley et al., 2013; Araghi et al., 2014; Pathak et al., 2016). Some studies have been conducted on spatio-temporal characteristics of hydro-meteorological variables such as rainfall (e.g. Shahid and Khairulmaini, 2009; McSweeney et al., 2010; Ahasan et al., 2010; Kamruzzaman et al., 2016a, Rahman and Lateh, 2016; Rahman et al., 2016; Syed and Al Amin, 2016), temperature (e.g. Shahid, 2010; Nasher and Uddin, 2013; Rahman, 2016; Syed and Al Amin, 2016; Kamruzzaman et al., 2016a),  $P_{ET}$  (Hasan et al., 2014; Acharjee, 2017) in Bangladesh. Karim et al. (2012) study the WBCs like  $P_{ET}$ ,  $A_{ET}$ , deficit and surplus of water of 12 districts in Bangladesh and Kanoua and Merkel (2015) study the water balance of Titas Upazila (Sub-district) in Bangladesh. So far, all studies carried out on hydrological variables in Bangladesh have the following limitations: most of the studies were limited to detect trends or forecasting of rainfall and temperature and a few studies on  $P_{ET}$  and water balance. Therefore, the present study has been conducted to detect trends and to identify periodicities in WBCs such as potential evapotranspiration ( $P_{ET}$ ), actual evapotranspiration ( $A_{ET}$ ), annual deficit and surplus of water by co-utilizing DWT and different forms of Mann-Kendal (MK) test in the western part of Bangladesh; and to develop WD-ARIMA models for forecasting the WBCs. To date, there is no comprehensive study that couples wavelet denoising methods with ARIMA models for forecasting WBCs. Wavelet denoising methods are widely used in many other engineering and scientific fields; however, they have been little used in hydrology (Sang, 2013). Hence, it is expected that the new combinations will better explore insight the water balance components which will ultimately help policymakers prepare sustainable water resources management plans.

#### **Comments 2 to 6:**

**Comment 2:** The first half of Section 2.3.1 is probably superfluous: it is well known that PenmanMonteith is the most appropriate method to use to calculate PET, data permitting.

**Comment 3:** Line 137: I'm not exactly sure what 'Deficit' and 'Surplus' mean in this context (nor is it clear why they are capitalised) – provide additional explanation.

**Comment 4:** Line 137-139: It is presented as a fact that 'the concept of water balance in the unsaturated zone...give the best estimation for the real world' - this is quite a statement and surely unjustified. I note that Bakundukize et al 2011 were investigating hydrology in Burundi – are there similarities to Bangladesh? Provide some additional arguments for using the Thornthwaite and Mather model.

**Comment 5:** Line 143: Wolock and McCabe (1999) examined hydrology in the United States – is it reasonable to assume a 5% runoff in Bangladesh, given its tropical climate?

**Comment 6:** Line 145-151: Express the water balance model as equations. The calculation of the water balance is fundamental to the subsequent analysis, so it should be clear what you have done.

#### **Reply to comments 2-6:**

*Thank you very much for your valuable comments. These comments are related to the section 'Calculation of  $P_{ET}$  and WBC (2.3.1)'. We will rewrite this section following your suggestions. Line 137.-we will also add a brief*

description of  $A_{ET}$ , deficit and surplus of water. In line 143, firstly, direct runoff (DRO) is not the total runoff. It is the fraction of rainfall that immediately enters low-lying areas and/or stream channels because of infiltration-excess flow is known as DRO. “The fraction of  $P_{rain}$  that becomes DRO is specified; based on previous water-balance analyses, 5 percent is a typical value to use (Wolock and McCabe, 1999)”. This concept has also been applied to estimate the direct runoff in Bangladesh and yields good results (Karim et al., 2012; Kanoua and Merkel, 2015). About line 145-151, we also agree with you and grateful to you for your critical findings. We will add the equations of water balance components in the main manuscript. However, we may not add the Penman-Monteith equation (Allen et al., 1998) as it is a well-established method.

**Action:** We have rewritten the section 2.3.1 following the reviewer’s suggestions.

### 2.3.1 Calculation of $P_{ET}$ and WBCs

Potential evapotranspiration is the key parameter to estimate WBCs. It has been calculated by Penman-Monteith equation (Allen et al., 1998) in the present study. The soil-water balance concept proposed by Thornthwaite and Mather (1955) is one of the most widely used methods for estimating the WBCs. It is suitable for assessing the effectiveness of agricultural water resources management practices and regional water balance studies as it allows estimating the actual evapotranspiration ( $A_{ET}$ ), water deficit and surplus (e.g., Chapman and Brown 1966, Bakundukize et al., 2011, Karim et al., 2012, Viaroli et al., 2017).  $A_{ET}$  is the amount of water which is removed from the surface due to the process of evaporation and transpiration. The amount by which  $P_{ET}$  exceeds  $A_{ET}$  is termed as deficit and surplus is the excess rainfall after the soil has reached its water holding capacity (de Jong and Bootsma, 1997). It is necessary to calculate the field capacity of the soil for estimating the WBCs. Field capacity of soil in the study area has been calculated using the soil texture map of Bangladesh prepared by Soil Resource Development Institute of Bangladesh (SRDI, 1998) and the description of soils of Bangladesh presented by Huq and Shoaib (2013). Thornthwaite and Mather (1957) suggested values for water holding capacity of soil and rooting depth of the plants have been used for WBCs estimation in the present study. The first step of the calculation is the subtraction of 5% rainfall from the monthly rainfall data as this amount of water has been lost due to direct runoff (Wolock and McCabe, 1999; Karim et al., 2012; Kanoua and Merkel, 2015). The remaining amount of rainfall has been included in the calculation. The WBCs like  $A_{ET}$ , surplus and deficit have been estimated based on the following formulas presented in Table 1:

**Table 1:** Calculations of water balance components (Thornthwaite and Mather, 1957)

		Wet Season $Surplus = (P - R_0) - P_{ET} > 0$		Dry Season $Surplus = (P - R_0) - P_{ET} < 0$	
	$S_B = C_{AP}$	$S_B < C_{AP}$			
		$(P - R_0) - P_{ET} \leq C_{AP} - S_B$	$(P - R_0) - P_{ET} > C_{AP} - S_B$		
$S_B$	$C_{AP}$	$S_B + (P - R_0) - P_{ET}$	$C_{AP}$	$C_{AP} * e^{-APWL/C_{AP}}$	
$A_{ET}$	$P_{ET}$	$P_{ET}$	$P_{ET}$		$(P - R_0) + \Delta S_B$
Deficit	0	0	0		$P_{ET} - A_{ET}$

Here,  $P$ = Rainfall,  $R_0$ = Direct runoff,  $P_{ET}$ =Potential evapotranspiration,  $A_{ET}$ =Actual evapotranspiration,  $APWL$ =Accumulated potential water loss,  $S_B$ =Water stored in soil:  $S_B = C_{AP} * e^{-APWL/C_{AP}}$ ,  $C_{AP}$ = Soil capacity: average rooting depth\* water content at field capacity and  $\Delta S_B$  = Changes in  $S_B$

**Comment 7.** In my view Section 2 would benefit from a short overview describing the reason for carrying out the various steps (water balance, Mann-Kendal, wavelet analysis, ARIMA) and how they relate to one another. At the moment this is not clear.

**Reply 7:** We will incorporate a short overview in the section 2.3. However, there are descriptions on water balance, wavelet analysis and ARIMA model in sections 2.3.1, 2.3.3 and 2.3.4 respectively. Therefore, we will only revise the trend test section (2.3.2).

**Action:** We have written a short over view of the methods in section 2.3 and rewritten the section 2.3.2 following the reviewer's suggestions.

### **2.3 Methods**

*In the present study, WBCs have been calculated and trends in WBCs have been identified by MK/MMK test for evaluating the long-term water balance of the highly irrigated western part of Bangladesh. DWT data of WBCs time series have been analyzed for identifying the time period responsible for the trend in the data. WBCs have been forecasted by ARIMA models and the model performance has been evaluated statistically. If the performance of the model is not satisfactory for forecasting the WBCs, original time series has been denoised using discrete wavelet transformation techniques to improve the performance of the model. The descriptions of the methods have been presented in the following sections:*

#### **2.3.2 Trend Test**

*In the present study, the trends in WBCs have been detected by non-parametric Mann–Kendall (MK) (Mann, 1945; Kendal, 1975) test as it shows better performance to identify trends in hydrological variables like rainfall (e.g. Shahid, 2010), temperature (e.g. Kamruzzaman et al., 2016a),  $P_{ET}$  (e.g. Kumar et al., 2016), soil moisture (e.g. Tabari and Talaee, 2013), runoff (e.g. Pathak et al., 2016), groundwater level (e.g. Rahman et al., 2016), water quality (e.g. Lutz et al., 2016) in comparison to the parametric test (Nalley et al., 2012). MK test cannot appropriately calculate the test statistic (Z) due to underestimating the variance (Hamed and Rao, 1998) if there is a significant serial correlation at lag-1 in the time series data (Yue et al., 2002). The lag-1 auto-correlation has been checked before analyzing the time series data if there is a significant lag-1 auto-correlation at 5% level, the Modified MK (Hamed and Rao, 1998) has been applied instead of MK test. The estimated Z statistic of MK/MMK test has been evaluated for the direction of the trend such as positive Z statistic to indicate increasing trend and vice versa. Moreover, it also indicates the level of significance of the obtained trend, for example, if the calculated Z statistic is equal to or greater than the tabulated value of Z statistic +1.96 that indicates a significant positive trend at 95% confidence level or if it is equal to or less than -1.96 that indicates a significant decreasing trend. Moreover, the sequential values of  $u(t)$  statistic of MK test derived from the progressive analysis of MK test (Sneyers, 1990),  $u(t)$  is similar to the Z statistic (Partal and Küçük, 2006), have been used for investigating the change point detection. The magnitude of the change has been calculated by Sen's slope estimator (Sen, 1968). There are many good explanations (notably Nalley et al., 2012) of these methods mentioned in this section and details regarding these, furthermore, can be referred to Mann (1945); Sen (1968); Kendall (1971); Hamed and Rao (1998); Sneyers (1990); Yue et al. (2002).*

**Comment 8.** Line 154: Which hydrological variables were investigated?

**Reply 8:** *Hydrological variables like rainfall, temperature,  $P_{ET}$ , runoff, groundwater level and water quality have been investigated by MK test to detect trends in time series data. We have mentioned about these in reply 7 (revised section 2.3.2).*

**Action:** *As we mentioned in reply 7, we have rewritten the section 2.3.2.*

**Comment 9.** Line 159: What are these ‘Z’ values, and what is their importance? This is the first the time they have been mentioned.

**Reply 9:** *Thank you very much for noticing the Z statistic. We have incorporated text about Z statistic in reply 7 (revised section 2.3.2).*

**Action:** *As mentioned earlier, we have rewritten the section 2.3.2 and added necessary text on Z statistic.*

**Comment 10.** Section 2.3.7 is unnecessary here unless it specifically influences the scientific results. Instead put this information in an Appendix or similar (however, I congratulate the authors for putting their computer code alongside the paper – this is not done often enough).

**Reply 10:** *This section will be moved to electronic supplementary material (ESM).*

**Action:** *This section will be moved to electronic supplementary material.*

**Comment 11:** I think Section 3 should simply describe the results, with an additional ‘Discussion’ section for placing the results in the context of other studies (e.g. Line 281, 288, 321 etc. should be put in a Discussion section). The discussion should include additional analysis discussing the various limitations and weaknesses of the present study as well as suggesting improvements.

**Reply 11:** *We are grateful to you for your valuable comments. We will incorporate a discussion section (3.4) after the results of analysis following your suggestions. We also hope that this section will help readers about the results described in the manuscript and how can we improve the performance of the model.*

**Action:** *We have written a discussion section (3.4) following the suggestions of the reviewers.*

### **3.4 Discussion**

*The present study reveals that a decreasing trend in  $P_{ET}$  dominates over the study area. However, positive trends in rainfall and temperature dominate in the western part of Bangladesh (e.g. Shahid and Khairulmaini, 2009; Kamruzzaman et al., 2016a). Moreover, a recent study has also found a negative trend in evapotranspiration in four stations located in northwest Bangladesh (Acharjee et al., 2017). Though annual rainfall and temperature of Satkhira station show positive trends (Kamruzzaman et al., 2016a),  $P_{ET}$  shows a significant downward trend. Increasing trends in temperature have been found in Yunnan Province of South China, but  $P_{ET}$  shows decreasing trend (Fan and Thomas, 2012). McVicar et al. (2012) have also found decreasing trends in  $P_{ET}$  in the different parts of the world. Therefore, temperature-based models for the estimation of  $P_{ET}$  cannot well explain the causes of changes in  $P_{ET}$ , though the temperature is the primary driver of changes in  $P_{ET}$  (IPCC, 2007). To get a detailed idea about the underlying mechanisms of changes in  $P_{ET}$ , it is necessary to do a detailed analysis of all climatic variables such as rainfall, temperature, sunshine hours, wind speed, humidity and climate controlling phenomena like El Niño Southern Oscillations (ENSO).*

*The study has also developed WD-ARIMA models for forecasting the WBCs. The performance of the model shows the benefit of denoising of hydrological time series data like  $P_{ET}$ ,  $A_{ET}$ , surplus and deficit. However, the model performance analysis criterion like NSE indicates that the performance of the model for  $P_{ET}$  forecasting is*

acceptable ( $NSE \geq 0.65$ ). To have a closer look at the forecast values and actual values, the deviation between forecast values and actual values increases with increasing time steps. Therefore, WD-ARIMA models are not suitable for long-term forecasting. The present study has developed the WD-ARIMA model by coupling the discrete wavelet denoise time series data and ARIMA model. The soft threshold method has been selected for denoising the time series data and universal threshold (UT) method (Donoho and Johnstone, 1994) which has been used for the determination of the threshold value. However, there are some approaches for threshold value determination such as SURE (Stein, 1981), MINMAX (Donoho & Johnstone, 1998) and so on. Moreover, Wang et al. (2014) develop a hybrid approach for denoising the hydro-meteorological time series such as rainfall and streamflow called adaptive wavelet de-noising approach using sample entropy (AWDA-SE). The study has shown that the performance of the developed denoising method is better than conventional de-noising methods for denoising rainfall and streamflow. These approaches may apply to increase the performance of ARIMA models for forecasting hydrological variables like  $P_{ET}$ . Moreover, there are several mother wavelet families such as Daubechies, Harr, Coiflets, Morlet, Mexican Hat and so on (Sang, 2013). In the present study, only Daubechies-6 from Daubechies wavelet family has been applied as mother wavelet of discrete wavelet transformation. WD-ARIMA models for forecasting the  $A_{ET}$ , surplus and deficit show very good performance, whereas the classical ARIMA model shows poor performance or unable to forecast the WBCs. Moreover, studies (e.g. Chou, 2011; Kisi, 2008; Partal, 2009; Santos and da Silva, 2014; Rahman and Hasan, 2014; Nury et al., 2016; Adamowski and Chan, 2011; Khalek and Ali, 2016) have also mentioned that the performance of wavelet aided models for forecasting non-stationary hydro-meteorological variables is better than classical ARIMA and ANN models. As the traditional methods such as Wiener filtering, Kalman filtering, Fourier transform are not suitable for non-stationary hydrological time series data (Adamowski and Chan, 2011; Sang, 2013), wavelet denoising can be used to improve the performance of the classical ARIMA models for forecasting hydrological variables.

**Comment 12:** Line 265: Use ‘Potential evapotranspiration’ rather than ‘Pet’ in section headings.

**Reply 12:** We will incorporate your suggestion. We will replace  $P_{ET}$  by Potential Evapotranspiration (3.2.1) and  $A_{ET}$  by Actual Evapotranspiration (3.2.2).

**Action:** We will replace  $P_{ET}$  by Potential Evapotranspiration (3.2.1) and  $A_{ET}$  by Actual Evapotranspiration (3.2.2) in the heading.

**Comment 13.** Line 359: This is just a piece of computer code – what does it do, and what insight does it provide that you cannot gain from manual interpretation of ACF, PACF, AIC, BIC?

**Reply to Comment 13:** ACF, PACF, AIC, BIC are important parameters for selection of an accurate ARIMA model for forecasting. For manual model selections, we need to find out the best combinations of these parameters with acceptable error. Besides manual model selections, automatic model selection option of the forecast package of R (R-language software) has been used in the present study. This option helps us find out the best model, especially when we could not find a satisfactory model (model with acceptable error) by manual interpretation of ACF, PACF, AIC and BIC.

**Action:** We have added the answer here for the reviewer.

**Comment 14.** Line 362: What is a Q-Q plot?

**Reply 14:** *The quantile-quantile (Q-Q) plot is a probability plot to check the hypothesis of normality for a certain samples. It is graphical method which compare between two probability distributions based on the quantile values (Filliben, 1975). In our study, we have prepared Q-Q plot to check the normality of residuals.*

**Action:** *We have added the answer here for the reviewer.*

**Comment 15.** Line 386-416: To my mind this passage is the strongest part of the paper -the discussion should emphasise this result and its relevance to water resources management more generally.

**Reply to Comment 15:** *Thank you very much again for your observations and comments. We will add a discussion section as we have mentioned and added in reply 11.*

**Action:** *As mentioned earlier, we have added a discussion section (3.4). Please go to the reply 11.*

**Comment 16:** As I mentioned earlier, I would strongly suggest creating an additional Discussion section in which to discuss the results in the context of other studies, highlight limitations and propose future research directions.

**Reply to Comment 16:** *We have mentioned the matter earlier. We are grateful to you for your comments that help us improve the quality of our present research work. Thank you very much again.*

**Action:** *As mentioned earlier, we have added a discussion section (3.4). Please go to the reply 11.*

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