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Temporal Variation of Groundwater Level and Quality in Tonle Sap Lake basin: Case Study in Chrey Bak Catchment

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Abstract: *Cambodia is lack of surface water in the dry season for serving the need of people in rural area. Another potential source of water may be groundwater, a supplement source to rainwater and surface water for additional irrigation of the wet season and dry season crop. It probably serves the needs of most of the rural and urban population. Being an integral part of the hydrological cycle, its availability depends on the rainfall and recharge conditions. This study was carried out with the objective of understanding the spatial and temporal variation of groundwater level and rainfall and their correlation in a Chrey Bak catchment with around 715 km^2 in area, one of the catchments in Tonle Sap Lake basin, Cambodia. The finding from this research is vital to ensure that groundwater exploitation in the catchment, as well as the whole Cambodia, proceed properly for sustainable use. The results show that the groundwater declined significantly from 2015 to 2016 due to the extreme event. Groundwater level itself in all wells mostly provides a good relationship in terms of the autocorrelation of groundwater level. Furthermore, groundwater variation is also responding fairly well to the rainfall but with some long response time based on cross-correlation analysis.*

Keywords: Chrey Bak, Groundwater, Rainfall, Auto-correlation, Cross-correlation, Temporal variation, Tonle Sap, Cambodia

1. Introduction

Cambodia has been found rich in lasting water resources including the Mekong River and the Tonle Sap Lake (Kummu et al., 2014). These rich resources are crucial in the development sustainability of Cambodia in terms of domestic use, industrial sector, and particularly agricultural sector (W. Yu, Kim, Lee, and Lee, 2018). Up to now, despite that richness, Cambodia agricultural production is lagging compared to neighbouring countries. Water management is one of the reasons (Erban and Gorelick, 2016).

Lacking water resources management (Sithirith, 2017), Cambodia is behind its neighbouring countries in terms of agricultural sector with lower rice production and yields based on ADB'study (Muyhong, 2014). Sithirith (2017) also stated that the reasons behind this are poor water availability and management mainly in the dry season. Cultivation practices in Chrey Bak catchment are dominated by rainfall and surface water irrigation. Rice cultivation in the downstream catchment is mostly dependent on dry season stream flow, which has then caused to damage of rice growing areas by its shortage (CHEM, HIRSCH, and SOMETH, 2011).

Besides surface water, groundwater may play a key role to intervene in this water issue to increase water quantity and to improve cultivation practices; accordingly, surface water and groundwater are both important to raise more opportunity in crop diversification, particularly for dry season cropping. Groundwater use in Cambodia is rising by 10 per cent each year according to the study of Erban and Gorelick (2016). They also found that growing dependence on groundwater could drop the water table below the level at which conventional suction pumps can operate within 15 years. Groundwater may also be used on a small scale for vegetable plantation during the dry season. Accessing to groundwater is an important factor in increasing adaption of double cropping (Chan, Basnayake, Chet, Fukai, and Men, 2004).

Chrey Bak catchment with the area of 700 km^2 is a selected study area located in the Kampong Chhnang province where groundwater irrigation should be considered. However, the exploitation of groundwater for irrigation in this area is low because during the dry season only a few areas are cultivated. A lack of groundwater information and farming techniques may cause the low utility of groundwater. Moreover, a study on its sustainability as a resource for irrigation is not yet developed. In this case, the study of groundwater variation is a key concept to understand the groundwater process, for long term groundwater management.

This paper aims to analyse the temporal variation of groundwater in Chrey Bak catchment and its response to the rainfall using statistical methods, auto-correlation and cross-relation. The seasonal change of groundwater level could also be investigated for proper management in agricultural and domestic use.

2. Materials and Methods

2.1. Study area

Chrey Bak catchment is one of the sub-basins of Tonle Sab lake basin with around 700 km^2 in area (CHEM et al., 2011), which is located in Kampong Chhnang province (Figure 1). Observations were taken in 15 dug wells throughout the catchment to monitor groundwater level (Figure 2). Head measurement in each well is taken every month. The river system in the study area is Chrey Bak River flowing from mountain range of Oral in the west towards Tonle Sab River to the east.

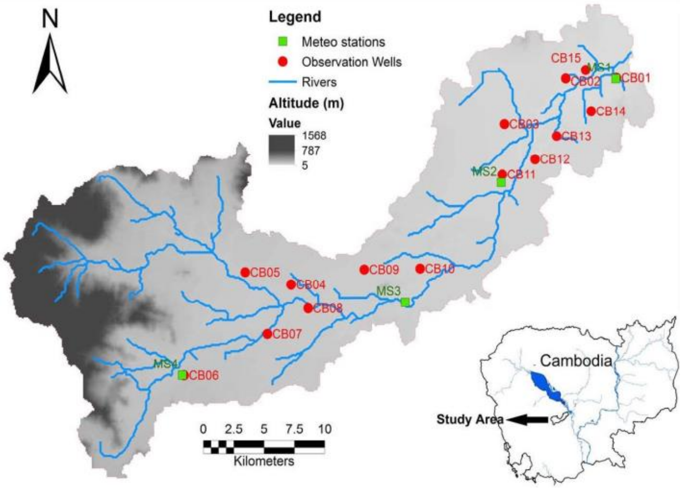

Figure 1: Location of study area (Chrey Bak), monitoring wells (CB), meteorological stations, stream network, and altitude of the catchment

2.2. Well monitoring

A total of 15 monitoring wells were observed in Chrey Bak catchment (Figure 1). Type of monitoring well is dug well which is belong to the inhabitants of the study area. The depth of well varies from 2 to 15 m. Each dug well is composed of concrete sewer pipe with a diameter of around 1.2 m. Most of the wells are pumped daily for the agricultural purpose are domestic use. Groundwater level measurement was taken once a month from upstream (CB04, CB05, CB06, CB07, CB08, CB09, and CB10) to downstream area (CB01, CB02, CB03, CB11, CB12, CB13, CB14 and CB15). Note that the maps clearly show the in-print of the distribution of our observed wells with stream network, digital elevation model, hydro station, meteorological stations and the pumping-test wells. Groundwater samples were collected monthly from fifteen wells to determine the variation for four hydrological seasons (from January 2015 to December 2016) to represent the temporal variation of each well, which will be then analysed with the rainfall during this period. All those wells are dug wells belonging to the villagers, who use groundwater by pumping through their wells hence making a problem with the measurement. The pumping rate and the water level drew down were unclear as the measurement was usually made after the extraction.

2.3. Rainfall

Four meteorological stations were installed in Chrey Bak catchment as illustrated in Figure 1. Rainfall was collected from one of the four stations in Chrey Back catchment and represented in the whole catchment. The groundwater level in wells was recorded with the help of a water level meter in the wells of residents in the catchment. Rainfall-groundwater relation has also been analysed to study how groundwater is highly sensitive to precipitation. Rainfall data is available only in three stations (MS2, MS3 and MS4), where two stations, MS2 and MS3, provided only the data in 2015 since meteorological instrument didn't work well in 2016. Hence, Rainfall of MS4 will be used to represent the precipitation in the whole catchment for 2016. All of the data not available in MS2 and MS3 in 2015 will be simply replaced by the one in MS4 as there is not many available stations around the study area for data interpolation.

2.4. Auto- and cross-relation for temporal analysis

Autocorrelation is the cross-correlation between a time-series itself at different points in time. It is used to quantify the linear dependency of successive values over a time period (Larocque, Mangin, Razack, and Banton, 1998) and study the memory effect, the time a system needs to forget its initial conditions (Mangin, 1984). For an uncorrelated time-series (e.g., rainfall), the autocorrelation function exhibits a sharp decline from one to below a pre-defined value (usually 0.2) within a short time lag. In contrast, an autocorrelation function expressing a slow decline for a long-time lag suggests that the time-series has strong interdependency and a long memory effect. The equation of the auto-correlation function can be written as:

$$C(k) = \frac{1}{n}\sum_{t=1}^{n-k}(x_t - \bar{x}).(x_{t+k} - \bar{x}), \quad k \geq 0$$

$$\gamma(k) = \frac{C(k)}{C(0)}$$

where C(k) is the correlogram, n is the length of the time-series, k is the time lag (k =0 to m, m ≤ n/3), x_t is the value of studied variables at time t, x is the mean value of the series x_t, $\gamma(k)$ is the auto-correlation function.

The cross-correlation analysis focuses on how the input affects the output in a system. The cross-correlation function represents inter-relationship between the input and output time- series. For a random input series, the cross-correlation function corresponds to the impulse response. For the cases where the cross-correlation function is not symmetrical and has a maximum or minimum for a positive lag, this indicates that the input signal has some impacts on the output signal. The lag time which corresponds to the maximum of the cross-correlation function is defined as the response time. The mathematical expression of the cross-correlation function can be written as:

$$C_{xy}(k) = \frac{1}{n}\sum_{t=1}^{n-k}(x_t - \bar{x}).(y_{t+k} - \bar{y})$$

$$\gamma_{xy}(k) = \frac{C_{xy}(k)}{\sigma_x \sigma_y}$$

where C_{xy} is the cross-correlogram, k is the time lag; n is the length of the time-series, xt and y_t are input and output time-series, respectively, $\bar{x}$ and $\bar{y}$ are the mean values of the series x_t and y_t, respectively, γ_{xy} is the cross-correlation function, and σ is the standard deviation of the time-series. To express a significant correlation between input and output time-series at the 95% confidence interval, the cross-correlation function must have a correlation coefficient greater than the standard error ~$2/N^{0.5}$, where N is the number of values in the time-series data (Diggle, 1990; Lee, Lawrence, and Price, 2006).

3. Results and Discussion

3.1. Seasonal changes of rainfall

Seasonal variations in groundwater in any areas are principally due to variations in groundwater recharge, pumping, well lithology and geochemical reactions. The infiltrated water depends on rainfall, the soil environment, agricultural use and the thickness of the unsaturated zone. The rain came lately in 2016 when severe drought occurred during the dry season. This could explain the late coming of precipitation. There were the severe drought in 2016 but the total rainfall of in 2016 is greater than rainfall in 2015. This lead to three peaks of precipitation occurred in the same year where drought occurred.

3.2. Groundwater level fluctuation

Figure 2 and 3 show monthly variations of groundwater level and rainfall at upstream and downstream parts of Chrey Bak catchment over two hydrological years (January 2015 to December 2016). There is a total of 15 individual wells across the catchment, which were used to monitor groundwater level from the high to the low elevation. However, a few measurements of groundwater level were skipped due to the difficulties of accessing to the wells.

At the upstream part, water level variations over the two hydrological years show a slightly different pattern in each well. Water levels in CB8 and CB4 show a significant change in pattern in the second hydrological year. The peak of the groundwater level in 2016 is lower than that in 2015. The drought during 2016 could explain by this variation, and much consumption of groundwater happened in this extreme event. More significantly, groundwater levels of all upstream wells seem to have the trend of a slight decrease at the beginning of 2016.

Water levels at the downstream part show high difference and fluctuation throughout the two hydrological years. The peak of the groundwater level in 2016 is also lower than that in 2015 due to the drought. The water level in CB13 shows the strange fluctuation between March and May 2016 during which there was no rain. Rainfall may occur at the downstream while upstream rainfall is used to represent the whole catchment. Moreover, CB13 is a deep well where the water level is affected by the deep groundwater level. The first hydrological year illustrates different groundwater depth below land surface. However, in the second year, they seem to have the same smooth trend and increase gradually during the rainy season.

Groundwater level is comparatively deeper in periphery and low in the central part to the upstream of the catchment. The lower part of the catchment has comparatively more fluctuated water level than the upper one because this area has many agricultural sites, used small-scale irrigation.

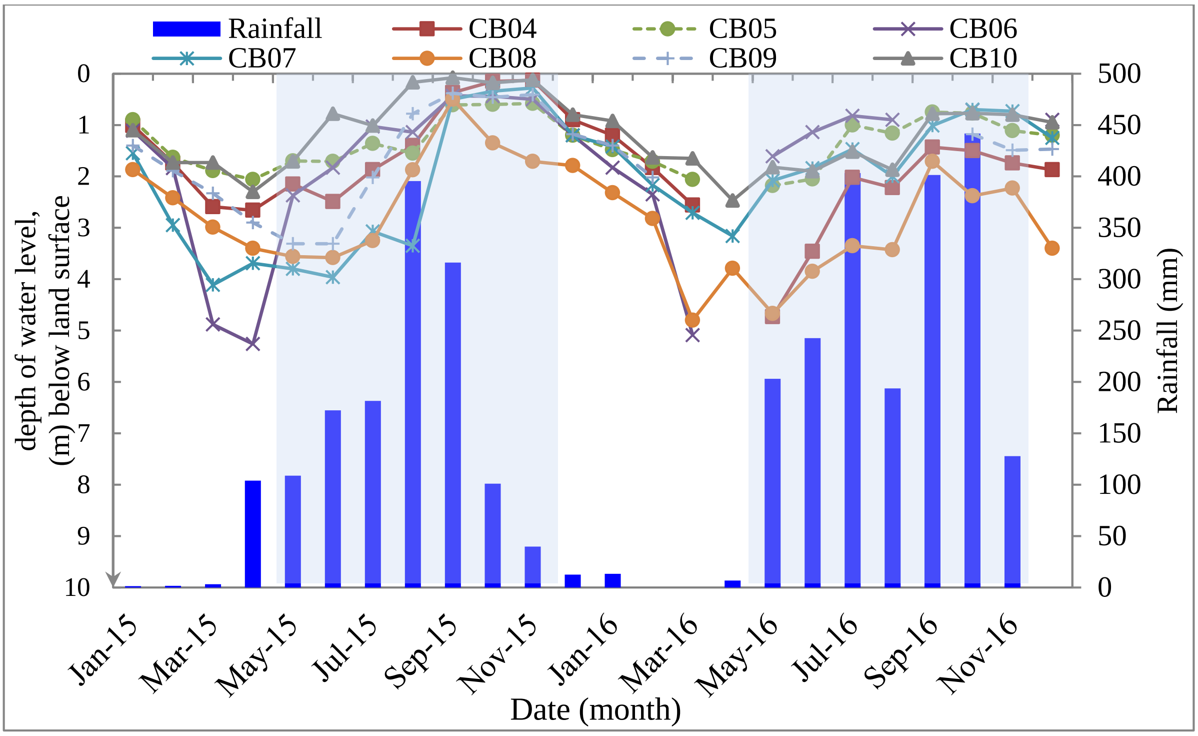

Figure 2: Seasonal variation in rainfall, groundwater level at the upstream part of Chrey Bak catchment

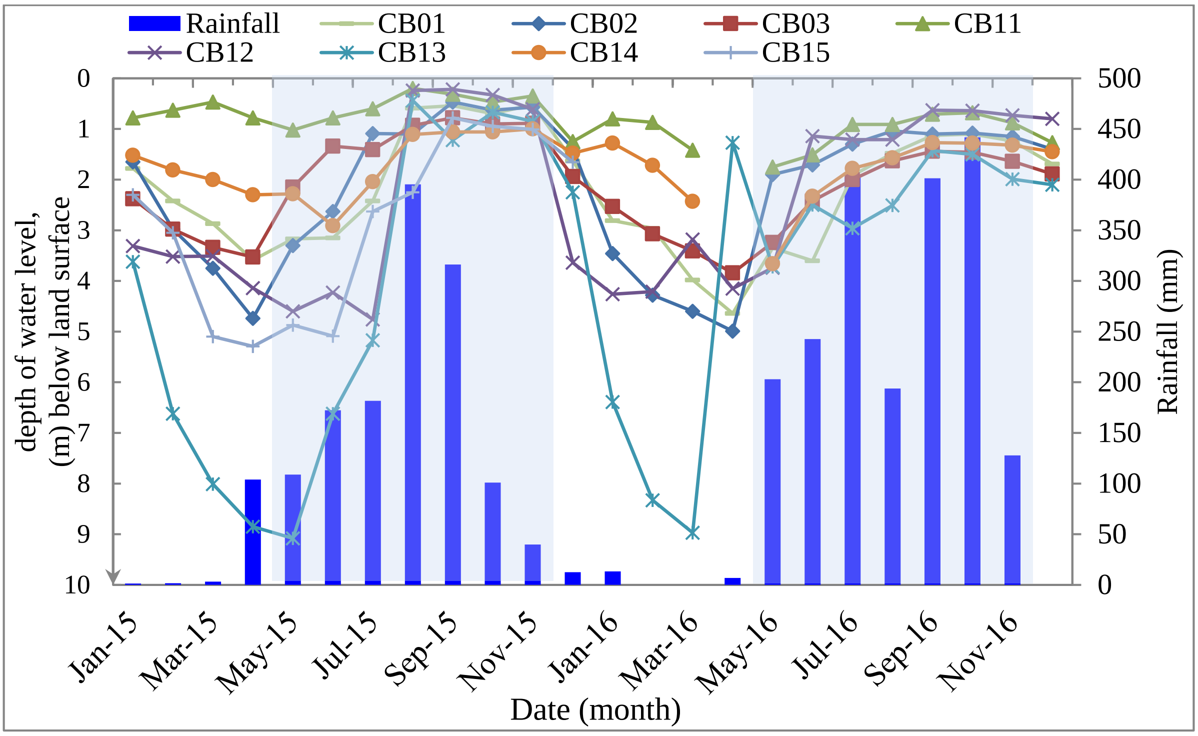

Figure 3: Seasonal variation in rainfall, groundwater level at the upstream part of Chrey Bak catchment

3.3. Auto-correlation and data characteristics

Auto-correlation analysis for the rainfall and groundwater-level time-series data can express the structure of the data. This could help to identify if rainfall patterns have impacts on the groundwater-level variations. At the upstream part, the auto-correlation functions of the rainfall and groundwater-level variations decline in the same pattern (Figure 4). However, the functions of CB5, CB6 and CB9 increase significantly and reach approximately to 0.5. This indicates a good correlation of the groundwater level variations over the two hydrological years. This represents a linear dependency and monthly repetition behaviour of the variable. Unlike other wells and rainfall, the auto-correlation functions of CB4, CB7, CB8 and CB10 show the slightly correlated characteristic of the monthly rainfall and groundwater level variation of the two years. This slight correlation indicates that there might be limited storage in these wells and this could affect the water level variation (Cai and Ofterdinger, 2016). Significantly rainfall shows some correlation through the period itself. However, rainfall time series could not be correlated, and its function declines sharply from one to below 0.2 (Cai and Ofterdinger, 2016).

At the downstream part (Figure 5), only CB1, CB2, CB3, CB14 and CB15 show a good autocorrelation of groundwater level through their period for the two years. However, CB11, CB12 and CB13 provide low autocorrelation whose function is lower than 0.2. Furthermore, CB11 almost reaches to zero due to the low depth of the well itself, and it is very sensitive to the surface water percolation.

3.4. Cross-correlation and recharge implications

The hydrographs clearly show that the water level rises to its peaks in the middle to late of rainy season between August and October where groundwater started to be replenished with rainwater percolation. It clearly shows the significant interactions between rainfall and groundwater level. Rainfall–groundwater interactions are complex and can depend upon a variety of hydro-geological and geographical conditions and can commonly present high nonlinearity (H.-L. Yu and Lin, 2015). The current observed data are monthly measurement and time lags between rainfall and groundwater recharges can vary in 3–75 days (H.-L. Yu and Lin, 2015). In this case, groundwater level response time to rainfall was analysed using cross-correlation where rainfall will be the input and provide the output partly as groundwater.

For the upstream part, the cross-correlation functions show a fairly good correlation (correlation function, $\gamma_{xy} > 0.5$) between rainfall and water level variations for CB4, CB5, CB6, CB8, CB9 and CB10 within a time delay of 2, 3 and 4 months, while a fair correlation (γ_{xy} almost reaches to 0.5) was found for CB7. At the downstream part, the cross-correlation analysis expresses a good response to rainfall within the same time delays as the upstream part for CB1, CB2, CB3, CB11, CB14 and CB15 ($\gamma_{xy} > 0.5$) though it seems to be long in response a time of rainfall to groundwater level fluctuation. And the fair response happened in CB12 and CB13. The longer response time may indicate that the groundwater level fluctuation might be influenced by the characteristic of heavy soil and/or shallow bedrock. All cross-correlation function shows positive response time and indicates that the rainfall does have a direct influence on the groundwater level fluctuation but in different response time based on the geological condition. However, the latter response of rainfall to groundwater level might also be influenced by water extraction for small-scale irrigation and domestic use.

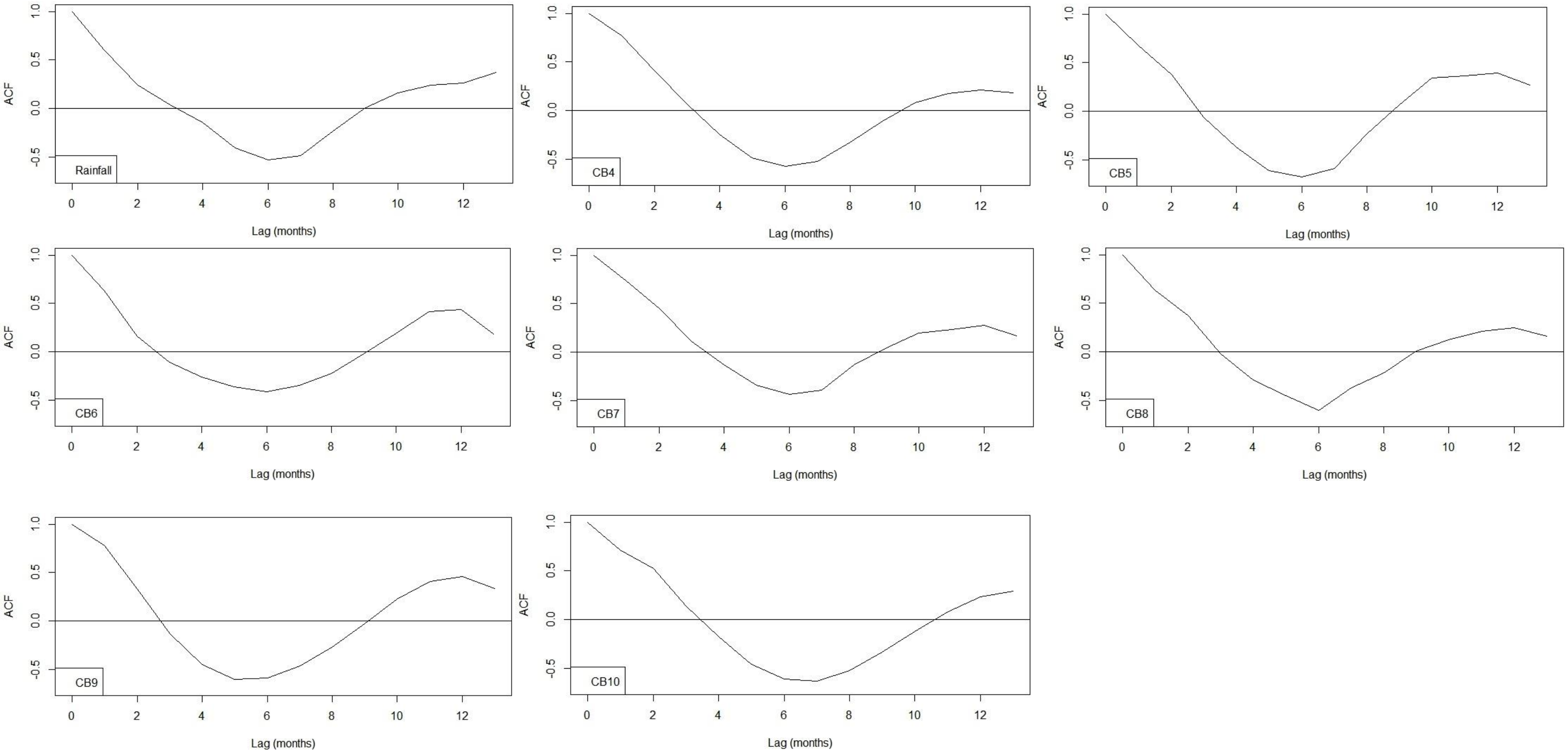

Figure 4: Autocorrelation (ACF) of rainfall and groundwater level hydrographs of the upstream part of Chrey Bak catchment

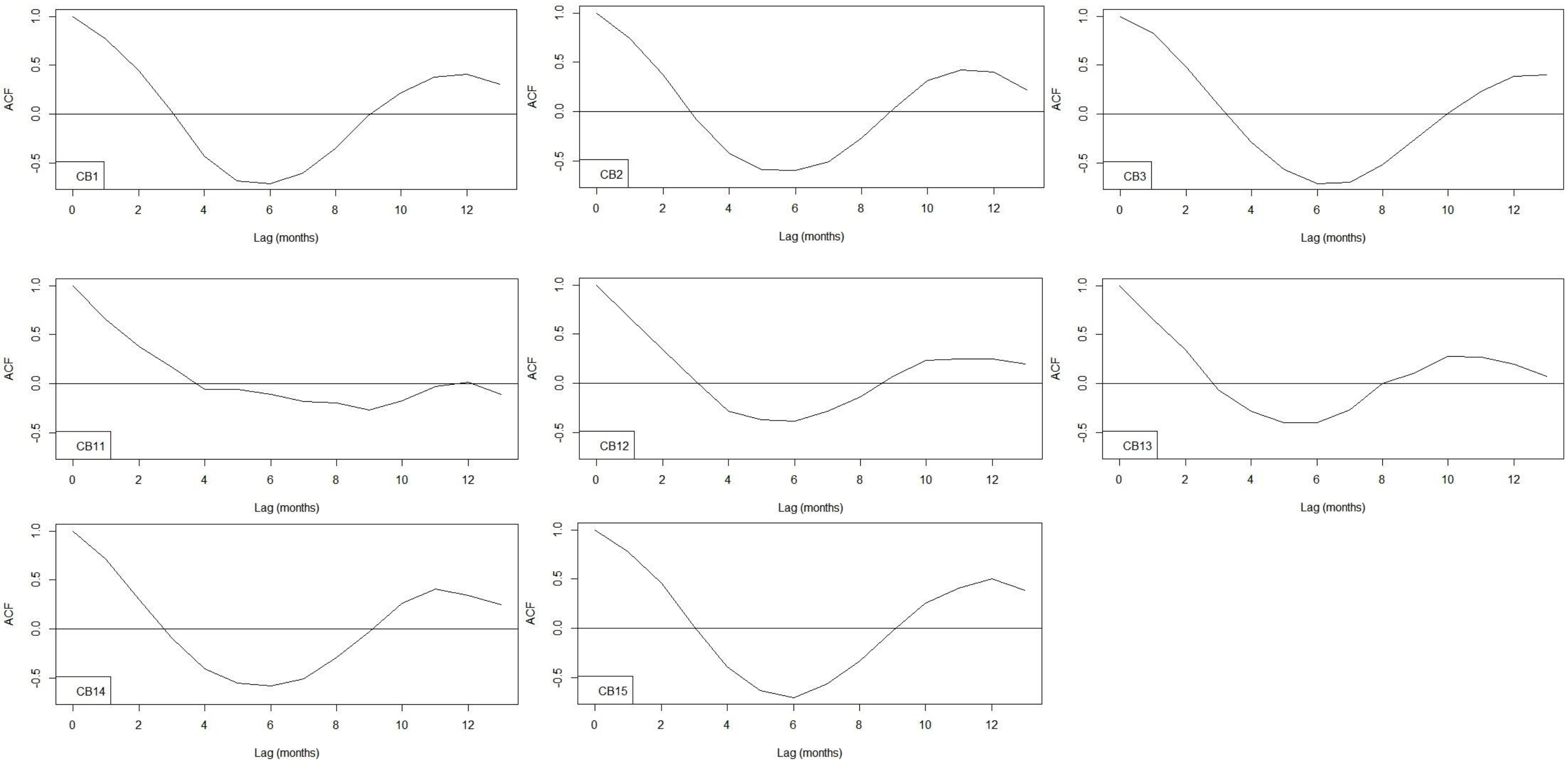

Figure 5: Autocorrelation (ACF) of rainfall and groundwater level hydrographs of the downstream part of Chrey Bak catchment

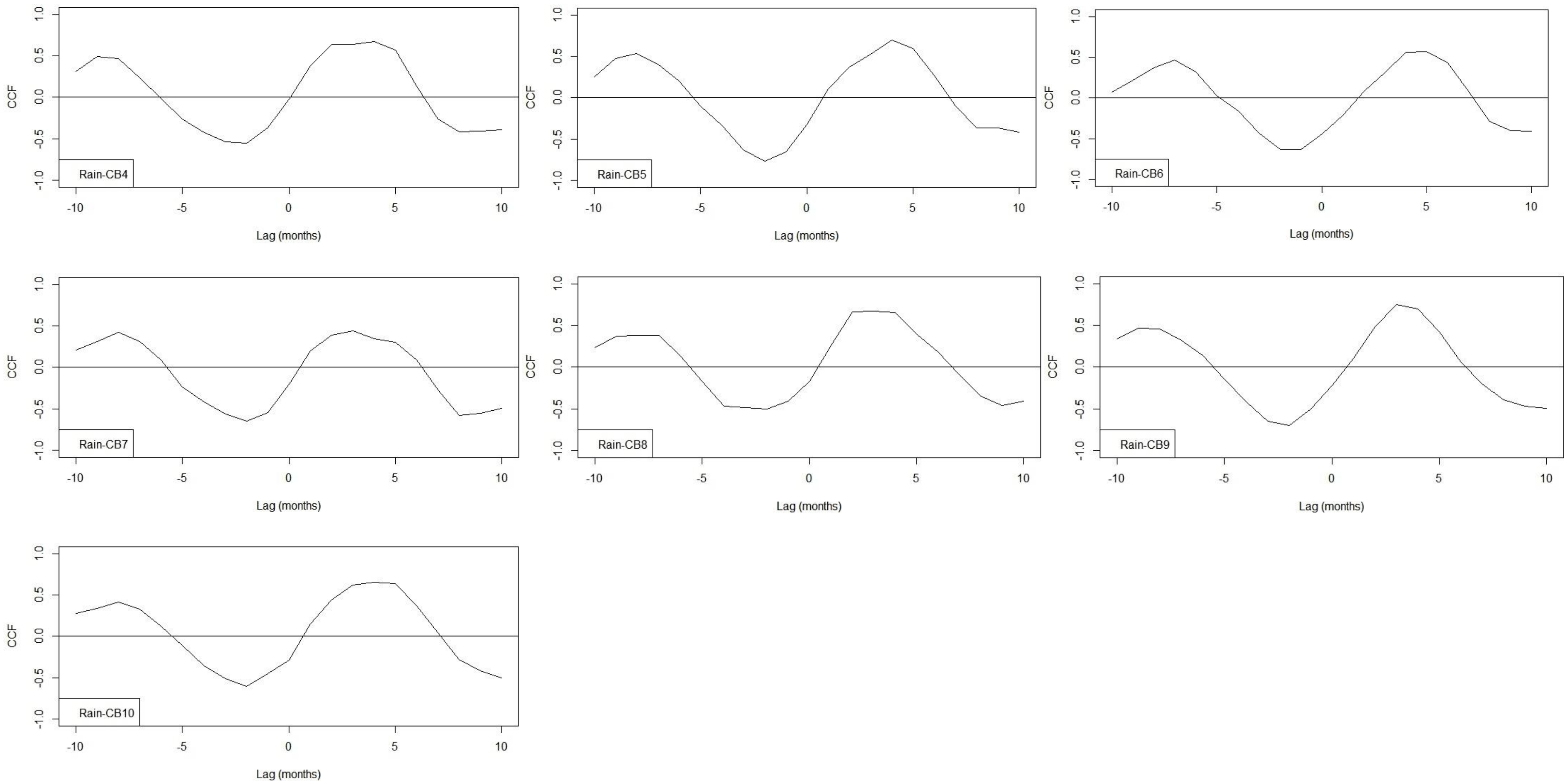

Figure 6: Cross-correlation (CCF) between rainfall and groundwater-level hydrographs at upstream part of Chrey Bak Catchment

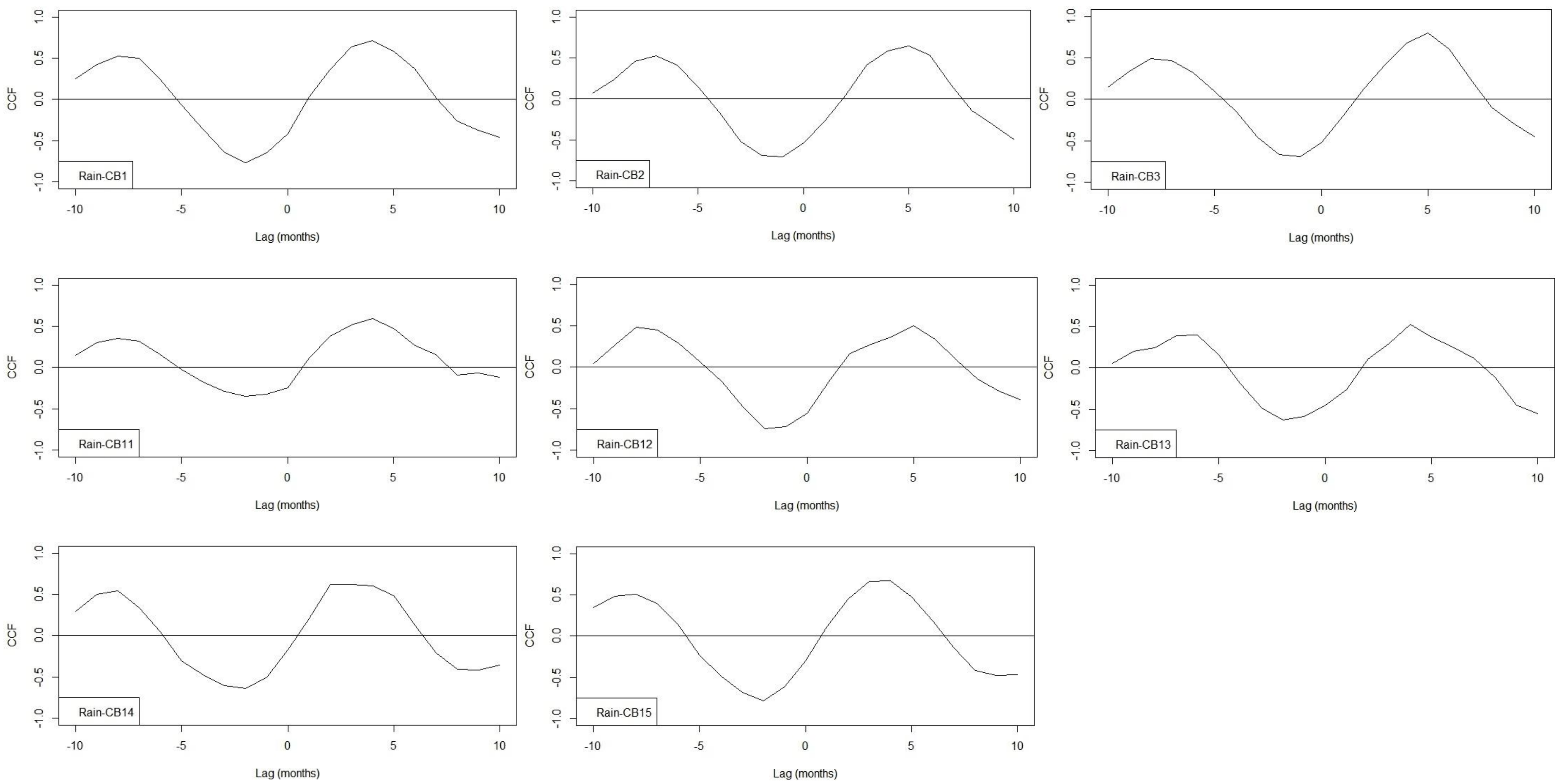

Figure 7: Cross-correlation (CCF) between rainfall and groundwater-level hydrographs at downstream part of Chrey Bak Catchment

4. Conclusion and Recommendations

To sum up, groundwater levels decreased significantly due to the drought, and they fluctuated in the downstream part of the catchment. These upper-part groundwater levels had a slight difference in a pattern over the two hydrological years but they had the same trend of slight decrease at the beginning of 2016. A good correlation of the groundwater level variations over the two years happened only some wells. This good indicator expresses a linear dependency and monthly repetition behaviour of the rainfall and the groundwater in the catchment. The slight correlation of groundwater itself might be due to the limited storage in the wells. Rainfall–groundwater analysis shows a good correlation in some wells with a long response time. It is probably due to different characteristics of soil and geological condition. For the further proper study, field monitoring should be conducted hourly to enhance the description of pattern change, to understand soil characteristic and geological condition of the catchment. The findings of the improved methods will be helpful in groundwater modelling and in better management of groundwater use.

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