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USE OF DISPLACEMENT METHOD WITH STFT WAVELET TRANSFORMATION FOR GROUNDWATER RECHARGES PREDICTION

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Abstract

The main aspiration behind this study was to calculate groundwater recession parameter using recently developed method and to apply calculated parameter for calculation of groundwater recharge. The equation for the hydrograph recession curve can be utilized to predict groundwater recharge during each recession period. The steps involved during recession curve analysis include selection of analytical expression, derivation of recession characteristic and optimization of the parameters. Each segment shows the outflow process which creates short-term or seasonal influence. The variations recession rate causes problems for derivation of recession characteristics. To avoid variations in recession parameters Short Time Fourier Transformation (STFT) was used. While applying STFT in real runoff data recession segments were chosen by user. The selected segments were further used for calculation of groundwater recharge assuming a linear hydrological model. The runoff hydrograph represents consist of three components: surface flow, intermediate flow and base flow. The applications of wavelet transformation can differential those flow components into were short, intermediate and long wavelet periods. The displacement method was used to obtain further information from wavelet transformation and to verify its practical application in groundwater studies.

Introduction

Groundwater has been an important part of hydrological studies. Groundwater plays a vital role in water system which acts as prominent source of water supply. The computation of groundwater parameters is an essential part of hydrological studies which provides knowledge about the climatic effects on the watershed (Hanson and Dettinger, 2005). It also provides the supply volume by which surface vegetation and nature can be preserved long duration of time. There are various methods of groundwater recharge in which hydrograph recession analysis is one of the prominent methods. In this method recession parameter indicates the flow of groundwater to surface water system. There are also various methods of recession analysis such as individual curve method, master recession curve and wavelet transformation. The recession parameters are obtained from hydrological time series using matlab codes. Also matlab codes are used to compute groundwater recharge for comparison using water balance method. Among the methods, wavelet transformation produces promising results in which end of direct flow and location of base flow component can easily determined (Sujono, et al., 2004). But the method is only capable visual analysis and is not applicable for the calculation of groundwater features. In this study an associative method is examined using displacement method and wavelet method to predict groundwater recharge of the catchments. To verify the accuracy of results the obtained groundwater recharge is compared to groundwater recharge from water balance. The components computed from water balance include errors but are negligibly small when computed for large catchment area (Kumar and Seethapathi, 2004). So, water balance approach is one the reliable approach for comparison of results for accuracy. The wavelet transform approach, however, produces promising results and minimizes a number of problems associated with hydrograph recession analysis. The end of direct flow and the location of the base flow component are easily determined through the wavelet maps. The wavelet transform approach, however, produces promising results and minimizes a number of problems associated with hydrograph recession analysis. The end of direct flow and the location of the base flow component are easily determined through the wavelet maps.

A runoff hydrograph aggregates information about water sources and flow characteristics. It contains three flow components: quick flow, interflow and base flow. The base flow component defines the groundwater contribution to surface water system. The base flow component can be separated by using various methods for further study of catchment response to base flow. The hydrograph recession analysis is one of the prominent methods (Onderka et al., 2013). The separated hydrograph section is used for prediction of groundwater recharge using associative method. The equation (1) is exponential expression for base flow in depletion recession hydrograph (González et al. 2011).

$Q_t = Q_o e^{-\alpha t}$ or $Q_t = Q_o K^t$

(1)

Where

Q_t = runoff at time t

Q_o = initial runoff at time t

$k = e^{-\alpha}$ = recession constant

The recession parameters can be used for quantifying various hydrological processes. The most common application in which the recession parameters is used are low flow forecasting, estimation of groundwater resource of the catchment, rainfall-runoff models and hydrograph analysis (Matonse and Kroll, 2009). Hydrograph recession analysis can be carried out in using the semi-logarithmic plot of a single hydrograph segments, master recession, relative new approach based on wavelet transformation and base flow separation (Sujono et al.,2004). The wavelength transformation has been only used for comparison of recession constant. The process is relatively new and requires further study to relate with groundwater processes. The further calculation requires initial flow and recession period. The calculation of these flow characteristics requires further studies on reconstruction of original signal. The original signals can be obtained from STFT transformation but phase angle cannot be regenerated (Zhu et al., 2007). Due change in phase angle random data is obtained and data obtained is not equal to original data. The FFT of signal results in randomization of phase. By doing IFFT original signal can be regenerate but at random phase (Rathod et al., 2014). By using this method the frequency at which base flow occurs is only obtained. It is unable to determine the original runoff and time at which base flow starts.

Material and Methods

The two catchments studied are Marjasuo and Röyvänsuo. The geographical locations for Marjasuo and Röyvänsuo catchments are at 65o48’19.79’’ latitude and 27o48’42.246’’ longitude and 65o49’12.213’’ latitude and 27o48’13.978’’ longitude respectively. Marjasuo covers land area of 65ha (0.65km²) while Röyvänsuo covers 75ha (0.75km²). The data used were runoff, precipitation, temperature and groundwater level which were recorded in catchment for the study duration.. The rainfall data was continuously collected by installing tickling bucket in the site. Temperature, runoff and groundwater level was continuously collected by data loggers. The runoff data was collected using Thomson V-notch weir dimensioned as per site. Runoff for each time step was calculated by using depth of water measured by Thomson-weir method. In this method flow depends on cross section of weir and backward accumulation height.

The yearly discharge data obtained from the catchment was used draw an annual hydrograph. From the annual hydrograph the recession segment are selected using Matlab codes. The selection recession segments were carried out on yearly basis. The numbers of recession segments for each year were different depending on the number of depletion curve formed on an annual hydrograph.

The short time discharge data were transformed to short time frequency wavelets using STFT. Each individual declining discharge data sets were transformed to frequencies using FFT. The transformed frequencies were adjusted to a Nyquist zones which acts as band filter for the low flow computation. From each Nyquist zones the central frequencies were computed using Matlab code. The centered frequency obtained from wavelet analysis was used to find the recession parameters for the catchment. The equation for calculation of recession parameter k using the centered frequency is shown in equation (2) (Sujono et al., 2004):-

K = e-fc

(2)

Where

k = recession parameter

F_c= centered frequency from Nyquist zone

Now, for the further computation of groundwater recharge displacement method was used. The selected short time discharge data, time of recession and recession parameter from the above calculation were used. The calculations of final discharge and groundwater recharge during recession period were carried out assuming a linear relation storage discharge relationship. The equation for potential groundwater flow, residual of potential groundwater flow and groundwater recharge during recession period is shown in equation (3), (4) and (5) respectively (Ichwana et al., 2013). Finally, the groundwater recharge obtained was compared with the groundwater recharge from water balance for accuracy.

$$V_{tp} = (Q_0 \times t_1) / 2.3 \quad (3)$$

$$V_r = (Q_0 \times t_1) / (2.3 \times 10^{t/t1}) \quad (4)$$

$$VR = V_{tp} - V_r \quad (5)$$

Where; Q_0= runoff when t = 0 (m^3/s)

V_{tp} = total potential runoff at beginning (m^3)

V_r = total potential runoff volume at end (m^3)

VR = volume between recession (m^3)

Results

The central frequency of each recession segments from wavelength transformation method was used to compute recession parameters from year 2010 to 2013 for each study catchments. From the recession parameters groundwater recharge on each hydrograph segments were computed.

Table 1 and Table 2 show the calculation of groundwater recharge using central frequency and displacement method. Similar calculations were made for 2011 to 2013 and results are shown in Table 3.

Table 1: Groundwater recharges calculation for Marjasuo catchment with 2010 data

Marjasuo (2010)								
Q_o	f_c	$K = e^{-fc}$	T (d)	Q_t (m^3/s)	T1(d)	Vtp (m^3)	Vr (m^3)	VR (m^3)
0.0081	0.005	0.995	14	0.0076	470.36	143119.27	133639	0.0146
0.0054	0.004	0.996	4	0.0053	566.49	115552.83	113689	0.0029
0.0103	0.008	0.992	5	0.0099	291.86	112928.79	108561	0.0067
0.0047	0.003	0.997	10	0.0045	667.27	117058.96	113088	0.0061
0.0384	0.026	0.975	13	0.0275	89.899	129679.43	92953.1	0.0565
0.0215	0.015	0.985	15	0.0172	155.62	125688.36	100672	0.0385
0.0104	0.007	0.993	6	0.0100	328.71	128419.56	123134	0.0081
Total								0.1334

Table 2: Groundwater recharges calculation for Röyvänsuo catchment with 2010 data

Röyvänsuo(2010)								
Q_o	f_c	$K = e^{-fc}$	T (d)	Q_t (m3/s)	T1(d)	Vtp (m3)	Vr (m3)	VR (m3)
0.0156	0.0098	0.990	5	0.0149	234.59	137472	130888	0.0088
0.0097	0.0072	0.993	10	0.0090	318.81	115952	107873	0.0108
0.0573	0.0342	0.966	13	0.0367	67.365	145003	92982	0.0694
0.0095	0.0060	0.994	8	0.0091	380.65	136386	129943	0.0086
0.0280	0.0174	0.983	15	0.0216	132.52	139392	107412	0.0426
0.0148	0.0062	0.994	5	0.0143	372.40	207043	200740	0.0084
Total								0.1485

Table 3: Groundwater recharge obtained from 2011 to 2013 for both catchments

Year	Marjasuo	Röyvänsuo
2010	0.1334	0.1485
2011	0.1256	0.1975
2012	0.0417	0.1529
2013	0.0862	0.0771

The groundwater recharge calculated by using displacement and wavelet method must be confirmed due to uncertainty arrival from inadequate data, measurement errors and complex spatial and temporal heterogeneous characteristics of hydrological processes. For the verification of accuracy the groundwater recharge obtained were statically compared to groundwater recharge from water balance method. The groundwater recharge calculated from water balance method is shown in Table 4.

Table 4: Groundwater recharge calculated from water balance method

Year	Marjasuo	Röyvänsuo
2010	0.1352	0.1472
2011	0.1292	0.1963
2012	0.0435	0.1532
2013	0.0824	0.0774

Various previous researches had proven the water balance estimates are often precise. Water balance estimates are important part of quality control and can be used to eliminate the changes from imprecise data. So, to verify the accuracy of the results obtained, the groundwater recharge obtained for both catchments were compared statistically using Pearson's correlation test and Kendall test. Table 5 shows the statistical test results from two methods for each catchment.

Table 5: Results from statistical comparison of groundwater recharge for each catchments

Method	Pearson's Correlation						Kendall's Rank		
Catchment	t	df	p-value	95% CI		Correlation	t	p-value	Tau
Marjasuo	19.659	2	0.002577	0.8778	0.9999	0.9974	6	0.0833	1
Röyvänsuo	102.63	2	9.493E-05	0.99522	0.99999	0.9999	6	0.0833	1

Conclusion

The test results obtained showed there is statically significant relationship between groundwater recharge calculated from both method. The Pearson's showed strength of relation terms of correlation coefficient which was nearly equal to 1 and statically significance was also obtained to be very high. Similarly, the rank based Kendall's test also showed there was is close association between two yearly groundwater recharge values. The coefficient Tau is obtained to be 1, which justifies the close association between two variables.

On the basis of the results comparison between combined wavelet and displacement method and water balance method, it was justified that the combine method was a reliable and accurate method of groundwater calculation. The method uses shot term discharge data hence the errors due to temporal and spatial variations in hydrological process can be eliminated. It also contributes in use of modern emerging method of wavelet transformation for quantifying groundwater properties. The information obtained can be developed and applied in many practical problems. The results obtained can be implicated for the purpose of rainfall designs, storage yield, and prediction of meteorological, study of hydrological and ecological processes.

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