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CHANGES IN THE CHARACTERISTICS OF SURFACE-SUBSURFACE WATER INTERACTIONS IN HUMID AND SEMI-ARID TROPICS

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ABSTRACT

Changes in precipitation characteristics, especially intensity, duration and number of rainy days have significant impact in the surface-subsurface water interactions. The changes in land surface and rainfall characteristics over the past few decades have posed immense stress on hydrological regimes of river basins. The problem is more severe in river basins draining densely-populated reaches like that of Western Ghats. In this study, changes in groundwater recharge and its relation with the changes in precipitation characteristics were studied in a watershed in the Attappadi Critical Zone Observatory (CZO). In order to understand the influence of vadose zone on groundwater recharge, a modelling scheme was developed by coupling vadose zone model with groundwater model. The model was run with rainfall data recorded in rain gauge and a synthetic rainfall generated based on evidences of the recent changes in the rainfall characteristics. Results showed that the annual recharge flux computed from normal rainfall is 7.8% of annual rainfall and annual recharge flux computed from synthetic rainfall is 5.1% of annual rainfall, whereas the runoff generated from the synthetic rainfall was higher than that of the normal rainfall, indicating that the rainfall pattern plays a major role in the groundwater recharge process. The areas where there is an increase in moderate rainfall events, showed increase in groundwater recharge, thus highlighting the importance of moderate rainfall events in groundwater recharge process. Further studies are progressing to understand the changes in rainfall characteristics and groundwater recharge through field level experiments at the CZOs and modelling studies.

Keywords: *Coupled modelling, Critical Zone, Groundwater recharge, Climate change*

INTRODUCTION

Changes in the land surface and the climate are two key factors that influence the global hydrological processes. Among the climatic variables, perhaps the most significant one that affects the hydrological cycle is the precipitation because of its large spatial and temporal variability across the land surfaces. Changes in the precipitation characteristics, especially the intensity, duration and time period of rainy days have a significant influence on the runoff regime, evapotranspiration and recharge to groundwater. The water cycling of a catchment area is a complex procedure influenced by climatic changes plus human interventions. Climate change factors and human activities strongly affected the stream runoff in the semi-humid and semi-arid regions. The hydrology of the semi-arid and arid regions is significantly regulated by variations in the climatic variables to a greater extent. The quantifiable appraisal of the relative effects of the factors such as changes in hydrological parameters like precipitation, temperature, and evapotranspiration on the stream hydrology is very crucial for the sustainable management of water resources. Various analyses have been carried out in the past few years to model the hydrological regime of the major catchments all around the world, Still, not much focus has been given to evaluate the effects of climate changes on the hydrology of the small rivers that are more sensitive to the environmental changes (Lutz et al., 2016). Since the tropical area are more likely to be affected by global climatic changes, it is essential to identify the changes in hydro-meteorological variables, the drivers of the changes and their potential impacts, in order to develop suitable strategy for efficient management of water resources. To identify and quantify the proportional contributors of the changes in the hydrology of a river basin it is necessary to explore the surface and subsurface water interactions. Surface water and groundwater systems are connected in most landscapes. Streams interact with groundwater in three basic ways, they are; streams gain water from inflow of groundwater through the streambed, streams lose water by outflow through the streambed, or they do both depending upon the location along the stream. Groundwater and surface water interactions represent an important series of issues in water resources management. Groundwater constitutes about two thirds of the freshwater resources of the world. It is customary to think of groundwater as being more important in arid or semi-arid areas and surface water as more important in humid areas. However, inventories of groundwater and surface water use reveal the worldwide importance of groundwater.

The interactions between the surface and groundwater are influenced by human interventions, climate change, changes in the land use/land cover, and urbanization. Studies in the past have often concentrated either on the changes in the surface water or on the groundwater due to natural and forced interventions. Many integrated models have been developed to study the interaction of surface water – groundwater systems.

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Very limited studies have explored the changes in the interactions between the surface water and groundwater in general and humid tropics in particular. The changes in the groundwater and surface water, rainfall characteristics and human interventions over the past few decades have posed immense stress on the hydrological systems (Mimikou et al., 2000). This is particularly true in the case of the river basins which are essentially fed by rainfall. The problem is more severe in the catchment basin draining the densely-populated reaches like that of the Southern Western Ghats. Very limited studies have explored the changes in the surface water-groundwater interactions of the river basins in the humid and semi-arid tropics that are more responsive to environmental changes.

In this context, the present study has been carried out to analyse the hydro-meteorological data, model and understand the interactions of surface and subsurface hydrology in selected river basins of southern Western Ghats as a case study. The changes in the hydrology of the river basin was explored using trend analysis of hydro-meteorological variables (precipitation, streamflow, groundwater, evapotranspiration and temperature) using Mann-Kendall trend test and Sen's estimator of the slope. The links between the changes in the streamflow, evapotranspiration and groundwater level were explored. To understand the feedback between the surface and the subsurface hydrological processes and its changes, a coupled surface-subsurface modelling was performed.

MATERIALS AND METHODS

Hydro-meteorological Data:

Rainfall -High resolution (0.25^o x 0.25^o) gridded rainfall dataset area for the time period from 1982 to 2013 collected from Indian Meteorological Department (IMD) has been used in the study.**Stream flow -**The discharge data was obtained from Central Water Commission, India (CWC), via the surface water module of the India-WRIS (Water Resources Information System) portal.**Temperature -** The temperature data is of (0.5^o x 0.5^o) gridded dataset collected of Indian Meteorological Department (IMD) is used in this study. **Evapotranspiration-** Evapotranspiration data is available from MODIS and it is available as gridded data. The ET data is available for a period of 2001 to 2014. **Groundwater Level Data -**The groundwater datais collected fromCentral Ground Water Board (CGWB), via the ground water module of the India-WRIS (Water Resources Information System) portal from 2000- 2016

Methods: Trend analyses were performed with the nonparametric Mann-Kendall test (Mann, 1955; Kendall, 1975). The modified M-K test proposed by Yue and Wang (2004) was applied for trend assessment. This test uses a non-parametric slope introduced by Theil (1950) and Sen (1968) to pre-whiten the time series before the classical M-K test was applied. The Mann-Kendall -test was applied for detection of monotonic increasing or decreasing trends and is based on the correlation between the ranks of a time series and their time order. The test statistic depends only on the ranks of the observations, rather than their actual values, resulting in a distribution free test statistic. The statistical significance of trends was defined using a significance level of $\alpha = 0.05$ for Kendall's p-value. When a linear trend is present in a time series, then the true slope (change per unit time) was estimated using the simple non-parametric method (Sen's Slope) developed by Sen (1968).

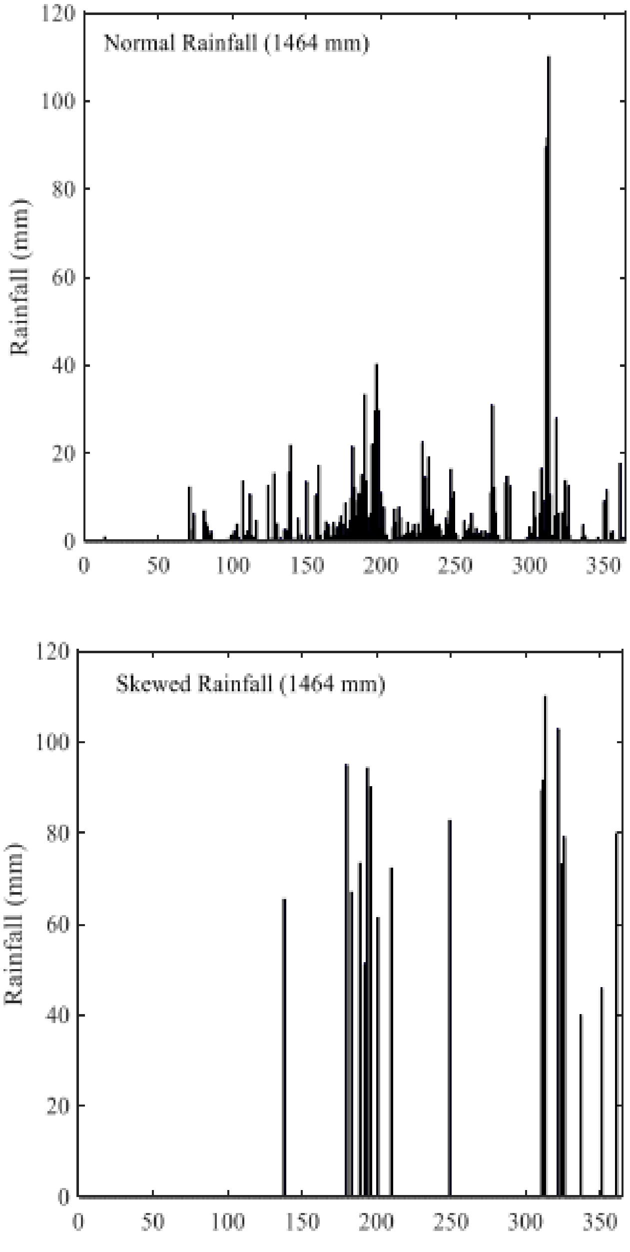


Fig. 1: Daily distribution of rainfall (mm) used in the study

The skewed rainfall data thus generated helps to understand the importance of vadose zone incomputing the recharge to groundwater.

In order to understand the influence of vadosezone on groundwater recharge, a modelling scheme was developed by coupling vadose zone model (HYDRUS) with groundwater model (AMBHAS) at plot scale. To check the reliability ofthe model, synthetic rainfall data was prepared. Fig. 1 shows the normal rainfall data and skewed rainfall data generated for modelling the groundwater recharge. Even though the total of the annual normal rainfall and annual skewed rainfall remains the same (1464 mm), the daily precipitation computed for skewed rainfall shows greater variation from the normal daily rainfall.

RESULTS AND DISCUSSION

Trend Analysis:

The changes in the land surface is primarily responsible for the changes in the water lost due to evapotranspiration. Fig. 2(a) shows the annual evapotranspiration map of the study area during 2001 and Fig. 2(b) shows the annual evapotranspiration of the study area during 2014. Widespread increase in evapotranspiration is observed in 2014 as compared to 2001. To understand the effect of changes in land surface on the evapotranspiration, Periyar river basin was studied in detail. Between 2001 and 2014, there was an increase of evapotranspiration by 12 % in the Periyar river basin. During the last two decades, large area under paddy cultivation in the Periyar river basins were converted to plantations, which could be one of the reasons for the increase in evapotranspiration throughout the Periyar river basin.

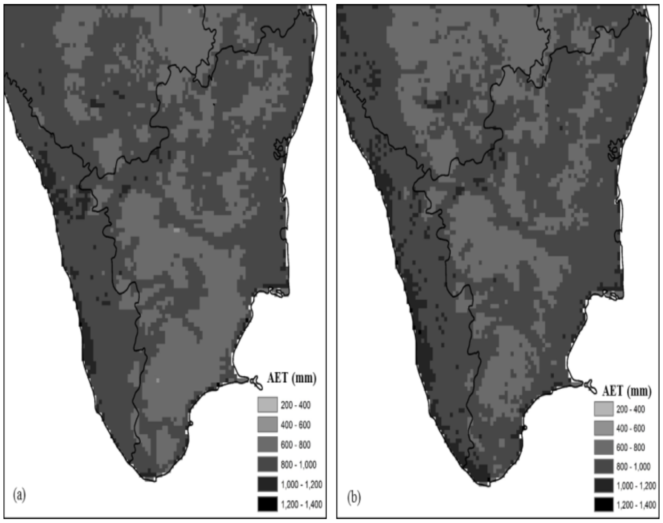


Fig. 2: Annual actual evapotranspiration (AET) in mm during (a) 2001 and (b) 2014 of the study area.

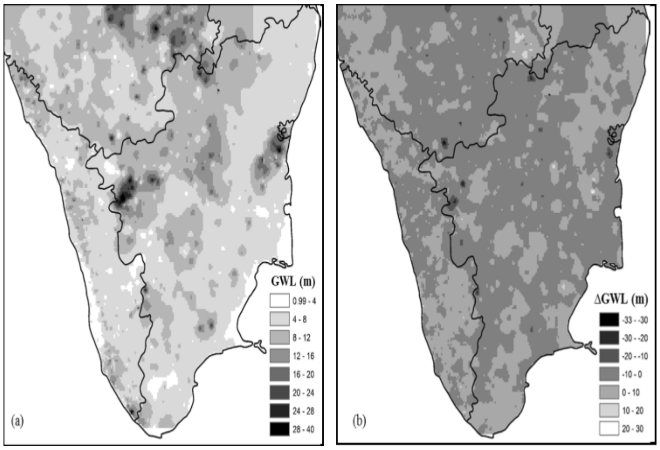
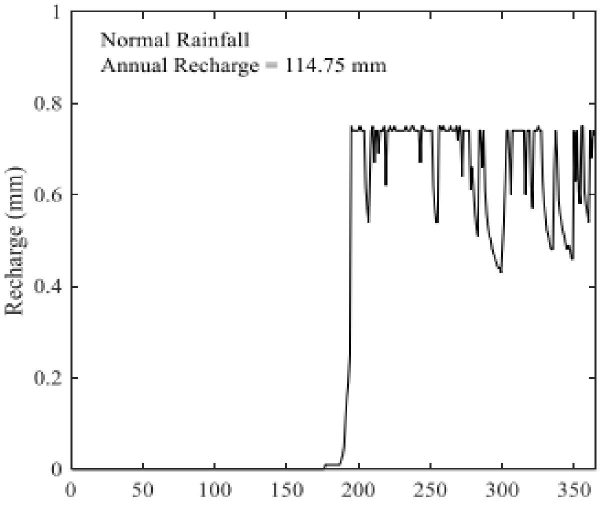


Fig. 3: (a) The mean groundwater level (GWL) (2001 to 2014) and (b) the changes in the groundwater level (ΔGWL) between 2001 and 2014 of the study area. The ΔGWL is computed as the difference between the GWL of 2001 and the mean GWL of 2002 to 2014.

In arid and semi-arid regions, moderate rainfall events play a major role in the groundwater recharge process. When the rainfall intensity exceeds the maximum infiltration capacity of the soil, it results in surface runoff. This also depends on the existing soil moisture conditions. The increase in high intensity rainfall events and decrease in moderate rainfall events will have an impact on the groundwater recharge process. The decrease in groundwater levels of the study area correlated significantly with the changes in the rainfall characteristics, particularly the increase in high intensity rainfall events.

Coupled Modelling:

The recharge flux computed from synthetic rainfall was compared with the recharge flux computed from normal rainfall. Fig. 4 shows the recharge flux computed by HYDRUS during normal rainfall and synthetic rainfall.



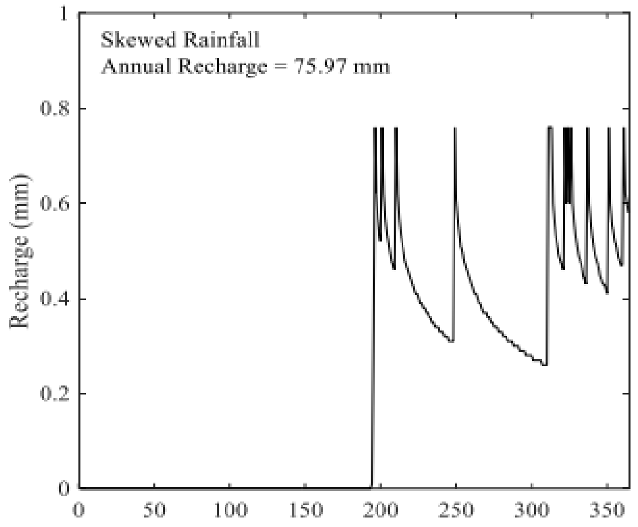


Fig. 4: Recharge flux of (a) Normal Rainfall and (b) Synthetic rainfall computedfrom HYDRUS

The results showed that the annual recharge flux computed from normal rainfall is 114.75 mm which is 7.8% of annual rainfall and the annual recharge flux computed from skewed rainfall is 75.97 mm which is 5.1% of annual rainfall. It is thus clear that, as the intensity of rainfall is increases, the recharge to groundwater decreases. Hence the assumption of a constant recharge factor (recharge coefficient as a percentage of rainfall) do not accurately provide the best estimates of groundwater recharge. Vadose zone models (soil moisture models) simulate the soil water flow based on the soil hydraulic properties and hence represent a realistic information about the potential recharge into the groundwater.

The annual surface runoff produced in normal rainfall is 899 mm which is 61% of annual rainfall and the annual surfacerunoff produced in skewed rainfall is 1001 mm which is 68% of annual rainfall. It revealed that high intensity rainfall was expected to contribute more towards streamflow rather than groundwater. Thus it is clear that from the above results the recharge coefficient obtained from normal rainfall and skewed rainfall was 0.051 and 0.078 respectively and hence it can be understood that an assumption of constant recharge factor is not valid for high intensity rainfall events. This shows the importance of simulating potential groundwater recharge through vadose zone modeling approach. Simulation was carried out for five different wells with different landuse using AMBHAS groundwater model. Calibration was done for the year 1981-2004 and validation for the year 2005-2013. The daily recharge flux produced from HYDRUS was converted into monthly recharge flux and annual recharge flux using MATLAB and then it is read in AMBHAS for simulation of groundwater flow. Well number 5 and well number 2,3,4 comes under forest and agriculture plantation mixed showed a better annual recharge coefficient of 0.09-0.004 than well number 1 which falls under the double crop with an annual recharge coefficient of 0.08-0.004.

Table 1:Performance of the coupled model in calibration

Well Location	Monthly		Annual	
	RMSE	NRMSE	RMSE	NRMSE
Agali	0.92	0.15	0.49	0.32
Pudur	0.58	0.2	0.55	0.26
Chavadiyur	0.04	0.03	0.02	0.43
Thavalam	0.5	0.14	0.37	0.31
Kakkupady	1.06	0.42	0.54	0.19

Table 2:Performance of the coupled model in calibration

Well Location	Monthly		Annual	
	RMSE	NRMSE	RMSE	NRMSE
Agali	0.61	0.15	0.14	0.11
Pudur	0.37	0.09	0.28	0.28
Chavadiyur	0.03	0.05	0.01	0.79
Thavalam	0.15	0.06	0.18	0.27
Kakkupady	0.71	0.18	0.5	0.35

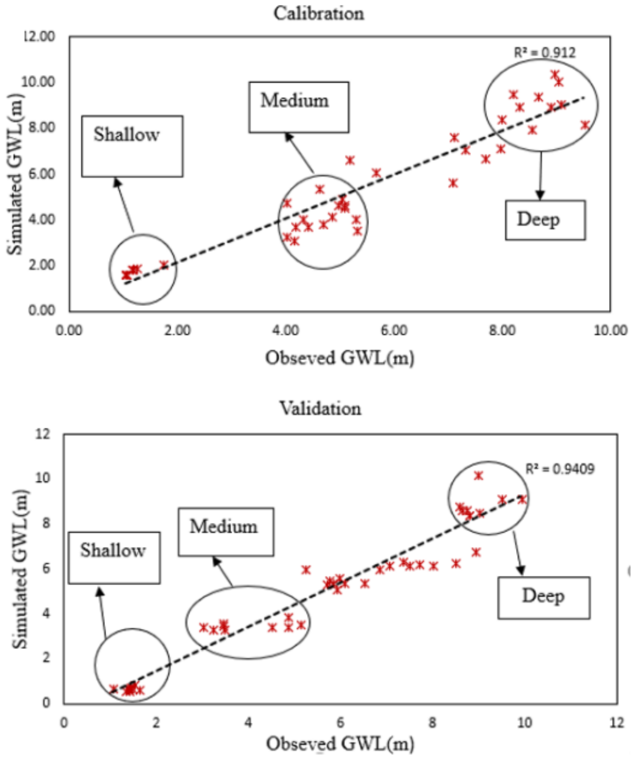


Fig. 5: Calculated and observed groundwater level of all five wells during (a) Calibration and (b) Validation period.

The performance of the model for all the five wells was satisfactory as shown in their computed RMSE and NRMSE values given in table 1 and 2. The R^2 value obtained in the calibration for all the five wells when simulation was done for annually was found to be 0.91 whereas R^2 value during validation period was found to be 0.94. Fig. 5shows the comparison between calculated and observed groundwater level for all the five wells annually during calibration and validation period. The results of the study revealed that the rainfall pattern plays a majorrole in the groundwater recharge process in semiarid and arid regions. The areas where there is an increase in moderate rainfall events, showed increase in the groundwater recharge, thus highlighting the importance of moderate rainfall events in the groundwater recharge process. With the projected changes in the number of rainy days and increase in high intensity rainfall events throughout the peninsular India, it is important to consider the outcome of this study for effective planning and management of the groundwater resources. The influence of recharge coefficient in groundwater modelling plays an important role. The influence of recharge coefficient during highintensity rainfall was demonstrated with the help of vadose zone model. The recharge estimated through vadose zone model provided better estimates of groundwater level when used in a groundwater model than assuming a constant recharge coefficient.

CONCLUSIONS

To study the changes in the recharge characteristics of river basins in humid and semiarid river basins in the context of increased number of high intensity rainfall events, a coupled vadose zone – groundwater model was developed. The results of the modelling study revealed that the rainfall pattern plays a major role in the groundwater recharge process in humid and semiarid regions. The areas where there is an increase in moderate rainfall events, showed increase in the groundwater recharge, thus highlighting the importance of moderate rainfall events in the groundwater recharge process. With the projected changes in the number of rainy days and increase in high intensity rainfall events throughout the peninsular India, it is important to consider the outcome of this study for effective planning and management of the groundwater resources. The influence of recharge coefficient in groundwater modelling plays an important role. The influence of recharge coefficient during high intensity rainfall was demonstrated with the help of vadose zone model. The recharge estimated through vadose zone model provided better estimates of groundwater level when used in a groundwater model than assuming a constant recharge coefficient. Detailed studies in this direction are progressing to quantify the drivers of the changes in the groundwater systems and identity the proportional contributors of the change. In this regard, National Centre for Earth Science Studies (NCESS) has initiated setting up of three Critical Zone Observatories (CZOs) in different agro-climatic regions of south India to study the changes the hydrological cycle as a whole and the effect of climate and anthropogenic changes in the evolution and sustainability of Earth's Critical Zone – the layer extending from the top of canopy to the bottom of the groundwater aquifer.

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