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Terrain Characteristics and their Influence on the Temporal Behaviour of Hydraulic Heads in Kallada River Basin, Kerala

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ABSTRACT

The terrain characteristics of an area play vital role in the spatial and temporal behaviour of the hydraulic heads of groundwater body. The present study was carried out to understand the influence of major terrain parameters such as slope, drainage, geology and soil characteristics on the seasonal variations of the hydraulic head in the Kallada river basin, South Kerala, India. Water table was measured at 166 open wells in the study area during pre-monsoon and post-monsoon periods to accomplish the objectives. Hydraulic heads in the study area varied seasonally from 0 to 4.33m during the study period. Wells with very less change in hydraulic head fall in the midland area, where the drainage frequency is very low to low. Areas with very high slope are characterized by less recharge and the wells at such areas show highest change in hydraulic head. Also, the wells with higher variation in hydraulic heads are associated with Kodumon, Mynagapally and Ummannur soil series.

INTRODUCTION

Assessment of terrain characteristics and hydrogeologic settings is important to understand the groundwater resources of an area. As nearly 70% of the land area in India is occupied by hard rock terrains characterized with lesser recharge and higher runoff, a better groundwater development and management plan is essential to manage the groundwater resources which would reduce the current water scarcity conditions. However, the intensity and changing patterns of rainfall in India during the recent past has severely affected the sustainability of groundwater resources (Gopinathand Seralathan, 2008). The groundwater availability and groundwater flow in an aquifer system are often affected by temporal and spatial fluctuations in hydraulic head. The varying rain fall patterns, increased deforestation and the large scale conversion of paddy fields and similar wetlands have caused rapid decline in hydraulic heads at many parts of Kerala state resulting in the deepening of water levels in wells (Imtiyaz and Rao, 2008). The hydraulic head in an area is controlled by several factors including topography, lithology, geological structures, depth of weathering, extent of fractures, primary porosity, secondary porosity, slope, drainage patterns, landform, land use/land cover, and climate (Jaiswal et al., 2003; Jha et al., 2007) in addition to pumping for various purposes. Proper understanding and quantification of changes in aquifers due to varying hydraulic heads are very much important to predict water table fluctuations. Several geological and hydrogeological methods are available for investigating the terrain parameters through ground measurements, which are expensive as well as time-consuming. Remote sensing data coupled with Geographic Information System (GIS) has been extensively used as a groundwater exploration tool all over the world (Shahid and Nath, 2000; Murugesan et al., 2012; Prabir et al., 2012; Deepesh et al., 2010; Jobin et al., 2011). The objective of the present study is to understand the influence of major terrain parameters in the temporal behaviour of the hydraulic heads during the pre-monsoon and post-monsoon periods in the Kallada river basin, Kollam district, Kerala state, India.

METHODOLOGY

Extensive field investigations were carried out to understand the geology, geomorphology and hydrogeologic settings of the area. Well inventory survey was carried out in the study area and 166 open wells were identified for consecutive hydraulic head monitoring. The well locationswere chosen at 2 km^2 interval. Hydraulic heads were measured during pre-monsoon and post-monsoon periods in April 2016 and November 2016 respectively. A geodatabase was prepared by digitizing the topographical contours onscreen from the Survey of India toposheets (1:50,000) using the software Arc GIS. The contour map was interpolated to prepare the Digital Elevation Model (DEM) which was further used to prepare slope map. Drainage network in the study area was analysed using Horton's scheme and Strahler's stream orderings (Strahler, 1957) methods. Since majority of the monitoring wells fall in the lateritic plateau with low elevation, the influence of elevation and geomorphology in the hydraulic head is minimal and hence not considered in the present case.

Study Area

The Kallada river basin covers an area of 1614.4 km^2, spreading over Kollam (85.9%), Pathanamthitta (7.8%) and Trivandrum (6.3%) districts of Kerala, India (Fig.1). The study area lies between latitudes 8º73' and 9º17' N and longitudes 77º26' and 76º54'E . The major river draining through the area is the west flowing Kallada river, which drains into Ashtamudi back water, near Kollam. This perennial river originates at Karimalai-Kodakkal in the Western Ghats, where the elevation is 1725 m amsl. The length of this 7th order river is 121 km. The main stream is formed by the confluence of 3 major tributaries, namely Kulathupuzha, Kalthuruthy and Chenduruni at Parappar near Thenmala. Kallada river shows an initial south-westerly course, which changes towards west and join Kulathupuzha river at Parappar. The river then attains a north-westerly course at the midland which is followed by a south-westerly course to join Ashtamudi back water. The river holds the biggest irrigation project in the state (Kallada Irrigation Project) covering considerable parts of Kollam, Pathanamthitta and Alappuzha districts. The largest fresh water lake in the state, i,e., Sasthamkotta and the longest dam of the state, i.e., Thenmala are located in the study area. A considerable portion along the upper reaches of the river basin is covered by the protected reserve forests. Hence no sampling was carried out in the upper reaches covering nearly 198 km^2 area.

Climate

The study area, characterized by tropical humid climate with average temperature varying from 25ºC to 32ºC, gets plenty of rainfall through both southwest and northeast monsoons, in which the former is from June to September and the latter is from October to November.

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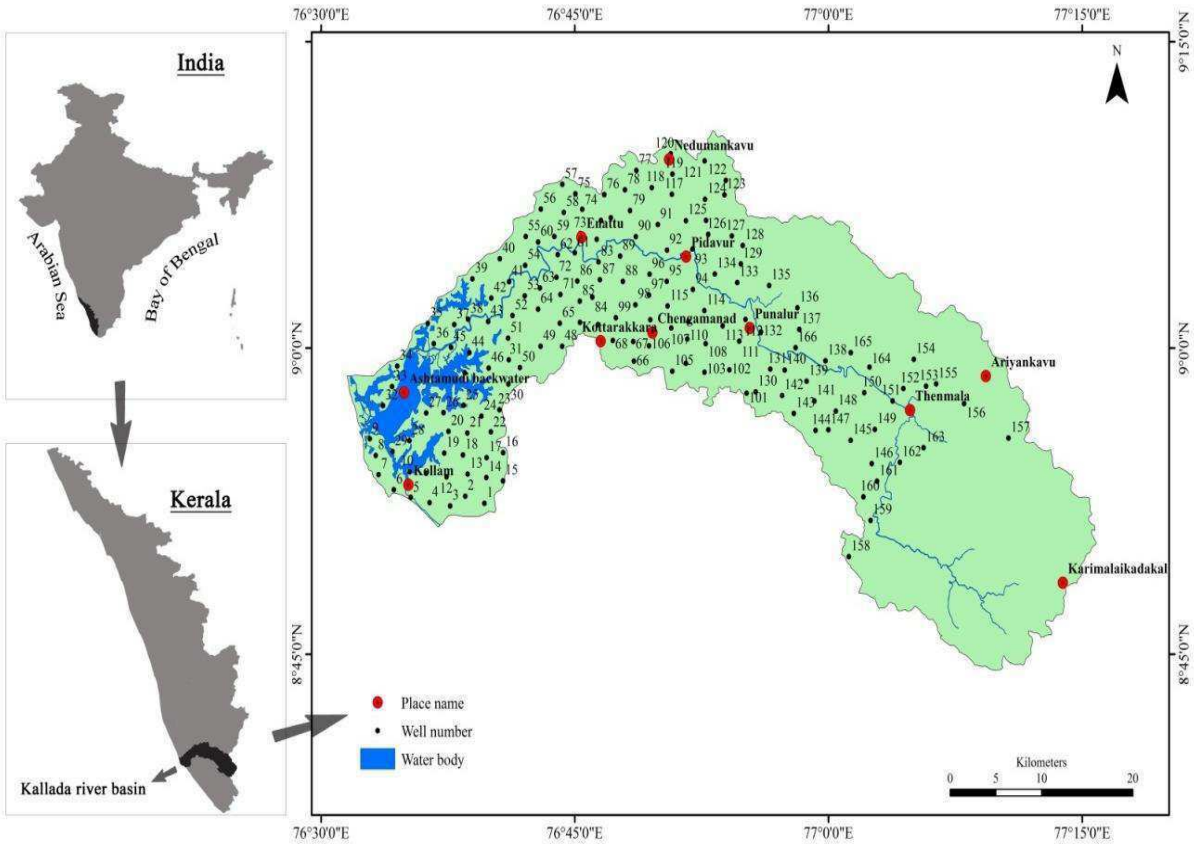

Fig.1. Map showing the study area and groundwater sampling locations

In peak summer, the temperature often rises above 40°C in and around Punalur, which is one of the hottest places in the state. The annual rainfall over the study area varies from 2225 mm to 4038 mm. The basin experiences uniform and moderate wind velocity throughout the year, which varies generally from 8.5 to 13.6 km/hour (www.india-wris.nrsc.gov.in). The monthly potential evapotranspiration in the area ranges from 119.3 to 177 mm (CGWB, 2013).

RESULTS AND DISCUSSION

Elevation

The DEM of Kallada river basin is shown as Fig.2. Based on the elevation, the basin is classified into 3 major physiographic units, namely highlands, midlands and lowlands with elevations above 75m, between 75m and 7.5m and below 7.5m respectively (Kerala PWD). About 55% of the area is occupied by highlands, 42% by midlands and 3% by lowlands. The southeastern portion of the area is characterized by numerous peaks with elevation above 1300m. These abrupt changes in elevation along a short areal distance of around 75 km or less cause the river to flow with high energy which inversely affects the recharge rate.

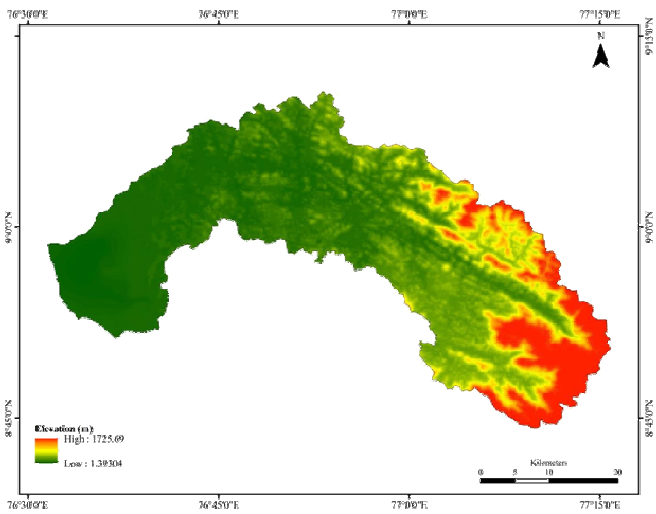

Fig.2. DEM of the Kallada river basin.

Slope

The slope of the area varies from 0° to 47°. Based on the degree of slope, the area is divided into 5 zones which are very steep, steep, moderate, gentle and very gentle with respective slope ranges of 30° to 47°, 15° to 30°, 9° to 15°, 3° to 9° and 0° to 3°. The slope map of the Kallada river basin (Fig.3) shows a progressive decrease in slope from the eastern mountainous regions to the western coastal areas. The major part of the Kallada river basin is characterized by very gentle slope with wetlands and paddy fields, covering approximately 40% of the total area. The central part of the area represents gentle to moderate slope zones mainly of cultivated lands, which accounts about 35% of the whole study area. Approximately 25% of the area falls under the steep to very steep category, which are located at the eastern part of the study area. In contrast, the slope abruptly reduces to gentle to very gentle in and around Thenmala, which is at the north eastern part of the study area.

Slope in the area plays a considerable role in the position of the hydraulic head, as infiltration has an inverse relation to slope (Agrawal et al., 2013). As the study area has a very rugged topography with diverse slope scenarios, the hydraulic head is inversely related to the slope factor. The average gradient of the stream is 14.4m per kilometer. About 75% of wells showing very low variation in hydraulic head are in the midlands, 16% in highlands and 9% in low lands. Majority of such wells (well number 67, 89, 75,116,117,90, 151 and 159) are found in areas with very gentle to gentle slope with minimum runoff

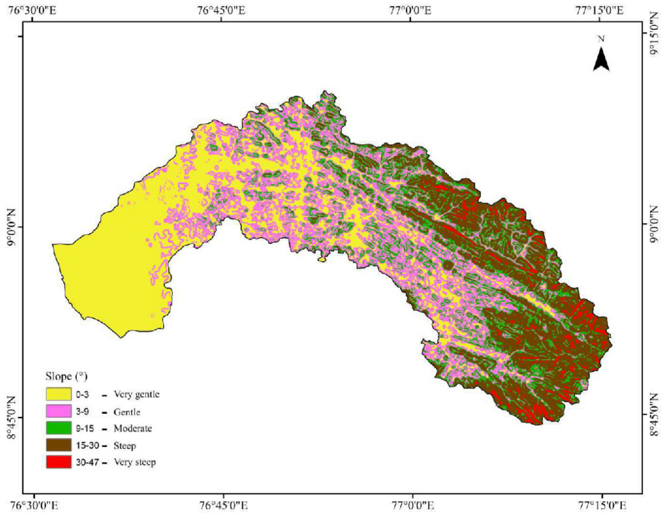

Fig.3. Slope map of the Kallada river basin

and high infiltration which leads to nearly stable hydraulic head throughout the year irrespective of the climatic seasons.

Drainage

Kallada is a 7th order river and the total number of 1st order, 2nd order, 3rd order, 4th order, 5th order and 6th order streams is 4853, 1074, 267, 58, 15 and 4 respectively (Fig.4). The drainage basin of Kallada river has an elongated southerly concave shape with dendritic drainage pattern. However, trellis pattern with straight course can also be observed towards the southeastern parts of the drainage basin.

The drainage frequency is very high towards the eastern parts of Kallada river basin, which gradually decreases towards west. However, the drainage frequency remains very high along the north-eastern border upto the central north part. The feeble changes in the hydraulic head along the eastern parts as compared to the west can be attributed to the very high and frequent rainfall in the highlands, which is influenced by the Western Ghats. As the drainage frequency shows an inverse relation to the permeability of the formation (Lazaras and Yadav, 2014), the hydraulic head in the area is strongly related to the number of streams in the area. Most of very low hydraulic head variation wells are distributed in areas with very low to low drainage frequency where higher infiltration and recharge to the aquifers are expected. Majority of wells with very high hydraulic head variation falls in areas with high drainage frequency (well no. 121 and 50). High drainage frequency with steep slope causes surface runoff which in turn affects the recharge rate. However, the western parts of the study area are characterized by less infiltration causing rapid and immense variation in hydraulic head.

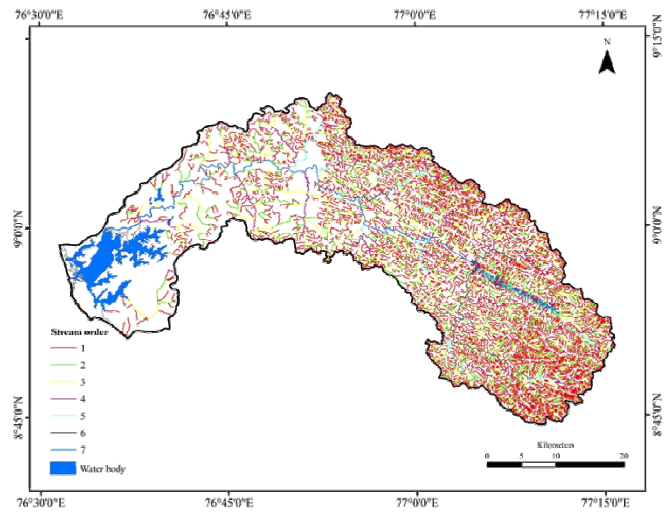

Fig.4. Drainage map of the Kallada river basin

Drainage Frequency

Drainage frequency is a significant parameter in morphometric analysis to delineate areas with diverse run off pattern. The drainage frequency in the study area varies from 0 to 25.4. Based on the drainage frequency, Kallada river basin is categorized into five zones as very poor, poor, medium, high and very high with respective drainage frequency ranges of 0 to 2.8, 2.8 to 6.30, 6.30 to 9.30, 9.60 to 13 and above 13 (Fig.5). Most of the northeastern and southeastern parts of thedrainage basin are characterized by very high drainage frequency. However, the central and western parts have very poor drainage frequency with the least along the north-south stretch of Nedumankavu-Pidavur-Chengamanadu.

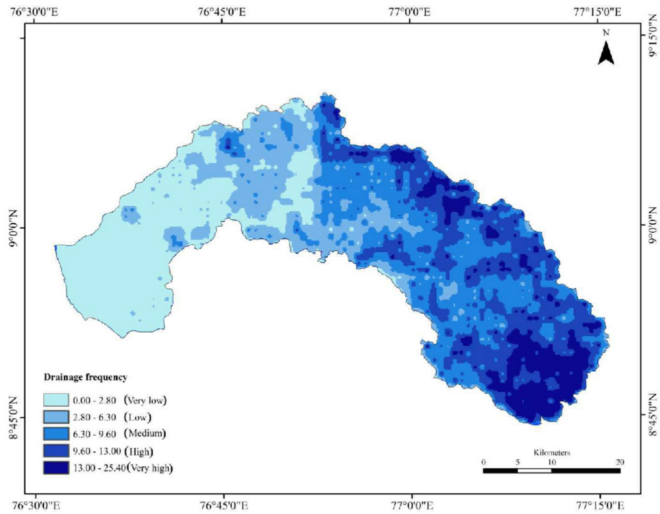

Fig.5. Drainage frequency map of the Kallada river basin

Geology

The study area has three major geologic units, namely, Precambrian crystallines, Tertiary sediments and laterites as well as Quaternary sediments. The geological map of the study area is shown as Fig.6. The eastern part of the study area is mainly of high grade Precambrian crystallines consisting of charnockite, khondalite, gneisses and disseminated basic intrusives. Secondary fractures and joints in these

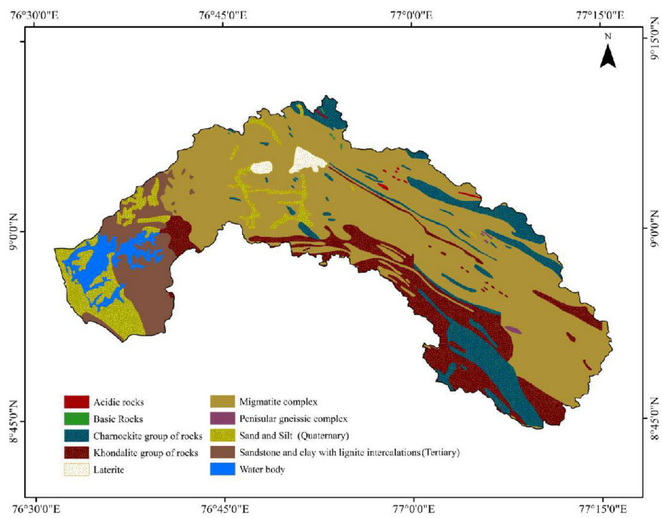

Fig.6. Geological map of the Kallada river basin (source: Geological Survey of India, _____year___)

rocks impart permeability to the bedrock, influencing groundwater circulation in the area. Tertiary laterites mostly occupy the central part of the study area, where leaching of iron ions from the laterite causes degradation of groundwater quality. The western part of the study area is comprised of Warkallai sandstone of lower Miocene age (Poulose and Narayanaswamy, 1968). These rocks are ferruginous in nature, often with lignite intercalations and are good aquifers. The lateritic and alluvial formations act as major phreatic aquifers, even though the deep fractures in these formations also form potential confined aquifers.

The lateritic terrains in the central part of the study area are characterized by very low variation in hydraulic head due to the high porosity and enhanced recharge during monsoon. The high porosity and the lithomarge base in the wells in laterite terrain cause a sudden rise in groundwater level soon after rain fall. These short-term water level changes are not highlighted in the present study. Since the lateritic formations in the central part falls in gentle to very gentle slope category, the underground draining of groundwater subjecting to topographical irregularity is very less, which favours insignificant variations in hydraulic head over seasons. As about 50% of the monitoring wells present in the crystalline zones with minimal soil cover, it is felt that the movement and storage of groundwater is also controlled by the secondary structures like lineaments and fractures (Vijith, 2007).

Geomorphology

The major geomorphic units identified in the study area are denudational structural hills along the eastern highlands and lower lateritic plateaus along the western part (Fig.7). Heavy precipitation in the highland areas results in the intense erosional activities which occasionally lead to small scale landslides. Some patches of pediplains are found on the northeastern area of highlands which are formed by the coalescence of pediments from the surrounding higher altitude areas. These pediplains often act as good recharge areas. Weathered/ buried pediplains, composed of lateritic soils and alluvial sediments, often follow the river channel. A few widely scattered residual hills are present at the central part of the river basin, which are the end product of peneplanation (Thornbury, 1990). The midlands are extensively covered by lower lateritic plateau, wherein the valleys are occupied mainly by crop lands and paddy fields. During monsoon, the upper lateritic plateau in the midlands often acts as recharge areas and aid in the formation of local springs. The most dominant geomorphological units in the lower reaches of the study area are coastal plains, composed of alluvial soils and coastal sediments. These areas generally act as potential aquifers in the phreatic zone.

Soil

There are 17 major soil types in the Kallada river basin, which are Adoor series, Alravan series, Channapettah series, Kallada series, Kallar seies, Kodumon series, Kottur series, Kumaranperoor series, Mannar series, Mylom series, Mynagapally series, Nedumangadu series, Nedumpara series, Palode series, Ponmudi series, Ummanur series andVarkala series (NBSS, 2006). The characteristics of the different soil types are detailed in Table 1.

Even though most of the highland areas are dominated with well drained Palode series with gravelly clayey texture, other soil types such as Channapettah series, Nedumpara series, Kallar series, Kottur series and Ponmudi series are also found in the high land areas (Fig.8).

Table 1. The major soil series found in the study area (National Bureau of Soil Survey)

S.No	Soil series	Description
1	Ponmudi series	Slightly acidic, and are very dark brown to yellowish brown in colour with sandy clayey loam to gravelly clayey loam texture
2	Adoor series	Lateritic soils, strongly acidic and are reddish brown to strong brown in colour with gravelly loam to gravelly clayey texture. Gravel content goes up to 70% in the subsoil
3	Alravan series	Alluvial soils, very strongly acidic and are dark greyish brown to dark yellowish brown in colour with silty loam to clayey loam texture
4	Channapettah texture	Medium acidic soils and are black to dark brown in colour with clayey loam to clay series
5	Kallada series	Alluvial soils, strongly acidic and are dark brown to dark yellowish brown in colour with sandy clayey loam to clay texture
6	Kallar series	Slightly acidic and are very dark brown to reddish yellow in colour with sandy clay loam to sandy clay texture
7	Kodumon series	Very strongly acidic and are very dark brown to strong brown in colour with sandy clayey loam to gravelly clay texture
8	Kottur series	Very strongly acidic and are very dark greyish brown to yellowish brown in colour with gravelly clayey loam to gravelly clay texture
9	Kumaranperoor series	Medium acidic and are dark reddish brown to yellowish red in colour with gravelly loam to gravelly clay texture
10	Mannar series	Slightly acidic and are pale brown to dark grey in colour with sand to loamy sand texture
11	Mylom series	Alluvio-colluvial soils, very strongly acidic and yellowish brown to light yellowish brown in colour with sandy loam to sandy clay loam texture
12	Mynagapally series	Lateritic soils, very strongly acidic and are yellowish red to red in colour with gravelly clayey loam texture
13	Nedumangad series	Strongly acidic and are brown to yellowish red in colour with gravelly loam to gravelly clay texture
14	Nedumpara series	Medium acidic and are dark brown to dark reddish brown in colour with loam to clayey loam texture
15	Palode series	Medium acidic and are dark greyish brown to strong brown in colour with gravelly loam to gravelly clay texture.
16	Ummanur series	Laterite soils, strongly acid and are dark reddish brown to strong brown in colour with gravelly sandy loam to gravelly sandy clay loam texture.
17	Varkala series	Laterite soils, slightly acid and are reddish brown to yellowish red in colour with gravelly loam to gravelly clay texture

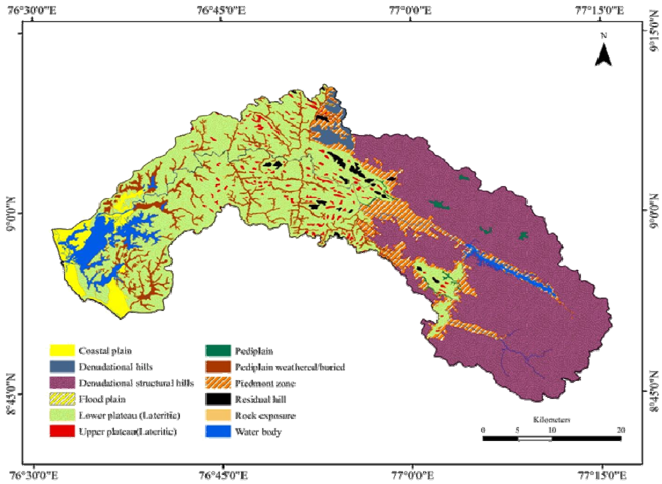

Fig.7. Geomorphological map of the Kallada river basin

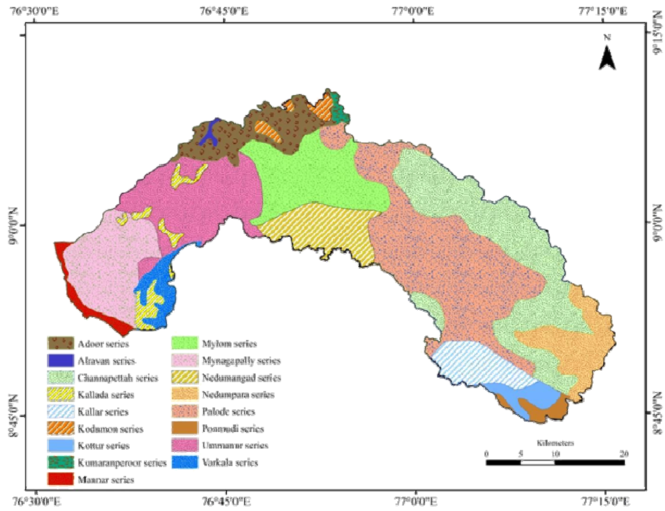

Fig.8. Soil map of the study area

Channapettah series is characterised by soils of well drained type with texture range from clay to clay loam. The Kallar series and Ponmudi series consists of excessively to moderately drained soils of gravelly clay loam to sandy clay loam nature. Nedumpara series are well drained with sandy loamy texture while the Kottur series are moderately drained with gravelly clay to gravelly loam texture. The majority of midland areas are dominated by Mylom series, Ummanur series, Mynagapally series, Adoor series and Nedumangadu series. However, some parts of the midlands are characterised by Kodumon series, Alravan series, Kumaranperoor series, Kallada series and Varkala series. Ummanur series is dominated by well drained lateritic soil with sandy loam to gravelly sandy loam. A large part around the river mouth is covered by Mynagapally series which is composed of gravelly clay loam. The western low lands are occupied by the alluvial Mannar series with sandy to sandy loam texture.

The type of soil in an area influences the infiltration of rain water and controls the hydraulic head of the region (Tesfaye, 2010). Most of the category I wells are located at the central parts of the basin, where Mylom and Adoor series with gravelly loam to clayey loam dominate. These aluvio-colluvial soils easily permit the rainwater to reach the underlying rock and thereby control the hydraulic head to a certain extent. The category V wells are distributed mainly in Kodumon, Mynagapally and Ummannur series. These lateritic soils are rich in clay and therefore limit the percolation of groundwater resulting in the seasonal deterioration in yield during the dry season. This leads to the drying up of about 95% of shallow wells by the end of dry seasons (MacDonald and Davies,1997).

Variation in Phreatic Water Table

The water table measured at the monitoring wells during the pre-monsoon and post-monsoon periods shows wide variation. The phreatic hydraulic head in the study area varies between 0.0 m to 4.3 m during an year. Based on the degree of variation in hydraulic heads, the wells are classified into 5 categories, which are very low (I), low (II), moderate (III), high (IV) and very high (V) with variation ranges of <0.1, 0.1 to 0.5, 0.5 to 2, 2-3.5 and >3.5 m respectively. The location along with number of wells in each category is shown in Fig.9. Category I, II, III, IV and V represents about 7%, 27%, 57%, 6% and 2% of the total number wells monitored in the area.

The significant terrain characteristics of various categories of wells are summarised in Table.2. The wells under category I are mainly distributed over the central as well as the western part of the study area. However, the north-south stretch of Nedumankavu-Pidavur-Chengamanadu is characterized by the very low variation in hydraulic head. The spatial diversity of change in hydraulic head is mainly attributed to the variations in the terrain characteristics which is brought

Table 2. Well categories and corresponding terrain characteristics

Well category	Slope range	Drainage Frequency	Geology	Soil type
I	Very gentle to gentle	Very low to low	Migmatic complex, khondalite and sand/silt	Mylom series, Adoor series, Palode series and Mannar series
II	Very gentle to moderate	Very low to medium	Migmatic complex, Charnockite and Sandstone/sand, silt	Kodumon series, Kallada series, Mylom series, Adoor series, Varkala series, Palode series and Mynagapally series
III	Very gentle to high	Very low to high	Migmatitie complex, charnockite, khondalite, laterite, sand and silt/sandstone	Mylom series, Ummannur series, Palode series, Channapetah series, Adoor series, Mannar series, Mynagapally series, Kumaranperoor series, Kodumon series, Kallada series and Nedumangadu series
IV	Moderate to gentle	Very low to very high	Migmatite complex, Charnockite complex, Khondalite, and Sand/silt	Palode series, Channapetah series, Nedumangadu series, Varkala and Mylom series.
V	Gentle to moderate	Very low to high	Charnockite, Khondalite and sandstone	Kodumon,Mynagapally, Ummannur series

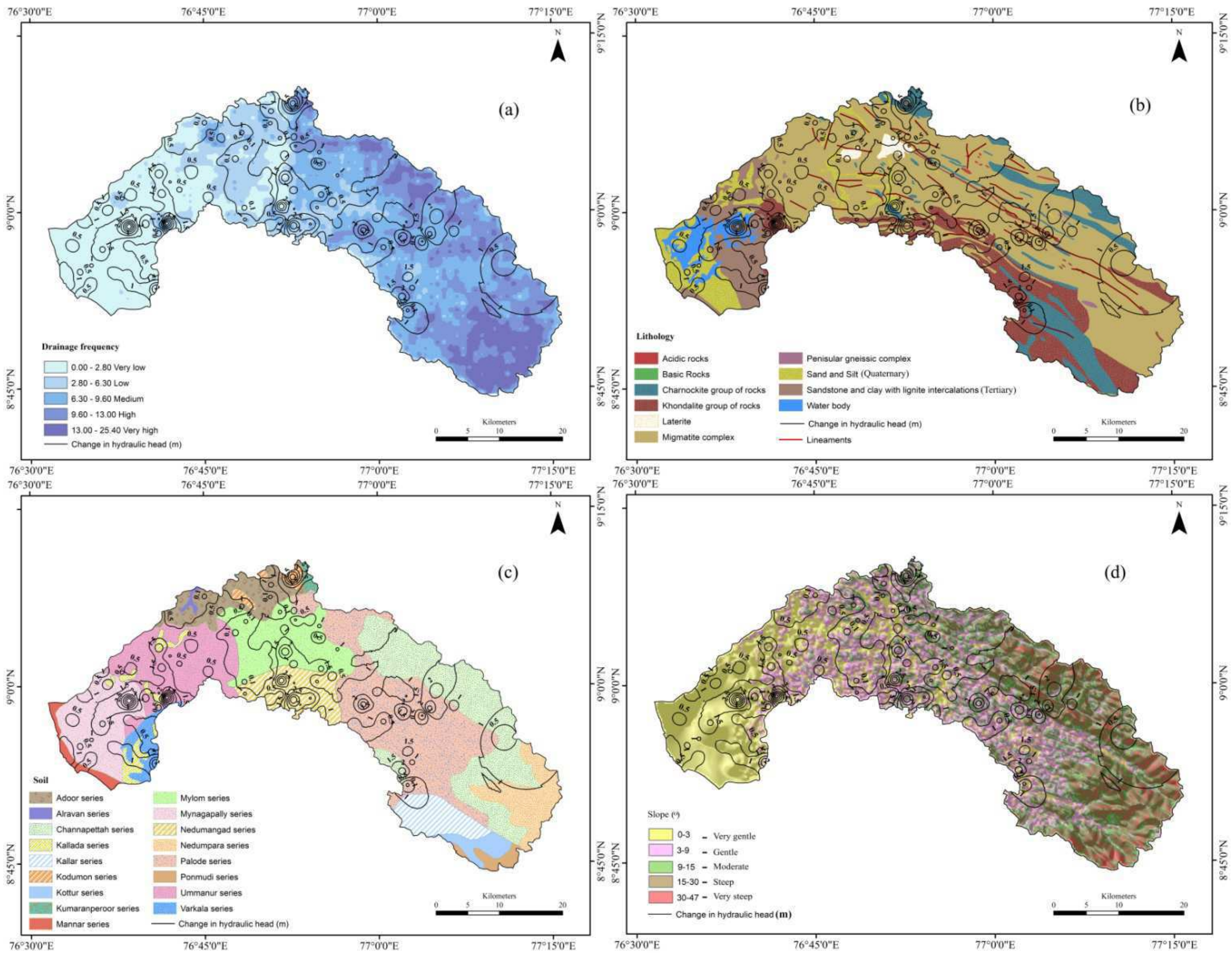

Fig.9. The spatial variation of changes in water table in the Kallada river basin.

out in the composite map in which the change in water table is overlaid on drainage frequency (Fig.9a), geology (Fig.9b), soil types (Fig.9c) and slope (Fig.9d). The map clearly reveals that the fluctuation is very less in the central part where the drainage frequency is very less, slope is gentle and the soil is of alluvial type.

CONCLUSIONS

The control of terrain parameters such as geology, drainage, soil cover and slope over the distribution and seasonal changes of hydraulic heads of groundwater in the Kallada river basin, South Kerala, during pre-monsoon and post-monsoon periods of 2016 was evaluated. The study shows that the changes in the hydraulic head within the drainage basin vary from 0 to 4.33m from pre-monsoon to post-monsoon periods. The least change in phreatic hydraulic head was noted in the central part of the river basin, where the slope and drainage frequency are very low indicating greater control of these terrain parameters in hydraulic head. The secondary structures like lineaments and fractures serve as feeders to the crystalline rocks, which in turn made the water table more stable during the pre-monsoon and post-monsoon periods. The wells with very little changes in hydraulic head are distributed mainly in the areas where soils are alluvio-colluvial in nature, whereas, remarkable changes in the hydraulic head values are associated with lateritic soils. However, it may be noted that water table may often fluctuate largely according to the aquifer characteristics coupled with recharge/discharge mechanisms, even if soil strata on the top is not favourable. Further, detailed aquifer mapping of phreatic zone and deeper confined layers would allow us to evaluate the quantum of possible inter-basin transfer of groundwater.

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