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SUMMARY AND CONCLUSION

The present investigation on “Hydrogeology, stratigraphy and evolution of the Palaeo-lagoon (Kole land basin) in the Central Kerala coast, India” is an integrated approach based on hydrogeological, geophysical, hydrochemical and stratigraphic aspects. A strong scientific data base of the study area is generated using interpretation of well observation and water quality analysis. The salient findings of the present study are given to provide a holistic picture on the hydrogeology (including groundwater resource and its quality), stratigraphy and evolution of the Palaeo-lagoon.

The aquifer parameters such as specific capacity, transmissivity, storativity, hydraulic diffusivity, drainage factor and optimum yield of phreatic as well as semi confined aquifers were determined by Slug test (ST), Step drawdown test (SDT) and Aquifer performance test (APT).

The results show that the specific capacity of phreatic aquifer of the basin varies from 65.33 lpm/m (Adichira-Chelakkara) to 521.74 lpm/m (Paluvaya-Chavakkad). The average specific capacity of the phreatic aquifer is 247.82 lpm/m.

The transmissivity (T) of the phreatic aquifer of the basin varies from 20 m²/day (Paruthipra-Mulloorkara) to 138 m²/day (Irinjalakuda). The average transmissivity of the basin is 91.925 m²/day. T value ranges from 20 m²/day (Paruthipra) to 94 m²/day (Prabhathnagar-Velur) in Jacob’s-Theis’s straight line method, while it ranges 92 m²/day (Prabhathnagar) to 138 m²/day (Irinjalakuda) in Papadopulos-Cooper curve matching method. The average T value of the basin during Jacob’s-Theis’s and Papadrioulos-Cooper are 48.85 m²/day and 135 m²/day respectively. A marginal increase in transmissivity with increasing well yield is observed.

The storativity of the basin varies from 4.5 x 10⁻³ (Paruthipra-Mulloorkara) to 1.1 x 10⁻³ (Adichira-Chelakkara) in Jacob’s-Theis’s method and 3.4 x 10⁻⁴(Padiyoor) to 5.9 x 10⁻³ (Choolissery) in Papadopulse-Cooper method. The average storativity of phreatic aquifer of the basin is 1.08 x 10⁻³.
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The hydraulic diffusivity of the basin varies from 3000 m$^2$/day (Adichira-Chelakkara) to 367647 m$^2$/day (Padiyoor). The average hydraulic diffusivity of the basin is 81491 m$^2$/day; while the drainage factor varies from 1.37 m (Adichira-Chelakkara) to 8.83m (Choolissery). The average drainage factor of the basin is 4.77 m. The high drainage factor indicates fast drainage of the aquifer. The optimum yield of the dug wells in the phreatic aquifer varies from 500 lph to 5000 lph in coastal plain. In mid and highland it varies from dry to 25000 lph.

The specific capacity of semi-confined aquifer of the basin varies from 3.22 lpm/m (Koorkamattom-Kodassery GP) to 208.90 lpm/m (Choolissery - Avannur GP). The average specific capacity of the aquifer is 38.98 lpm/m, while the specific drawdown varies from 0.0047 m/lpm (Choolissery - Avannur GP) to 0.4705 m/lpm (Melillam - Thekkumkara GP). The average specific drawdown of the basin is 0.072 m/lpm. The formation loss of the aquifer varies from 0.57 m (Parappuram - Kaiparambu GP) to 27.22 m (Kannara-Peechi), while the well loss shows a variation from 0.09 m (Kunnetheri – Erumapetti GP) to 23 m (Kumaranellur-Mulloor kara GP). The average formation loss and well percentage of the basin is 57.66 and 41.65 respectively. The formation loss of the basin varies from 18% (Gramela-Avannur GP) to 94% (Kannara-Peechi), whereas the well loss varies from 6% (Kunnetheri – Erumapetti GP) to 82% (Gramela-Avannur GP).

The transmissivity (T) of the semi-confined aquifer of the basin vary from 0.38 m$^2$/day (Padavaradu) to 485.05 m$^2$/day (Choolissery). The average transmissivity of the basin is 61.05 m$^2$/day. T value ranges from 0.38 m$^2$/day (Padavaradu) to 485.05 m$^2$/day (Choolissery) in pumping phase and 2 m$^2$/day (Thuruthiparambu) to 369 m$^2$/day (Choolissery) during recovery phase. The average T value of the basin in pumping and recovery phase are 58.46 m$^2$/day and 63.64 m$^2$/day respectively. Transmissivity of the semi-confined deep aquifer in the sedimentary area (Tube wells) vary from 22 m$^2$/day (West Mathilakam) to 104 m$^2$/day (Nattika). There is an increase in transmissivity with well yield is observed in the area. The initial flow is not only from bore well storage but also from the fractures.

The storativity of semi-confined aquifers at Adichira-Chelakkara and Prabathnaga - Velur is 6.4 x10$^{-4}$ and 1.1 x 10$^{-4}$ respectively. In sedimentary (tube wells) area it varies from 1.07 x 10$^{-3}$ (Nattika) to 4.04 x 10$^{-3}$ (Chavakkad). The optimum yield of the bore wells varies from 1000 lph to 41700 lph. The yield of tube wells in the sedimentary area of the basin varies from 12000 lph to 115000 lph.
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Drawdown - recovery analysis of phreatic as well as semi-confined aquifers were done by using the pumping test data. The following characteristics of the aquifers during pumping and recovery phase of the area are noted.

In phreatic aquifer the maximum observed drawdown vary from 0.46m (Paluvaya-Chavakkad) to 3.42m (Paruthipra-Mulloorkara). The average drawdown of the basin is 1.79m. The percentage of drawdown in 1st minute since pumping stopped varies from 0.00 (Choolissery-Avanur) to 13 (Padiyoor). The average drawdown percentage in 1st minute since pumping started is 1.79. The percentage of recovery in 1st minute since pumping stopped varies from 0.00 (Choolissry, Paluvaya) to 1(Edamuttom, Padiyoor, Irinlalakuda and Prabhathnagar). The average percentage recovery of the basin in 1st minute since pumping stopped is 0.63.

In semi-confined aquifer, the observed drawdown vary from 0.77m (Thippallur-Erumapetti) to 43.05m (Adichira-Chelakkara). The average drawdown of the basin is 16.70m. The percentage of drawdown in 1st minute since pumping started varies from 7.2 (Padavaradu-Puthur) to 87 (Gramela-Avanur). The average drawdown in percentage of the basin in 1st minute since pumping started is 38.60. The percentage of recovery in 1st minute since pumping stopped varies from 5 (Padavaradu-Puthur) to 87 (Gramela-Avanur). The average percentage recovery of the basin in 1st minute since pumping stopped is 42.29.

The other main characters of the aquifer reflected in drawdown - recovery analysis of the basin are (i) responses similar to double porosity model, (ii) linear fracture zone with barrier (no-flow) boundaries, (iii) connectivity of semi-confined fracture aquifer with phreatic aquifer, (iv) drawdown curve shows slope change due to heterogeneity of the aquifer (v) depth wise interconnection between fractures and (vi) apparently homogenous response during pumping.

The average water level of dug wells in coastal plain region varies from 0.79 m bgl (Nattika) to 2.46 m bgl (Mathilakam) while it varies from 2.73 m bgl (Mannuthi) to 10.83 m bgl (Cherpu) in midland and highland regions of the basin. The long term rise of groundwater level varies from 0.22 m/year (Chavakkad) to 0.532 m/year (Kunnamkulam). The maximum long term fall of groundwater level is in Puthur (0.008 m/year).
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The average piezometric surface in coastal plain varies from 0.79 m bgl (Nattika) to 2.46 m bgl (Mathilakam), while the average piezometric surface varies from 2.22 m bgl (Madakathara) to 22.58 mbgl (Kandanissery) in midland and highlands. The long term rise of groundwater level of bore wells varies from 0.016m/year (Mattahtur) to 0.352m/year (Athani). The long term fall of groundwater level varies from 0.017m/year (Tholur) to 0.173 m/year (Kandanissery). A falling trend in water level during pre-monsoon indicates that there is an increase in groundwater development in the area. As long as the same trend is not observed in the post monsoon water level, it is a positive indication for optimum development. A falling trend of water level in the post-monsoon indicates that the rainfall is not sufficient to recharge the aquifer to the required level or an increase in groundwater draft/out flow.

The rising water levels in both phreatic and semi-confined aquifers are closely related to increase in rainfall and vice-versa. Rainfall has a major control over the water level fluctuation in the basin but in semi-confined aquifers, structure and geology of the area are the main controlling factors.

The major recharge areas of the basin are Pattikkad, Ottuppara, Chelakkara, Vaniyampara and Wadakkancherry fall on eastern and north eastern part of the basin. In addition to the above, two local pockets of recharge are seen around Irinjalakuda in Karuvannur basin and Kunnamkulam in Kechery basin; which lies in south central and north western part of the Palaeo-lagoon (Kole land basin) respectively. The discharge zone lies in the western part of the basin covering more than 45% of the terrain. The groundwater flow direction of the basin more or less coincides with the grid deviation map suggesting that topography play a considerable role in groundwater movement.

As per the norms of GEC-97, the estimated annual ground water availability of the basin is as follows: (i) recharge from rainfall during monsoon season-305.88MCM, (ii) recharge from rainfall during non monsoon season-131.93MCM, (iii) recharge from other sources during non monsoon season-128.20MCM, (iv) total annual groundwater recharge- 566.01MCM, (v) natural discharge during non monsoon season-52.99MCM, (vi) net annual ground water availability- 513.03MCM, (vii) existing gross groundwater draft for all uses- 222.09 MCM and (viii) stage of groundwater development of the basin- 50.07%. The areas such as Wadakkancherry, ollukkara, Thalikulam, Mathilakam and Mala are found semi-critical with a stage of groundwater development between 70 and 90%. All other areas are found safe with groundwater development less than 70%. No areas of the basin is found critical and over exploited.
Groundwater occurs as three layered sequence in the basin; (i) Overburden portion (10 to 20 m thick) including clay and laterite above crystalline rock (first layer), (ii) between 30 and 50 mbgl (fractured rock; second layer) and (iii) between 60 and 90 m bgl (fractured rock; third layer). The \( \rho_1 \) (resistivity of the first layer) of this basin ranges from 5 ohm-m (Vatanapalli) to as high as 3400 ohm-m (Peechi). Thickness of this layer varies from 5 to 50m. The average resistivity of this layer is 643 ohm-m. The resistivity of the second layer (\( \rho_2 \)) ranges from 25 (Pulavaya) to 1200 ohm-m (Alur) which are weathered or fractured rocks, that may or may not be saturated with water. The thickness of this layer varies from 12 to 70 m and the average resistivity is 397 ohm-m. The resistivities of the third layer (\( \rho_3 \)) range from 20 to 1600 ohm-m which are fractured rocks associated with major and minor lineaments. The average resistivity of this layer is 414 ohm-m. The low resistivity values, below 50 ohm-m, in the places like Chittilapilli, Venkidangu, Adat, Penagam etc. are due to the occurrence of brackish water in fractured hard rock aquifers of the area that is in contact with saline water. Overabstraction of groundwater from bore wells of these places may cause saline water incursion since the fractures are connected to brackish water.

The percentage of geophysical curve types in the area are 35% (H type), 26% (A type), 21% (Q type) and 18% (K type) respectively. H type curve is common for mid and highland while it is Q and A in coastal plain.

The groundwater of both phreatic (dug wells) and semi-confined (bore wells) aquifers of the basin is suitable for domestic, agricultural and industrial uses. In phreatic aquifer (dug wells) pH varies from 5 to 8.74. The maximum pH is recorded along coastal plain (Chavakkad) and the minimum in the northeastern (Wadakkancherry) part of the basin. Electrical conductivity (EC) ranges from 29 \( \mu \)mhos/cm to 980 \( \mu \)mhos/cm at 25°C (northwest of the basin). TDS ranges from 24 mg/l (M.G.Kavu) to 696 mg/l (Chavakkad) and total hardness from 9 mg/l (M.G.Kavu) to 305 mg/l (Chavakkad). Fluoride ranges from 0 mg/l to 1.26 mg/l (Vaniyampara), Ca\(^{2+}\) from 0 mg/l to 94 mg/l (Chavakkad), Mg\(^{2+}\) from 0 mg/l to 28 mg/l (Chavakkad), Na\(^+\) from 2 mg/l to 86.5 mg/l (Chavakkad), K\(^+\) from 0.7 mg/l to 34.3 mg/l (Chavakkad), Fe\(^{2+}\) varies from 0 mg/l to 3.86 mg/l (Ottuppara), Cl\(^-\) from 8 mg/l (M.G.Kavu) to 195.9 mg/l (Chavakkad), CO\(_3\)\(^-\) from 0 mg/l to 37.5 mg/l (Engadiyoor), HCO\(_3\)\(^-\) from 7.17 mg/l (Kodakara) to 199.8 mg/l (Chavakkad) SO\(_4\)\(^-\) from 0.0 mg/l (Pazhanji) to 81 mg/l (Chavakkad) and NO\(_3\)\(^-\) from 0.28 mg/l to 8.62 mg/l (Irinjalakuda).
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In semi-confined deep aquifer (bore wells), pH varies from 5.5 to 8.8. The maximum pH is noted in the south and central part and the minimum in southwestern part of the basin. Electrical conductivity ranges from 10μmhos/cm to 930μmhos/cm at 25°C (northeast of the basin). TDS ranges 48 mg/l (Vellangallur) to 630 mg/l (Wadakkancherry), total hardness varies from 15 mg/l (Aloor) to 445 mg/l (Wadakkancherry), fluoride from 0 mg/l to 1.18 mg/l (Panancherry), Ca²⁺ from 2 mg/l to 100.4 mg/l (Mattathur), Mg²⁺ from 0 mg/l to 56.8 mg/l (Wadakkancherry), Na⁺ from 1 mg/l to 158.7 mg/l (Nellai), K⁺ from 0.4 mg/l to 11.9 mg/l (Aloor), Fe⁺ from 0 mg/l to 6.658 mg/l (Kaiparambu), Cl⁻ from 7 mg/l (Kaiparambu) to 111.6 mg/l (Nellai), CO₃⁻ from 0 mg/l to 46.5 mg/l (Tholur), HCO₃⁻ from 1 mg/l (Choondal) to 225.7 mg/l (Wadakkancherry), SO₄²⁻ from 0.87 mg/l (Tholur) to 125 mg/l (Wadakkancherry) and NO₃⁻ from 0 mg/l to 8.58 mg/l (Velapaya).

Bacteriological analysis of water samples indicates that, almost all the dug wells in the study area are contaminated with coliforms and E.coli, while in bore wells contamination percentage of E.coli is less than 50% in comparison with dug wells. E.coli contamination is higher in urban areas such as Thrissur, Chavakkad, Irinjakkuda and Kunnamkulam than the rural areas.

The groundwater of the basin is generally potable, even though some variations are seen in some pockets. The pH of groundwater is above permissible limit for drinking in the places like Pudukkad, Chelakkara and Chavakkad. Fluoride content is above desirable limit and below permissible limit for drinking (1 to 1.5 mg/l) in the water samples of Vaniyampara, Mathilakam and Ottuppara. The iron concentration is above permissible limit for drinking (>1 mg/l) in ground water samples of Pattikkad, Pudukkad, M.GKavu, Ottuppara, Chelakkara, Kunnamkulam and Edamuttom. The source of iron in the groundwater is from laterite, which covered major portion of the basin, that is due to leaching under low pH condition.

Evaluation based on the concentration of Na%, electrical conductivity and total dissolved solids indicates the groundwater of the basin is generally good for irrigation. Some precaution is necessary while using the ground water particularly for sensitive crops from bore wells of Avanur, Chittilapilli, Adat and Wadakkancherry areas and tube wells of sedimentary (coastal) areas.

The Wilcox and U.S.S.L diagram for the water samples shows that, almost all samples of phreatic (dug wells) and semi-confined deep aquifer (bore wells) belong to C1 and C2 types. The EC of
water samples of phreatic aquifers at Chavakkad and Irinjalakuda and semi-confined deep aquifer at Velapaya, Chittilapilli and Wadakkancherry shows an EC greater than 750 mhos/cm and are C3 type. The SAR values of phreatic aquifer of the basin vary from 0.32 (Mathilakam) to 2.35 (Elavally). The average SAR of basin is 0.95. The SAR values of semi-confined deep aquifer of the basin vary from 0.35 (Chengaloor) to 6.32 (Nellayi). The average SAR of deep aquifer is 0.86. The water samples at Nellayi, Choondal and Arthat shows an SAR more than six during the period of investigation. Almost all samples of both phreatic and semi-confined aquifers of the basin belong to CS1 and C2S2 type, which is suitable for irrigation. Only very few samples show medium suitability for irrigation.

The spatial variation of the residual sodium carbonate (RSC) of the phreatic aquifer of the basin varies from -3.14 meq/l (Thrissur) to 1.11 meq/l (Chavakkad). The average RSC of the basin is -0.39 meq/l. The RSC values of semi-confine deep aquifer of the basin vary from -4.49 meq/l (Wadakkancherry) to 2.93 (Nellayi). The average RSC of deep aquifer is -0.32. The RSC concentration of the all water samples of the basin is <1.25 mg/l, and hence it is suitable for irrigation.

The permeability index (PI) of phreatic aquifer of the basin varies from 32.22 (Pattikkad) to 172.42 (M.G kavu). The average permeability index of phreatic aquifer of the basin is 89.00. Out of 240 water samples analysed, 39% shows a permeability index ≤ 75 (Class I & Class II) and 62% shows a PI between 75 and 172 (Class III). The permeability index of semi-confined deep aquifer of the basin varies from 27.83 (Wadakkancherry) to 172.18 (Chittilapilli). The average permeability index of semi-confined deep aquifer of the basin is 79.60. About 51% of water samples show a permeability index ≤ 75 (Class I and Class II) and 49% shows a PI between 75 and 172 (Class-III). The class I and II are suitable for irrigation while the Class III is not suitable.

The magnesium ratio of phreatic aquifer of the basin varies from 12.53 (Engadiyoor) to 59.07 (Puthur). The average magnesium ratio of phreatic aquifer of the basin is 36.74. About 92% of water samples show a magnesium ratio ≤ 50 and 8% shows a MR between 50 and 59. In semi-confined deep aquifer of the basin it varies from 23.24 (Mudicode) to 59.78 (Athani). The average magnesium ratio of semi-confined deep aquifer of the basin is 44.71. Hence the groundwater of shallow and deep aquifers of the basin is suitable for irrigation.
The water sample of both shallow and deep aquifer shows a pH and TDS (as CaCO₃) below the maximum allowable limit for industry (pH 6.4 to 8.5 & TDS 50 to 3000mg/l and is generally suitable for industries. The corrosivity ratio of waters of both shallow and deep aquifers of the basin is <1 (CR, 1) and considered under safe category.

In Gibbs diagram, density of sample points are maximum in precipitation dominance area (79%), while in the case of phreatic shallow aquifer only few points fall (21%) in the rock dominance area. The clustering of points in precipitation domain indicates the rock chemistry of the phreatic aquifer is not a major factor in controlling the groundwater chemistry of the basin, but precipitation. But the situation is different in semi-confined deep aquifer of the basin. 77% data points fall in rock dominance area and only 23% data points fall in precipitation dominance area. The clustering of data points in rock domain indicates that the rock chemistry of the semi-confined deep aquifer is a major factor in controlling the groundwater chemistry of the basin not precipitation.

The Hill-Piper plot of phreatic and semi-confined aquifer indicate that, about 70% of the samples fall in the Field 1 (alkaline earth exceeds alkalies) and the water belong to Ca-Mg-HCO₃ facies. Calcium and magnesium are the major cations and bicarbonate is the major anion in the study area. Total hydrochemistry of the area is dominated by alkaline earths and weak acids.

Three hydrochemical facies identified for the water samples of phreatic aquifer of the area are (i) Ca²⁺-Mg²⁺ - HCO₃⁻ facies (Field I), (ii) Na⁺-K⁺-Cl⁻ - SO₄ facies (Field 3) and (iii) Ca²⁺-Mg²⁺-Cl⁻ - SO₄²⁻ facies (Field 4). The post monsoon samples are enriched with bicarbonate and sodium. The calcium and magnesium are the major cations (about 70 to 75%) and bicarbonate is the major anion (60 to 65%) of the basin. This indicates the influence of rainfall on ground water chemistry of phreatic aquifer of the basin rather than geology. The hydrochemical facies for the water samples of semi-confined deep aquifer of the basin are (i) Ca²⁺-Mg²⁺ - HCO₃⁻ facies (Field I) and (ii) Na⁺-K⁺-Cl⁻ - SO₄⁻ facies (Field 3). The calcium and magnesium are the major cations (about 60 to 65%) and bicarbonate is the major anion (70 to 75%) of the basin. Facies changes during pre and post monsoon indicates that, the geology of the area plays a major role in controlling the ground water chemistry of semi-confined deep aquifer of the basin rather than rainfall.
The DRASTIC score for groundwater vulnerability towards pollution of the basin varies from 110 (Tholur) to 176 (Kuttichira). As per the norms of DRASTIC it is found that the groundwater in phreatic aquifer of the entire basin area is highly vulnerable to pollution.

GALDIT score for vulnerability of shallow aquifer towards saline intrusion of the basin varies from 32 (Kundannur) to 121 (Kadappuram). As per the norms in GALDIT it is found that the coastal areas and some low land connected with back waters and sea are vulnerable areas of phreatic aquifer to saline intrusion in the basin (GADIT index >100. Range of EC values, hydrochemical facies diagram, Ionic ratios of major cation and anions, TDS etc. of the samples of the coastal area rejects the possibility of saline intrusion in the basin.

The groundwater potential of the basin has been demarcated by conducting hydrogeological, geophysical investigations and other available secondary data. The midland region of the basin gives potential aquifer with good quality. Groundwater potential of the coastal plain region is also high but shows seasonal chemical variations especially in semi-confined deep aquifers and shallow aquifer in contact with channels connected to sea. Phreatic aquifer of the highland region of the basin shows only a low to moderate ground water potential. Deep semi-confined aquifers of the northwest, northeast and southern part of the basin show moderate to high groundwater potential. The deep aquifers at the central and western part of the basin are productive but show quality variation (high EC) if the withdrawal is in higher quantities. A narrow strip of Tertiary sediments (width less than 1000m from the coast) of Vaikom formation, along the coast of the basin, is productive with moderate potable quality.

The stratigraphical analysis of the basin gives a clear picture about the origin and evolution of palaeo-lagoon (Kole land basin). The $^{14}$C ages and shell assemblage help to separate the different lithological units. Chamockites, gneisses and intrusives (Precambrian), laterites and gravels (Tertiary), ferruginous clay, clayey sand, coarse to medium sand and molluscan shells (Pleistocene), greenish black/grey clay, sand and sandy clay interbeded with thin layers of clay (Holocene) and clay, sandy clay, silt, loam (Recent) are the major stratigraphic units identified in the basin. The $^{14}$C dates from Quaternary sediments of the Palaeo-lagoon area shows three ranges of age groups viz. (i) 24700 ± 1890 to 35060 ± 5570 Yrs.BP (ii) 5160 ± 130 to 8820 ± 120 Yrs.BP and (iii) 2180 ± 170 to 3160 ± 110
Yrs.BP. A sedimentation gap for 10000 years is seen between (iii) and (ii), for 1000 years between (ii) and (i) groups of samples respectively indicating a break in deposition. Radiocarbon dates suggest Middle to Late Pleistocene period for group (i) Early to Middle Holocene period for group (ii) and Late Holocene period for group (iii).

The sediments of the beach ridges range from medium to very fine sand, moderately sorted to poorly sorted, near symmetric skewness and meso to leptokurtic nature and show coarsening downward sequences in the bottom most layers. In the middle part of the basin fining upward sequences have been observed.

The average standard deviation of the sediments of the basin varies from 0.82 to 1.34 6 and the sorting is generally decreases towards southern side of the basin. The poorly sorted nature in the southern side of the basin shows the fluvial influence in deposition. The sorting worsens as the phi mean size decreases. But a reverse trend is seen in Nattika area. The medium and fine sands show moderate to moderately well sorted nature. It is difficult to demarcate the palaeo-ridge sediments from the recent ridge sediments due to the presence of coarse as well as fine sediments in both the ridges.

Bivariate plots of the textural data indicate beach and inland environment for the sediments in the area. There is not much variation in the environments along and across the coastal plain. The beach ridges of the study area would have been formed from near shore sand supply.

The sand content in the samples varies from 85 (Vatanapilli) to 99% (Mathilakam). The clay content in the samples is increasing from southern (Mathilakam) to northern (Chavakkad) part of the basin. This indicates the fluvial influence during deposition in the northern and central part of the basin was more than the south.

The heavy minerals in the sediments are primarily opaques, garnets, hypersthenes, glaucophane, biotite and actinolite in very fine sands whereas chlorite, glaucophane, garnets and opaques are found in fine and medium fractions. The heavy mineral distribution shows that the concentration decreases towards central part of the study area. The source for the mineral assemblage is the drainage basins of Chalakudi, Karuvannur, Kecheri and Bharathapuzha rivers.
The predominant clay minerals found in the study area are kaolinite, illite, chlorite, and montmorillonite.

The approximate evolutional history of the area that, around 40 to 42 ky BP, shoreline coincided with the western boundary of present Palaeo-lagoon (Kole land). Around 7 to 9 ky BP, sea was further advanced to east and coincides with almost the eastern boundary of the present Palaeo-lagoon. A wide littoral zone was created by transgression while the lagoonal water bodies and the ridge-runnel topography developed during regression. Regressive phase was started from around 4 to 5 ky BP and created a lagoon in the foredeep side (present Palaeo-lagoon). Successive regression was continued and became standstill for a couple of time around 2 to 3 ky BP at the western side of Conoli canal (coincides with Conoli canal). Further regression around 1 ky BP caused the formation of present day coast and Conoli canal parallel to it. The earlier deposits in the basin show marine/ lagoonal character but later deposition shows fluvial character.

The major conclusions of the study are:

- Based on the aquifer parameters analysis most of the areas of the basin are found suitable for groundwater prospecting. The main groundwater zones of the study area are (i) sedimentaries in the west and (ii) laterites and crystalline rocks in the east of palaeo-lagoon. Coastal area of the basin is suitable for tube wells, filter points and shallow dug wells, while the midland region is suitable for large diameter dug wells with moderate to high yield and the highlands are desirable for construction of low yielding dug wells. The north, northeast and southeast portion of the basin is very much suitable to moderate to high yielding bore wells.

- The movement of groundwater is mainly controlled by topography and lithology in phreatic aquifer, but lineaments and structure in semi-confined aquifer. The average drawdown is 1.79 m in phreatic aquifer and 16.70 m in semi-confined aquifer of the basin.

- Groundwater occurs as three layered sequence in the basin viz. (i) 10 to 20 mbgl (including clay and laterite above crystalline rock), (ii) between 30 and 50 mbgl (fractured rock) and (iii) between 60 and 90 m bgl (fractured rock associated with lineaments).
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- Geochemically the groundwater is generally potable and suitable for irrigation and industry.

- The groundwater in phreatic aquifer of the entire basin is highly vulnerable to pollution as deduced by DRASTIC method.

- The phreatic aquifer of the coastal area and some lowland region connected either to back waters or sea is vulnerable to saline intrusion. Overabstraction of groundwater by tube wells along coastal plain and bore wells in places like Chitilapilli, Velapaya, Arthat, Puzhakkal, Penagam etc. may cause saline water incursion through the fractures that cut across the brackish water.

- Laterites and gravels (Tertiary), ferruginous clay, clayey sand, coarse to medium sand and molluscan shells (Pleistocene), greenish black/grey clay, sand and sandy clay interbeded with thin layers of clay (Holocene) and clay, sandy clay, silt, loam (Recent) are the major stratigraphic units identified in the basin.

- Three stratigraphic breaks have been observed in the depositional history of the basin viz. (i) above 42000 Yrs. BP, (ii) between 20000 and 10000 yrs. BP and (iii) between 3000 to 2000 yrs. BP. This may be due to the break in sedimentation related to sea level oscillations.

- The heavy minerals in the sediments are found to be primarily opaques, garnets, hypersthenes, glaucophane, biotite, actinolite chlorite, glaucophane garnets etc. and the source for the mineral assemblage is the drainage basins of Chalakudi, Karuvannur, Kecheri and Bharathapuzha rivers.

Areas such as Wadkkancherry, Ollur, Mala and Thalikulam are found semi-critical as far as groundwater development (between 70-90%) is concerned. Proper groundwater management and schemes for artificial recharge are necessary in these areas to overcome the further groundwater depletion. Geochemically groundwater of the basin is good for all domestic, irrigational and industrial, even though some red signal are given by coastal areas regarding aquifer vulnerability and saline intrusion. Further intervention in the coastal aquifers of the basin should be cautiously managed. High resolution dating has to be carried out in the area to correlate the various lithostratigraphic units of the Central Kerala.