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Characterization of Typical Complex Hydrogeological Condition of Structurally Disturbed Shear Zone Areas of Palakkad District in Western Ghats Region, Central Kerala

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Abstract

Aquifer characteristics and hydrogeological condition of structurally disturbed shear zone areas of Palakkad district in Western Ghats Region of Palakkad district have been studied. The study of sub-surface hydrogeological framework of aquifers up to 200 meters below ground level (m bgl) was carried out to quantify groundwater resources, water quality, hydraulic properties with an aim to evolve a sustainable aquifer management plan in consideration with the water level monitoring and exploratory drilling. The hard rock terrains have been structurally controlled by shear a zone, which facilitate to develop numerous fractures and becomes potential repositories of groundwater. The thickness of lateritization changes between 1.02 and 24.1 m. The premonsoon depth to water level varies from 1.58 to 14.20mbgl, but that of PSM in between 0.60 and 21.50 m mbgl with a fluctuation about 6m. The quantification of groundwater potential in the aquifers of consolidated formation within the shear zones and establishment of a futuristic model of aquifer management plan for the area are the highlights of the work.

Keywords: Laterite, Aquifer, Potential, Management, GIS, SWOT

Introduction

Groundwater draft from the aquifer systems has been evaluated from well inventory data and integrated use of lithological and geophysical data used to define the aquifer geometry of the area. Comte *et al*. (2012) developed a methodology on heterogeneity in Irish hard-rock aquifers based on geological and geophysical approaches and found that thickness of overburden, compartmentalization of the bedrock and spatial variation of weathered bedrock and tectonic fabric control anisotropy of aquifer properties in the area. The deep groundwater resource in Quartzitic hard rock ridge examined by using 2D Electrical Resistivity Tomography (Kumar *et al.*, 2014) and found that ground water resources were occurred within the clayey sand and weathered/fractured Quartzite with apparent resistivity values range between 3–35 and 100–200 ohm.m and depth of occurrence 40 - 88 mbgl. Foster (2012) examined groundwater scenario in crystallines aquifers of tropics and proposed policy issues for the management of the ground water resources for achieving UN Millennium Development Goals for drinking water supplies in rural areas and enhanced standard of living. Gopinathan *et al.* (2020) studied the groundwater regime of crystallines of Charnockites and Hornblende epidote gneisses terrain of Morappur with abundant secondary porosity developed by fractures / shear zones in Dharmapuri district, India and by using RS and GIS tools delineated structural, lithological and geomorphic units and correlated groundwater occurrence and movement in the area. Shailaja *et al.* (2018) delineated groundwater potential zones with the aids of fuzzy and the analytical hierarchical process for a Deccan Trap terrain, Maharashtra, India by using groundwater potential factors related to ground water reservoir like apparent resistivity, thickness, transverse resistance, electrical anisotropy, drainage density, density of lineaments, rainfall, slope of terrain, geology and land use/land cover and found that very high groundwater potential ares found in the plateau and plains of the study area. Das (2017) had categorized Gangajalghati block, Bankura district in to very good, good, moderate, and poor ground water potential zones by using RS and GIS and the study became highly useful for proper sustainable management of water resources of the area. Narendra *et al.* (2019) delineated Groundwater Potential Zones of Narkhed Taluka of Nagpur district, Maharashtra by carrying out 31 VES coupled with hydrogeological data to translate the geoelectrical layers to sub-surface lithological units in basaltic formations. The water

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management policy for Kerala by using Delphi and sustainable development and management of ground water were studied by several workers (Joji *et al.*, 2014; Joji and Nair, 2002). The detailed study on aquifer characteristics, geometry of fracture pattern, discharge of characteristics, overburden thickness of the various formations in parts of Chittur, Kollenkode and Alathur blocks of Palakkad district and surrounding areas were carried out by Joji (2007). The objective of the present work is to examine aquifer characteristics and present hydrogeological scenario of the area to propose management strategies for sustainability of ground water resources of the area for attaining water security to the stakeholders.

Study Area

The study carried out in Palakkad district, 'Rice bowl of Kerala' which is noted for extensively paddy cultivation with the water from 12 reservoirs in Bharathapuzha (Nila) and Bhavani Rivers and their tributaries. The land locked hard rock terrains of Palakkad district are disturbed by lineaments, fractures and fissures, shearing (Palakkad-Cauvery shear zone) and the shear zone responsible for the development of discontinuity in the Western Ghats in the form of Palakkad Gap (Thara, 1992). The wind gap in the Palakkad district is termed as Gate way of Kerala and its N^n part is fractured by Bhavani shear zone (NE-SW trend). The study area with an areal extent of 4480 sq.km lies between the N latitudes 10^o 20' 20" and 11^o 14' 24" and E longitudes 76^o 0' 40" and 76^o 54' 21" (Fig.1). The maximum temperature of the study area varies from 32.3 to 41^0C and the minimum 22.2 to 25.3^0C.

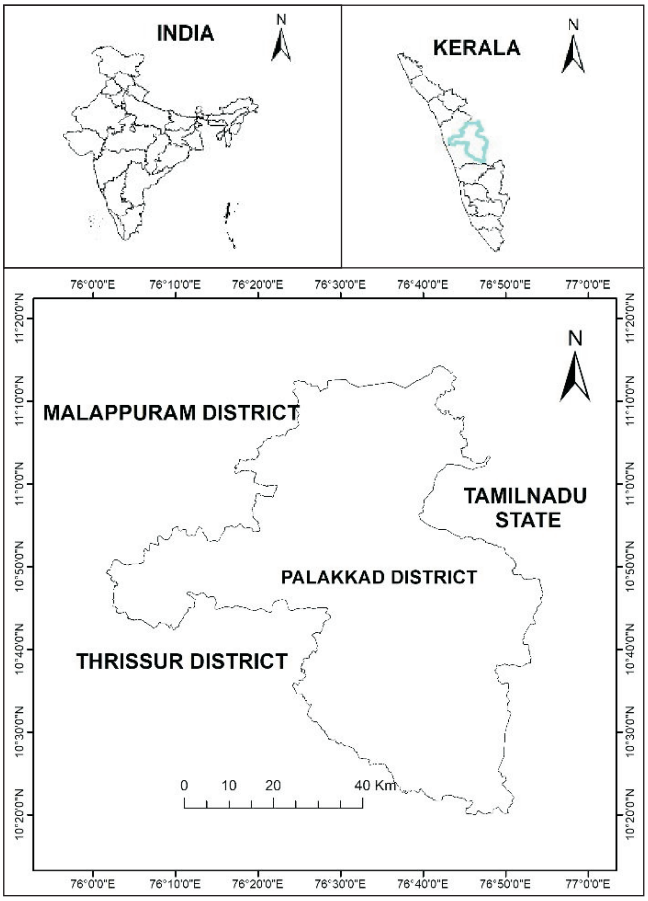

Fig.1. Base map of the study area

Materials and Methods

Topographical maps of Survey of India (1968) 58B/1, 5, 6, 9, 10 and 14 and 58A/8 and 12 (scale 1:50,000) have been used for the preparation of base map (Fig.1). The projection [WGS 84] [EPSG: 4326] has been used in the preparation of layers. The digitization, editing and annotation were done by Map Info 11.0 at the GIS platform. The various parameters like rainfall, depth to water table (DTW), yield characteristics of the wells, water quality and other related data pertaining to hydrology and hydrologeology have been used in the study for various types of analysis. The DTW data of ground water monitoring wells monitored by the Central Ground Water Board (CGWB) and its exploratory well (EW) details on rock type, overburden thickness, yield test data, data on discharge, duration of pumping, maximum drawdown and various aquifer parameters are utilised. Hydrochemistry has been briefly discussed. The information from 97 EWs has been analyzed to understand depth of weathering, geometry of fractures, yield characteristics and aquifer parameters. The various software like Microsoft Excel and Aquachem, have been extensively used for the preparation of various layers and statistical analyses under GIS platform (Map Info 11.0). The major ions were determined by procedures of APHA, 2017. The Cl^- , F^- and NO_3^- ions were calculated by ion selective electrode; HCO_3^- potentiometric titration; SO_4^{2-} modified titration method after Fritz and Yamamura (1955) and Haartz *et al.* (1979); Ca^{2+} and Mg^{2+} in absorption mode while Na+ and K^+ emission mode of the AAS. The chemical results were tested by ionic charge balance of ±5% (Huh *et al.*, 1998).

Results and Discussion

The various parameters controlling characterization of structurally controlled typical aquifer systems in the area are briefly discussed.

Climate, Drainage and Soil

The average annual rainfall of the area in 2020 was 2096mm (IMD, 2021). The area receives rainfall from SW monsoon (June to September) contributes 71% of rainfall and NE (October to November) 18%, The rainfall from 2012 to 2020 varied from 1349.9 to 3144.4 mm, and 2016 experienced lowest annual rainfall of 1349.9 mm but 2018 with highest. The monthly rainfall variation is compiled (Table 1).

The tributaries of Bharathapuzha (Nila) are mainly responsible for the geological activities responsible for the present day development of various geomorphic units. The soil types include lateritic soil, valley fill materials, alluvium, black soils of Chittur taluk and forest loam. The geomorphologic units are mid land (elevation between 7.6 and 76 mamsl) and high land (elevation > 76 mamsl) regions and the elevation varies from 20 to 2386 m amsl. The main discontinuity in the Western Ghats is Palghat gap with a width of 32km. The peaks in the Western ghat areas of the study area are Anginda, Padagiri, and Karimala Gopuram with elevations of 2386, 1585 and 1440 m.amsl, respectively.

Regional Geological Setting

The predominant Precambrian crystallines in the area are Migmatites, Gneisses, Charnockites and Khondalites and the

Table 1: Mean Monthly Rainfall (mm) distribution in the study area

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
2012	0	0	6.2	141.6	64.4	386.9	297.5	367	171.7	197	61.6	4	1697.9
2013	0	43.5	34.1	34.4	55.6	729.2	796.8	279.3	283.7	235.2	74.4	4.6	2570.8
2014	0	3.1	5.2	36.4	190.8	314	602.2	561.4	230.6	282.5	40.2	12.1	2278.5
2015	0	2	27.1	184.2	245.6	455.2	281.8	219.2	199.3	141.8	185.8	43.2	1985.2
2016	0.2	0	4.2	4.1	169.2	461.5	336.6	159.2	77.4	88.2	21.7	27.6	1349.9
2017	0	0	83.1	28.3	139.5	433.2	317.2	398	375.6	102.8	35.2	38.9	1951.8
2018	0	25.7	47	73.5	353.6	679.9	776.9	848.8	72.3	227.7	37.9	1.1	3144.4
2019	0	3.8	1.5	96.3	46.8	273	421.9	979	454	358.1	133	1	2768.4
2020	0	0	21.7	85.3	67.7	309.4	417	520.2	455	162.3	38.7	19	2096.3

(*Modified after* IMD, Customized Rainfall Information System)

regional geological set up of the area. Palghat gap is the discontinuity feature in the district and may be formed by wind gap, crustal up warping followed by jointing and fracturing and block faulting (Thara, 1992).

Water Bearing Formations

The water bearing formations of the area are alluvium of Recent / Anthropocene**,** laterites of Sub-Recent (Pleistocene) and weathered and fractured crystallines.The shallow aquifers or phreatic aquifer are the weathered Hornblende biotite gneisses, Charnockites and Gneisses with the thickness of 1.02 (Vannamada) to 22.1 (Moolakombupirivum. The groundwater extraction structures in the weathered zones are open small diameter shallow dug wells, open small diameter shallow dug-cum- bore wells and *kokaranis* (crystalline formations at the dug well bottom are blasted out and developing water from weathered and crystalline formations with same diameter from top to bottom). The depth of shallow open dug wells abstracting phreatic aquifers generally varies from about 4.0 to 19.00 mbgl with diameter of 1.5 for the domestic wells and 4.0 irrigational wells. The premonsoon (PRM) DTW ranges from about ground level to 10 m bgl and that of post-monsoon (PSM) 1.5 to 19.0 mbgl. The wells constructed along canal command areas of Malampuzha and lineaments are highly yielding. The yield characteristics of shallow aquifers depend upon rainfall availability, nature of aquifers, depth of weathering, rock type undergone weathering, porosity, permeability, fluctuation of water level, existing wells in the area, and proximity to water sources (Joji, 2019). The CGWB has made number of exploratory drilling activities in the area with depth varieties from 65 (Kollenkode Mundikavu) to 300.81(Palakkazhi) mbgl. The depth of weathering varies from rock type to rock type. In the depth of weathering or lateritisation in and Hornblende Biotite Gneiss, Biotite gneiss and Charnockites varies from 2.5-24.1, 1.02-12.30 and 2.54-21.2, respectively. Among the predominant rock types of the area, depth of lateritisation lowest in the case of Biotite gneiss with a lowest value about 1 m and highest reported in the case of Hornblende Biotite Gneiss with a value of 24.1 m. It is noticed that dug wells in the weathered laterites of Hornblende Biotite Gneiss are more potential than other weathered formations. Productive fractures generally occur between 50 and 110 mbgl, and highest yield reported in the case of bore wells ranged between meager and 36 lps. The lineament directions like NE-SW, N-S, ENE-WSW, NE-SW and NNE-SSW and the NE-SW lineaments are the productive. In connection with ground water exploration number of horizontal resistivity proofing (HRP) and vertical electrical soundings (VES) has been carried out by Central and State Govt. organizations by Schlumberger electrode spacing. The VES results indicated that there were 4 to 5- layered geoelectric sections and the last layer was extending with depth and also indicated that depth of basement generally between 5 and 60 m.

Depth to the Water Level (DTW) Variation in 2019

The DTW data of ground water monitoring stations maintaining by CGWB has been analyzed during 2019-20. The premonsoon (PRM) DTW ranges from 1.58 to 14.20 m.bgl in 2019. It is noted that usually eastern areas of the district with shallow DTW and that of western deeper. The DTW during PSM varies from 0.60 to 21.50 m.bgl (Table 2). It is noted that the thickness of the weathered portion is mainly controlling the potential and DTW and are controlled by rainfall, and proximity tank/pond, drainages and canal command areas of Malampuzha reservoir. The well hydograph studies reveal that most of the wells are showing long term decline in water level and one of hydrographs with steep decline in water level at Palakkad tapping Laterite phreatic aquifer is as shown in Fig.2.

Table 2: Depth to Water Level for different seasons in the area under study

Period	No. of Wells Analysed	Depth to Water level (mbgl)		No. & Percentage of Wells Showing Depth to Water Table (mbgl) in the Range of					
		Min	Max	0.0 - 2.0	2.0 - 5.0	5.0 - 10.0	10.0 - 20.0	20.0 - 40.0	> 40.0
April 2019	121	1.58	14.20	1 0.82%	37 30.57%	66 54.54%	17 14.04%	0	0
August 2019	133	0.10	20.70	40 30.08%	64 48.12%	24 18.05%	4 3.01%	1 0.75%	0
November 2019	121	0.60	21.50	27 22.31%	54 44.63%	37 30.58%	2 1.65%	1 0.83%	0
January 2020	107	2.30	14.2	0	37 34.58%	56 52.34%	14 13.08%	0	0

(*Modified after* Anon[2], 2020)

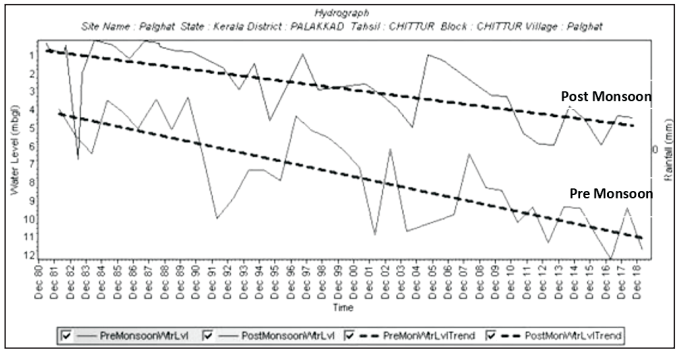

Fig.2. Well hydrograph tapping laterites at Palakkad, Palakkad District (Anon[2], 2020)

Tectonism, Ground Water Potential

The hydrogeological investigations and exploratory studies reveals that the study area is highly tectonically disturbed with moderate to well pronounced, vertical to sub-vertical gneissic foliation and trend of foliation varies from NW – SE in the western part, E-W in the central part and ENE – WSW to NE – SW in the eastern parts of the district (Joji, 2019). The hard rock terrain is affected by the structural elements of jointing, fracturing, foliation, folding, and lineaments and the lineament map prepared from toposheets and satellite imageries (Fig.3). Sheet joints reported in granites and chanockites, but becomes widely spaced, tight and less frequent at depth. The main fracture directions in the terrain occur in E-W, ENE – WSW and NNW – SSE, WNW – ESE, NW – SE and N-S (Joji, 2019). The lineament map of the terrain has been prepared and overlay in GIS platform (Map Info 11) revealed that exploratory wells along E-W lineaments with a yield variation from 120 to 600 lpm and along NE-SW lineament in the range of 250 to 900 lpm. The wells along the NNW lineament are having very good yield of 700 to 720 lpm. The productive fracture zones are mainly found between 60 and 85 m mbgl but water yielding fractures are occasionally encountered at the depth of 130 m mbgl at places like Kulukkur, Chittur and Mukkalli *etc*. The study reveals that hornblende biotite gneiss is more fractured and productive than other aquifers and very high yielding wells are generally striking parallel to NW-SE lineament direction (Joji, 2019).

Hydrochemistry

There were 53 dug well water samples analyzeded and the hydrochemistry revealed that water quality was good but EC varied between 135 and 2500 µs/cm at 25°C with mean value of 834 µs/cm at 25°C and the highest value of Fluoride reported to be 4.58 mg/L at Koppanur. The fluoride contamination has been reported in many exploratory wells in the study area above the permissible limits from the Chittur, Kollengode, Nenmara and Alathur blocks (Joji, 2007). The occurrence of fluoride in groundwater in the area is due to weathering and leaching of fluoride-bearing minerals from the in situ metamorphic rocks especially Hornblende Biotite Gneiss. The consolidated chemical quality data is compiled (Table 3) and chemical parameters is depicted in Modified Piper Diagram and Schoeller Plot (Fig.4). As per Modified Piper diagram (Chadha, 1999) majority of the samples are coming under Ca-HCO_3 hydrochemical facies (recharge type) followed by Na-Cl type (sea water type), Ca-Mg-Cl type of water (reverse exchange type) and a few Ca-HCO_3 (base exchange type water). The Gibbs' plots revealed that the rock (aquifer material) – water interaction has played major role in the evolution of ground water than precipitation and evaporation (Gibbs, 1970). Based on various studies it is revealed that some dug well samples with fluoride concentration in the range of 0.70 – 4.58 mg/L. The deeper bore wells with fluoride concentration above permissible levels were reported from Chittur, Nenmara, Kollengode blocks with a range of 0.3 to 3.12 ppm (Chinnamoolathara EW of CGWB).

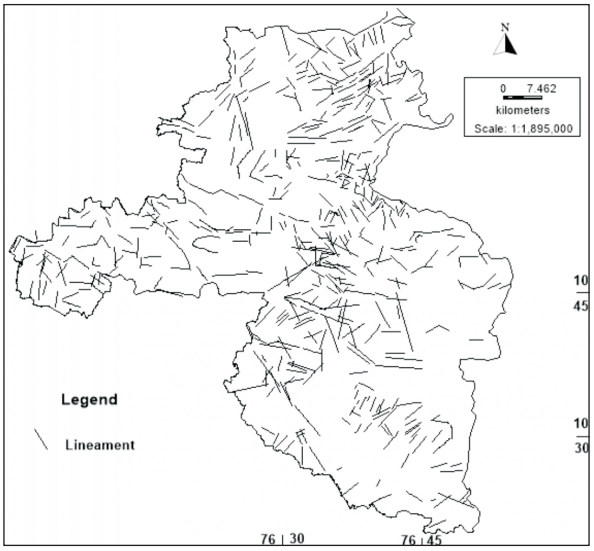

Fig.3. Lineament map of the area under study

Management of Ground Water Resources

The stage of ground water extraction (%) in the district varies between 26.35 (Attappadi block) and 104.49 (Chittur block) with an average stage of extraction 56.44% (Anon[1], 2019). The Chittur block of the area coming under Over-exploited and Malampuzha block Critical. As the area is blessed with surplus surface water sources there are many scopes for conjunctive use of water and other management interventions. The problems at the water sector identified during the hydrogeological investigations are high Fluoride content in shallow and deep aquifers (1-5.75) and inland salinity in and around Kadumthuruthi (Yakkara) and Kuduvayoor (Anil Chand, 2013) and may be due to application of potassium as a fertilizer, irrigational, industrial and domestic waste waters (Abbasi, 1998; Bohlke, 2002). The drying up of dug wells resulted from indiscriminate construction of bore wells, localised water scarcity due to sand mining from river beds, high stage of ground water extraction in many areas, excessive draft of groundwater for irrigation purposes especially in the eastern parts of the study area, Kanjikode (industrial hub of the district), ground water pollution reported from industrial effluents. There are much acute water

Table 3: Water quality parameters of dug wells

#	Item	pH	EC	TH	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3	F
1	Min.	3.55	135	20	5	2	15	1.30	NA	1.00	15.30	1.80	0.00	0.00
2	Max.	9.07	2500	689	102	136	559	75	NA	1000	572	462	183.0	4.58
3	Mean	7.58	834	224	42	29	90	8	NA	231	99	50	25	0.70
4	SD	0.67	564	146	23	26	93	12	NA	176	103	81	32.89	0.90

(*Modified after* Anon[2]. 2020)

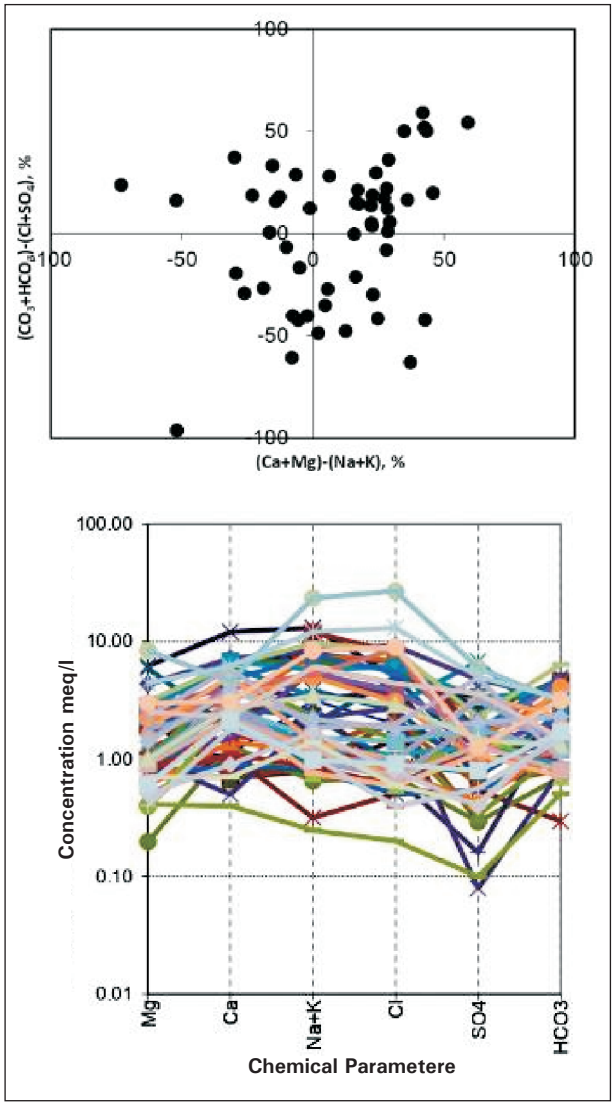

Fig. 4. Modified Piper Diagram and Schoeller Plot of chemical parameters

scarce area reported in all the blocks of the study area. The severe scarcity of water has been reported during lean period include Mundur, under these circumstances, one SWOT (Strength, Weakness, Threat and Opportunities) analysis attempted to know the real ground water scenario of the Palakkad district. High rainfall availability, springs and water falls in the area are the strength under water sector, heavy draft of ground water as one of the weakness, threads include falling trend in water level, pollution and contamination of ground water and opportunities include scope for rainwater harvesting, artificial recharge and integrated watershed management and other details are compiled (Table 4).

Conclusions

Characterization of typical complex Hydrogeological condition of structurally disturbed shear zone areas of Palakkad district in Western Ghats Region, Central Kerala has been examined. The mean annual rainfall of the area is 1976 mm and the rainfall increases from south to NW^n direction. The ground water extraction structures in the area are small diameter open dug wells, naked bore wells and *kokaranis. The* NE-SW lineaments in the hard rock terrains are more potential zones. The ground water potential in the weathered zone depends on the thickness of the weathering and the potential wet fractures of fractured crystalline aquifer exist between the depth of 50 and 120 mbgl. The lateritisation thickness reported lowest in the case of Biotite gneiss with 1.02 m and Hornblende Biotite Gneiss (24.1 m). Among the different lineament directions, NE-SW lineaments are more productive. The hydrochemical studies of ground water revealed that majority of the samples are coming under Ca-HCO_3 hydrochemical facies (recharge type) followed by Na-Cl type (sea water type) and Ca Mg Cl type of water (reverse exchange type). The fluoride contamination above the permissible limits in the ground waters of deeper aquifers are common in the blocks of Chittur, Kollengode, Nenmara and Alathur blocks with Hornblende Biotite Gneiss as the host rock. The water in the area is formed by rock-water interaction and is suitable for drinking and irrigation purposes. As a futuristic model of aquifer management plan for the area, SWOT (analysis carried out to find out various measures to be adopted for the sustainable development of water resources of the area. The highlights of SWOT include high rainfall availability, springs and water falls in the area as strength, huge ground water draft for agricultural and industrial purposes as the main weakness, water scarcity, declining water level trend and quality issues as opportunities, site specific implementation of artificial recharge

Table 4: SWOT Analysis of ground water scenario of the Palakkad district

Strength ❑ Rainfall availability very high ❑ Many springs in Thachampara panchayath ❑ Existence of water falls (Meenvallam and Alta), reservoirs, ponds / tanks Weakness ❑ Micro level study required for 100% well inventory to find out actual draft of ground water ❑ Heavy draft of ground water development in Over-exploited, Critical areas & the fluoride affected areas ❑ Pinpointing high-yielding bore/tube wells Threat ❑ Water level falling trend in many areas especially in Chittur block ❑ Bore well construction increasing in an alarming rate ❑ Inland Salinity, Fluoride in ground water ❑ Severe water scarcity in summer due to drying up of wells	Opportunities ❑ Availability of rain water and sub-surface water for the practicing conjunctive use of water ❑ Desilting the tanks / ponds ❑ Roof top rainwater harvesting and artificial recharge schemes to be implemented ❑ Scope for developing the springs (vernacular term Cholas) at Vakottu mala and Irumbumutty mala in Thachampara panchayath for water supply schemes ❑ Scope for integrated watershed management ❑ Capacity building on water conservation and artificial recharge to stakeholders at grass root level ❑ High-yielding bore wells of Govt. agencies can be utilised for water scarcity. ❑ In situ collection of rainwater in salinity affected areas for direct use and recharge. ❑ Use of water use efficiency (WUE) methods ❑ Conservation and protection of existing ground water abstraction structures

schemes, rainwater harvesting, integrated watershed management etc are the threats in front of the planners and water specialists.

Authors' Contributions

V.S. Joji: Study Conception and Design, Data Collection, Draft of Manuscript Preparation. **Y.W. Mawale:** Analysis and Interpretation of Results, Draft of Manuscript Preparation. **Anadi Gayen:** Analysis and Interpretation of Results, Draft of Manuscript Preparation, Reviewing and Editing.

Conflict of Interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

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