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Statistical Analysis of Hydrogeological Parameters of Kantapara Block, Cuttack District, Odisha

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Abstract

The hydrogeological parameters, which control the quantity, storage and movement of groundwater in the subsurface are of paramount importance and their study has become imperative now-a-days. The present research is concerned with the statistical analysis of hydrogeological parameters like ground slope, thickness of soil zone, pre- and post-monsoon depths of water table, water table fluctuation, porosity, specific yield, specific retention, permeability, static water level, discharge, draw down, specific capacity index, storativity, hydraulic conductivity, hydraulic diffusivity and transmissivity of the Kantapara block of Cuttack district, Odisha. The univariate, bivariate and multivariate statistical techniques depict both the inter- and intra-parameter as well as sympathetic and antipathic relationships between the hydrogeological parameters.

Keywords: Hydrogeological parameters, Correlation analysis, Factor analysis, Cluster analysis

Introduction

Water is an essential constituent for existence of life. It occurs both on the surface and in the subsurface of the Earth. Increasing population growth, urbanization, industrialization and food grain production coupled with climate change and polluted surface water bodies have increased the importance of groundwater. As a result, most of the human population prefers to use groundwater. The quantity and quality of groundwater present in the aquifer depend on the amount of precipitation, ground slope, permeability of the soil cover in addition to the types of sediments and rocks present in subsurface (Murkute, 2023; Solanki and Murkute, 2019). Increased urbanization has appreciably reduced the recharge areas of the aquifers by construction of buildings and roads. At the same time, the quantity of rainfall is declining due to climate change. The water supply condition has become very bad in populous cities sitting on hard rocks. However, the per capita water consumption in alluvial terrains is more due to the porous and permeable nature of aquifer materials. Though the Central Ground Water Board (CGWB) mapped the aquifers of Kantapara block of Cuttack district of Odisha in 2013 and 2018, no systematic research has been undertaken so far. Though Nayak and Hota (2021, 2023a-b) studied the groundwater chemistry and quality, detailed study of hydrogeological parameters has not been done. Murkute (2014, 2017) has studied the interrelationships of texture and types of sediments with aquifer parameters. In view of this, an attempt has been made in the present work to study the hydrogeological parameters of the Kantapara block of Cuttack district, Odisha by statistical methods.

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Geological Setting

Study Area

The present research pertains to the Kantapara block of Cuttack district, Odisha. It is bounded by east longitudes 85 57' 30 to 86 03' 40" and north latitudes 20 12' 30" to 20 21' 30" featuring in the Survey of India toposheets F45T15, F45T16, F45U3 and F45U4 in 1:50,000 scale (Fig.1). It covers an area of about 119 Km^2. The area experiences a warm humid tropical climate with annual rainfall of about 1.39 m and variable temperature of 20 - 40^oC.

Geology

The Eastern Ghats Supergroup of Precambrian age consisting of khondalite, charnockite, quartzite, granite and gneisses forms the basement of the Kantapara block. It is overlain by the rocks of Athgarh Formation that comprises conglomerate-sandstone-shale sequences. These sedimentary rocks are succeeded by Palaeocene to Miocene sediments of Tertiary period. The Quaternary gravels, sands and clays, which overlie the Tertiary rocks form the main aquifer system ranging in thickness from 200-400 m (Nayak and Hota, 2021). The area is characterized by moderate slope of about 5 degrees towards south.

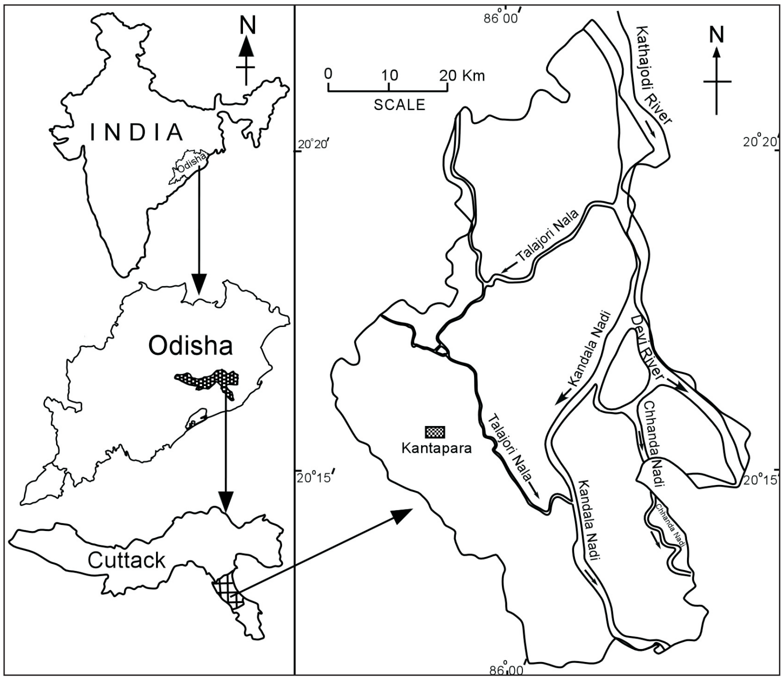

Fig.1. Map of the Kantapara block showing major drainage

Hydrogeology

The Mahanadi River enters the Cuttack district at Naraj, where it bifurcates giving rise to Kathajodi River. After separation from the Mahanadi, the Kathajodi river splits at Gobindpur village and flows in the Kantapara block bifurcating into Kandala and Chanda rivers (Fig. 1). The Kathajodi River is known as Devi River in downstream, flows in the border of Kantapara block and Jagatsinghpur district. This is one of the most active distributaries in the delta system that discharges maximum amount of water during the flood period. The Talajori nala, which is a distributary of Kathajodi River and tributary of Kandla river, provides irrigation facility in the block. The rivers and their tributaries are ephemeral in nature.

Methodology

The hydrogeological parameters used in the present research are ground slope (Sl), thickness of soil cover (St), pre- and post-monsoon depths of water table (Prd and Pod), water table fluctuation (Wf), porosity (Po), specific yield (Sy), specific retention (Sr), permeability (Per), static water level (SWL), discharge (Dis), draw down (Dd), specific capacity Index (SCI), storativity (S), hydraulic conductivity (Hc), hydraulic diffusivity (Hd) and transmissivity (Tr). The ground slopes were calculated from contour values and compared with district thematic map published by NATMO (2020). Thickness data of weathered soil zone were obtained from the well logs. The pre- and post-monsoon depths of water table were measured from the dug wells and the water table fluctuation was obtained from the difference between these two values. The porosity, specific yield, permeability, storativity and hydraulic conductivity were computed by weighted arithmetic average method from the values of these parameters suggested by different workers (Todd, 1980; Reddy, 2013). Static water level, discharge, draws down and specific capacity index were obtained from CGWB (2013, 2018) and District Level Implementation Committee (2016) reports. Specific retention was obtained by subtracting specific yield from porosity, hydraulic diffusivity by dividing the hydraulic conductivity by storativity and transmissivity by multiplying hydraulic conductivity by aquifer thickness (Reddy, 2013). The univariate statistical attributes of hydrogeological parameters were determined by MS Excel. Since the seventeen hydrogeological parameters have different units of measurements, the data were standardized by the formula

$$z = (x_i - \bar{x}) \div s$$

Where 'z' is the standardized value, 'x_i' is the individual value, $\bar{x}$ is the arithmatic mean and 's' is the standard deviation. The computation of correlation coefficients between pairs of hydrogeological parameters and the factor analysis were done using the standardized values of statistical parameters by SPSS software. The cluster analysis was done using the correlation coefficients (Davis, 2002).

Results and Discussion

The univariate statistical attributes like maximum, minimum, average, standard deviation and coefficient of variation of seventeen hydrogeological parameters are presented in Table 1 and their descriptions are given in following paragraphs.

Ground Slope (Sl)

The minimum and maximum elevations in the study area are less than 10 m in southeast and more than 50 m in the northwest respectively. The ground slope controls the rate of water infiltration that recharges the groundwater. In areas of higher amount of slope, the velocity of runoff is more, as a result of which the infiltration becomes less and vice versa. The ground slope varies from 72 cm/Km in the northwest to 25 cm/km in the south with an average of 49 cm/Km, standard deviation of 18.22 cm/Km and coefficient of variation 37.19% (Table 1). The slope values are comparable with the palaeo-slopes of Talchir Gondwana drainage system (38-59

Table 1: Minimum, maximum, average, standard deviation and coefficient of variations of the hydrogeological parameters of Kantapara block.

Hydrogeological parameter	Symbol	Minimum	Maximum	Average	Std. dvn.	CV (%)
Ground slope in cm/Km	(Sl)	25.00	72.00	49.00	18.22	37.19
Weathered soil thickness in m	(St)	3.00	4.80	4.18	0.62	14.92
Pre-monsoon depth to water table in m	(Pod)	3.20	4.50	3.96	0.45	11.25
Post-monsoon depth to water table in m	(Prd)	1.60	2.60	2.10	0.36	17.04
Water table fluctuation in m	(Wf)	1.60	1.90	1.86	0.13	6.89
Porosity in %	(Po)	34.00	37.00	36.00	1.26	3.51
Specific yield in %	(Sy)	14.00	19.00	16.33	2.07	12.65
Specific retention in %	(Sr)	20.00	18.00	19.67	1.03	5.25
Permeability in darcy	(Per)	0.81	2.08	1.16	0.51	44.26
Static water level in m	(SWL)	2.40	3.60	3.08	0.52	16.88
Discharge in lps	(Dis)	10.00	15.00	12.67	1.75	13.83
Draw down in m	(Dd)	5.58	7.56	6.28	0.68	10.87
Specific capacity Index in lpm/m	(SCI)	1.58	2.42	2.06	0.31	15.10
Storativity	(S)	0.017	0.048	0.03	0.01	44.10
Hydraulic conductivity in m/day	(Hc)	8.67	53.95	25.14	16.38	65.17
Hydraulic diffusivity in m/day	(Hd)	413.00	1158.00	906.36	288.43	31.82
Transmissivity in m^2/Day	(Tr)	1460.50	8092.50	3840.97	2535.71	66.02

cm/Km) which have been proved to be alluvial in nature (Hota *et al.*, 2007).

Thickness of Soil Zone (St)

As usual with many places, the ground surface of the Kantapara block is covered with soil formed by weathering of the underlying alluvium. It is composed of gravel, sand and clay in different proportions at different places. Higher porosity and lesser thickness of soil zone favors infiltration and groundwater recharge and vice versa. The thickness of soil zone varies from 3 to 4.8 m with mean value of 4.18 m, standard deviation of 0.62 m and coefficient of variation of 14.92% (Table 1).

Pre-monsoon Depth of Water Table (Prd)

The depths of the water table below the ground surface during pre-monsoon season were measured from different dug wells during water sample collection in May, 2018. The depths vary from 3.2 to 4.5 m with average of 3.69 m, standard deviation 0.45 m and coefficient of variation of 11.25% (Table 1).

Post-monsoon Depth of Water Table (Pod)

The post-monsoon water table depths were measured during November 2018. It varies from 1.6 to 2.6 m with average, standard deviation and coefficient of variation of 2.10 m, 0.36 m and 17.04%, respectively (Table 1).

Water Table Fluctuation (Wf)

The difference between pre- and post-monsoon water table depths is known as the water table fluctuation. It occurs due to combined effects of rainfall and withdrawal of groundwater. In the study area, it ranges from 1.6 - 1.90 m with average, standard deviation and coefficient of variation of 1.86 m, 0.13 m and 6.89%, respectively (Table 1).

Porosity (Po)

Porosity is the amount of voids present within aquifer material. It is commonly expressed as a percentage and indicates the volume of voids relative to the volume of aquifer material. The total porosity of sediment or rock is of two types, effective porosity which consists of interconnected pore spaces and isolated porosity. In case of alluvial aquifers, these values are nearly same. The porosity values of unconsolidated sediments vary widely depending on factors like grain size, shape, orientation, packing and sorting. The average porosity values of pure gravel, sand and clay are 25%, 35% and 45%, respectively (Reddy, 2013). The Kantapara alluvial sediments are composed of gravels, sands and clays in variable proportions. The porosity values range from 34 – 37% with average of 36%, standard deviation of 1.26% and coefficient of variation of 3.51% (Table 1).

Specific Yield (Sy)

Specific yield refers to the portion of groundwater that an aquifer can yield. It is the amount of water that can be taken out from an aquifer by pumping and gravitational drainage. Specific yield is expressed in percentage. It is a significant parameter in groundwater resource management and hydrological modeling. Specific yield values for unconsolidated sediments vary widely depending on factors like grain size, sorting and hydraulic conductivity. The average specific yield values of pure gravel, sand and clay are 22%, 25% and 3% respectively (Reddy, 2013). The lowest specific yield value of clay is due to its finer particle size and lower hydraulic conductivity. The Kantapara alluvial sediments have specific yields ranging from 14-19%, with average of 16.33%, standard deviation of 2.07% and coefficient of variation of 12.65% (Table 1).

Specific Retention (Sr)

Specific retention is the part of groundwater that remains trapped within the pore spaces after gravitational drainage. Specific retention is expressed as a percentage and is a critical parameter in understanding the water storage capacity of aquifers. It influences groundwater flow dynamics, storage behavior and the water resource of an area. Specific retention, which is the effective porosity minus specific yield, varies depending on factors like grain size, packing and sorting of unconsolidated sediments. The specific retention values of pure gravel, sand and clay are 3%, 10% and 42%, respectively (Reddy, 2013). The Kantapara alluvial sediments have specific retention ranging from 18 – 20% with average of 19.67%, standard deviation of 1.03% and coefficient of variation of 5.25% (Table 1).

Permeability (Per)

Permeability is the ability of a material to permit fluids to pass through it. It is a critical property in hydrogeology as it governs the flow of water through porous media like rocks, soils and sediments. Permeability is quantified in terms of the rate of flow of fluid through a unit cross sectional area of aquifer under a unit pressure gradient. The unit of permeability is darcy. Higher permeability indicates easier fluid flow, while lower permeability signifies resistance to fluid movement. Permeability values of unconsolidated sediments vary widely depending on factors like grain size, shape, sorting and their interconnection. The permeability values vary from 10-1 darcy, 1 to 0.1 darcy and 10^{-4} to 10^{-6} darcy in cases of gravels, sands and clays, respectively (Reddy, 2013). Clays have lower permeability values due to their finer grain size, high specific surface area and the tendency to form tight impermeable layers. The Kantapara alluvial sediments have permeabilities ranging from 0.81 to 2.08 darcy with average, standard deviation and coefficient of variation of 1.16 darcy, 0.51 darcy and 44.26%, respectively (Table 1).

Static Water Level (SWL)

The static water level is the height at which water naturally stands in a well when there is no extraction of groundwater. It represents the equilibrium position of the water table in the aquifer under natural conditions, when the downward force of gravity is balanced by the upward pressure of groundwater. The static water level is measured as the vertical distance from the ground surface to the water surface in the well. It serves as a fundamental parameter in hydrogeological assessments, providing information about the water table depth. Changes in static water level happen due to variations in groundwater recharge, extraction and natural processes affecting groundwater levels, such as precipitation and evaporation. Monitoring of static water levels is essential for understanding groundwater dynamics, assessing aquifer sustainability and managing water resources effectively. The value of the static water level in unconsolidated sediments vary significantly depending on factors such as local hydrogeological conditions, precipitation patterns, proximity to surface water bodies and groundwater extraction activities (Reddy, 2013). In the present case it varies from 2.4 m to 3.6 m with mean of 3.08 m, standard deviation of 0.52 m and coefficient of variation of 16.88 % (Table 1).

Groundwater Discharge (Dis)

Groundwater discharge is the rate of flow of groundwater through an aquifer expressed in litre per second (lps). The value of discharge vary widely depending on factors such as hydraulic conductivity of the alluvium, gradient of water table, thickness of aquifer and the presence of impermeable layers. In the present study the discharge varies from 10 to 15 lps with mean, standard deviation and coefficient of variation of 12.67 lps, 1.75 lps and 13.83%, respectively (Table 1).

Drawdown (Dd)

Pumping out of water from a well creates a cone-shaped depression of water table around the well resulting in a decrease of the water level within the well. Drawdown is measured as the difference of water level before and after pumping. It is an essential parameter in groundwater pumping tests and well design, as it provides information about the response of the aquifer to pumping, the hydrogeologic properties of the aquifer and impact of nearby wells and surface water bodies. The value of drawdown depends on rate and duration of pumping, aquifer properties like hydraulic conductivity, storativity *etc*. In general, drawdown in unconsolidated sediments tends to occur more rapidly compared to consolidated rock formations due to their higher porosity and permeability. Excessive drawdown can lead to groundwater depletion, reduced well yields, land subsidence and adverse impacts on ecosystems dependent on groundwater (Reddy, 2013). Therefore, management of drawdown is crucial for sustainable groundwater use and resource management. The values of drawdown of unconsolidated sediments vary widely. In the present study, the draw down varies from 5.58 to 7.56 m with mean, standard deviation and coefficient of variation of 6.28 m, 0.68 m and 10.87%, respectively (Table 1).

Specific Capacity Index (SCI)

The specific capacity index is a hydrogeological parameter used to evaluate the efficiency of a well in providing groundwater. It is the discharge rate per unit drawdown. A higher specific capacity index indicates that the well can sustain a higher discharge rate for a given drawdown, suggesting better well performance and aquifer productivity. Hydrogeologists and well drillers use specific capacity index data to assess the suitability of wells for groundwater extraction. Significant decrease in specific capacity index of a well may be due to decrease of transmissivity consequent upon lowering of the water table in unconfined aquifer (Todd, 1980). The average specific capacity index of coarse sand, fine sand and clay are 1.0, 0.5 and 0.25 lpm/m, respectively (Reddy, 2013). In the present study the specific capacity index varies from 1.58 to 2.42 lpm/m with mean, standard deviation and coefficient of variation of 2.06 lpm/m, 0.31 lpm/m and 15.10%, respectively (Table 1).

Storativity

The storativity is the volume of water that an aquifer releases or takes into storage per unit surface area of aquifer per unit change in hydraulic gradient. It is a dimensionless quantity (Todd, 1980). It is a crucial parameter in groundwater flow and storage analyses, aquifer characterization and the design and management of groundwater extraction systems. Storativity values depend on factors such as aquifer lithology, porosity, compressibility and other hydrogeological conditions and ranges from 0.01 to 0.30 in case of unconfined aquifers (Reddy, 2013). It is determined by pumping test. In the study area it varies from 0.017 to 0.048 with mean of 0.03, standard deviation of 0.01 and coefficient of variation of 44.10%.

Hydraulic Conductivity (Hc)

Hydraulic conductivity depicts the ability of a porous medium to transmit water through it. It quantifies how easily water can flow through an aquifer. It is the rate of flow of water through a unit cross-sectional area of the aquifer under unit hydraulic gradient. Hydraulic conductivity depends on a number of factors, including the characteristics of the porous medium (such as grain size, sorting and porosity) and the character of the fluid (such as density and viscosity). Fine-grained materials like silt and clay have lower hydraulic conductivity than coarse-grained materials like gravel and sand. Hydraulic conductivity plays a crucial role in groundwater flow and transport processes, influencing the rate and direction of groundwater movement as well as the distribution of contaminants in groundwater system. It is a key parameter used in groundwater modeling, aquifer characterization and design and management of aquifers. The hydraulic conductivity values vary from 150 – 450 m/day, 2.5 to 45 m/day and 0.0002 m/day in cases of gravels, sands and clays respectively (Todd, 1980). While hydraulic conductivity and permeability are related and often used interchangeably in many contexts, they are not precisely same. Hydraulic conductivity is a specific term used in the context of fluid flow within porous media, while permeability is a more general term that describes the ability of a medium to transmit fluids. The hydraulic conductivity of the Kantapara block varies from 8.67 – 53.95 m/day with mean, standard deviation and coefficient of variation of 25.14 m/day, 16.38 m/day and 65.17%, respectively (Table 1).

Hydraulic Diffusivity (Hd)

Hydraulic diffusivity is the capability of an aquifer to transmit and store water under the influence of hydraulic gradients and changes in pressure. It is a measure of how quickly water can move through the aquifer and how readily the aquifer can respond to changes in hydraulic head (Todd, 1980). It is a crucial parameter in groundwater flow modeling and helps in understanding the behavior of groundwater systems, such as groundwater recharge, discharge and contaminant transport. The hydraulic diffusivity of unconsolidated sediments varies widely depending on factors such as grain size, sorting, packing and porosity. The hydraulic diffusivity values of the Kantapara block varies from 413 to 1158 m/day with mean, standard deviation and coefficient of variation of 906.36 m/day, 288.43 m/day and 31.82%, respectively (Table 1).

Transmissivity (Tr)

Transmissivity is a fundamental parameter in hydrogeology that symbolizes the capability of an aquifer to pass water horizontally through it under a unit hydraulic gradient. It describes how easily water can flow through an aquifer. It is the product of hydraulic conductivity and aquifer thickness. It is a key parameter used in groundwater modeling, aquifer characterization as well as design and management of groundwater extraction systems. The value of transmissivity in unconsolidated sediment varies broadly depending on properties like grain size, sorting, porosity, hydraulic conductivity and aquifer thickness. The transmissivity values vary from 100 – 10,000 m^2/day, 10 to 1,000 m^2/day and 0.1 to 10 m^2/day in cases of gravels, sands and clays, respectively (Reddy, 2013). Clays have lower transmissivity values due to their fine grain sizes and low hydraulic conductivities. In the present study, the transmissivity varies from 1460.50 to 8092.50 m^2/day with mean, standard deviation and coefficient of variation of 3840.97 m^2/day, 2535.71 m^2/day and 66.02%, respectively (Table 1).

Correlation Analysis

The statistical significances of the correlation coefficients computed by SPSS software were determined by Student's 't' test (Davis, 2002). The significant correlation coefficients are flagged by '*' in Table 2. Significant positive correlation (0.872) between slope and thickness of the soil zone implies that areas with higher slopes have thicker soil zones or the thickness of soil zone controls the slope of the study area. Significant positive correlation (0.973) exists between pre- and post-monsoon water table depths as both are controlled by rainfall and withdrawal of groundwater. Porosity has significant positive correlations with specific yield (0.919), specific capacity index (0.861) and static water level (0.956). The porosity and specific yield control the water holding and yielding capacities of the aquifer; more porous materials hold and yield more water and vice versa.

Higher specific capacity index indicates higher discharge that leads to increase of static water level in the well. These parameters are primarily controlled by the amount of pore spaces present in the aquifer, which are also directly related to porosity and specific yield. Specific yield is directly proportional to specific capacity index (0.886) and static water level (0.931) and inversely related to specific retention (-0.875), transmissivity (-0.909) and hydraulic conductivity (-0.824). The relationships of specific yield with

Table 2: Actual correlation coefficients (above diagonal) and apparent correlation coefficients (below diagonal) extracted from Fig.4

	Sl	St	Prd	Pod	Wf	Po	Sy	Sr	Per	Dis	SCI	Dd	SWL	S	Tr	Hd	Hc
Sl		0.872*	-0.256	-0.135	-0.514	0.191	-0.037	0.308	-0.131	-0.451	-0.100	-0.007	-0.017	0.059	0.095	0.192	0.125
St	0.872		0.105	0.269	-0.386	-0.203	-0.305	0.362	0.164	-0.116	-0.396	0.156	-0.369	0.267	0.350	0.248	0.290
Prd	-0.062	-0.062		0.973*	0.761	-0.763	-0.525	0.116	0.486	0.273	-0.445	0.013	-0.64	0.233	0.373	-0.068	0.138
Pod	-0.062	-0.062	0.973		0.589	-0.840*	-0.622	0.217	0.509	0.287	-0.607	0.046	-0.768	0.270	0.456	0.077	0.219
Wf	-0.062	-0.062	0.675	0.675		-0.309	-0.088	-0.202	0.268	0.149	0.150	-0.081	-0.081	0.056	0.024	-0.450	-0.130
Po	-0.024	-0.024	-0.062	-0.062	-0.062		0.919*	-0.612	-0.763	-0.542	0.861*	-0.389	0.956*	-0.569	-0.786	-0.554	-0.630
Sy	-0.024	-0.024	-0.062	-0.062	-0.062	0.919		-0.875*	-0.799	-0.461	0.886*	-0.524	0.931*	-0.694	-0.909*	-0.793	-0.824*
Sr	0.017	0.107	-0.062	-0.062	-0.062	-0.024	-0.024		0.664	0.258	-0.718	0.570	-0.691	0.691	0.855*	0.907*	0.877*
Per	0.107	0.107	-0.062	-0.062	-0.062	-0.026	-0.024	0.614		0.818	-0.501	0.865*	-0.632	0.952*	0.943*	0.469	0.893*
Dis	0.107	0.107	-0.062	-0.062	-0.062	-0.024	-0.024	0.614	0.755		-0.265	0.830*	-0.365	0.779	0.673	0.227	0.661
SCI	-0.024	-0.024	-0.062	-0.062	-0.062	0.909	0.909	-0.024	-0.024	-0.024		-0.222	0.967*	-0.377	-0.684	-0.797	-0.579
Dd	0.107	0.107	-0.062	-0.062	-0.062	-0.024	-0.024	0.614	0.905	0.755	-0.024		-0.283	0.961*	0.822*	0.429	0.888*
SWL	-0.024	-0.024	-0.062	-0.062	-0.062	0.909	0.909	-0.024	-0.024	-0.024	0.967	-0.024		-0.47	-0.750	-0.687	-0.607
S	0.107	0.107	-0.062	-0.062	-0.062	-0.024	-0.024	0.614	0.905	0.755	-0.024	0.961	-0.024		0.928*	0.489	0.940*
Tr	0.107	0.107	-0.062	-0.062	-0.062	-0.024	-0.024	0.614	0.918	0.755	-0.024	0.905	-0.024	0.905		0.706	0.968*
Hd	0.107	0.107	-0.062	-0.062	-0.062	-0.024	-0.024	0.907	0.614	0.614	-0.024	0.614	-0.024	0.614	0.614		0.755
Hc	0.107	0.107	-0.062	-0.062	-0.062	-0.024	-0.024	0.614	0.918	0.755	-0.024	0.905	-0.024	0.905	0.968	0.614	

*Statistically significant correlation coefficients. Abbreviations: Sl - Ground slope, St - Thickness of soil zone, Prd - Pre-monsoon depth of water table, and Pod- Post-monsoon depths of water table, Wf - Water level fluctuation, Po - Porosity, Sy - Specific yield, Sr - Specific retention, Per - Permeability, SWL - Static water level, Dis - Discharge, Dd- Drawdown, SCI - Specific capacity Index, S – Storativity, Hc - Hydraulic conductivity, Hd - Hydraulic diffusivity and Tr – Transmissivity

Table 3: Matrix of four factors and seventeen hydrogeologic parameters with their factor loadings, eigenvalues and percentage of variance

Hydrogeological parameters	Symbol	Factor -1	Factor - 2	Factor - 3	Factor - 4
Ground slope	(Sl)	-0.063	0.065	-0.243	0.959*
Thickness of soil	(St)	0.100	0.207	0.095	0.950*
Pre-monsoon depth of water table	(Prd)	0.088	0.199	0.975*	-0.032
Post-monsoon depth of water table	(Pod)	0.086	0.346	0.926*	0.088
Fluctuation of water table	(Wf)	0.065	-0.273	0.804*	-0.356
Porosity	(Po)	-0.364	-0.696	-0.609	0.056*
Specific yield	(Sy)	-0.467	-0.808	-0.330	-0.085*
Specific retention	(Sr)	0.487	0.765*	-0.086	0.239
Permeability	(Per)	0.873*	0.338	0.348	-0.019
Static water level	(SWL)	-0.219	-0.837	-0.475	-0.111*
Groundwater discharge	(Dis)	0.837*	0.097	0.189	-0.327
Draw down	(Dd)	0.985*	0.123	-0.097	0.032
Specific capacity index	(SCI)	-0.139	-0.929	-0.267	-0.120*
Storativity	(S)	0.954*	0.244	0.105	0.128
Hydraulic conductivity	(Hc)	0.832*	0.529	-0.041	0.126
Hydraulic diffusivity	(Hd)	0.297	0.905*	-0.282	0.076
Transmissivity	(Tr)	0.782*	0.567	0.199	0.155
Eigen-values		9.298	3.296	2.520	1.320
Percentage of total variance		54.697	19.388	14.822	7.764
Cumulative percentage of total variance		54.697	74.085	88.907	96.671

*Significant factor loadings; Extraction method: Principal component analysis. Rotation method: Varimax with Kaiser normalization.

specific capacity index and static water level have been explained above. The inverse relationships of specific yield with specific retention, transmissivity and hydraulic conductivity can be explained by the fact that, while the former indicates the water yielding capability, the later three parameters control the water retaining capability of the aquifer. Specific retention is directly related with transmissivity (0.855), hydraulic diffusivity (0.907) and hydraulic conductivity (0.877) as all these four parameters control the water holding properties of the aquifer. Permeability is directly related with drawdown (0.865), storativity (0.952), transmissivity (0.943) and hydraulic conductivity (0.893). These four parameters control the ability of the aquifer to hold and transmit water. Higher permeability favours easier water drawing from the aquifer which increases the draw down value. The storativity is the property related to water releasing and taking capacity of the aquifer while transmissivity and hydraulic conductivity are related to water movement through the aquifer, which is facilitated by higher permeability value. Discharge is directly proportional to draw down (0.830) because as more and more water is extracted, the water level in the well is lowered increasing the drawdown value. SCI is directly related to SWL (0.967). The former is the discharge rate per unit drawdown while the later is the depth of water level in the well. Increase of SCI leads to lower the water table in the well, thus increasing the SWL. Sympathetic positive relationships among drawdown, storativity, transmissivity and hydraulic conductivity can be explained by the fact that these four parameters are mutually related to each other in case of alluvial aquifers. Change in any one parameter affects the values of other three proportionately.

Factor Analysis

The factor analysis is a classification technique that segregates the variables (hydrogeological parameters in the present case) into a number of closely related groups (Davis, 2002). In the present case, the factor analysis was carried out by principal component analysis method with varimax rotation and Kaiser normalization by SPSS software. The factor analysis results are presented in Table 3 and shown their distribution in three dimensions (Fig.2).

Out of possible 17 factors, 4 are significant as their eigenvalues are greater than 1. These four factors with eigenvalues 9.298, 3.296, 2.520 and 1.320 account for 54.697, 19.388, 14.822 and 7.764 percentages of variance cumulating to a total of 96.671%. Factor – 1 includes permeability, groundwater discharge, draw down, storativity, hydraulic conductivity and transmissivity (Table 3; Fig. 2). These are the parameters which primarily contribute to the well performance. Factor-2 includes specific retention and hydraulic diffusivity. These two parameters contribute to the storage of groundwater in the aquifer. Pre- and post-monsoon depths of water table and water table fluctuation are grouped under factor-3. These three parameters are the outcomes of groundwater recharge and discharge. Factor- 4 consists of two groups of parameters, one represented by high positive values of factor loadings (ground slope and thickness of soil zone) and another group of highest values of factor loadings amongst all the four factors (porosity, specific yield, static water level and specific capacity index). The three-dimensional plot of factors (Fig. 2) illustrates the separation of these two subgroups of Factor- 4.

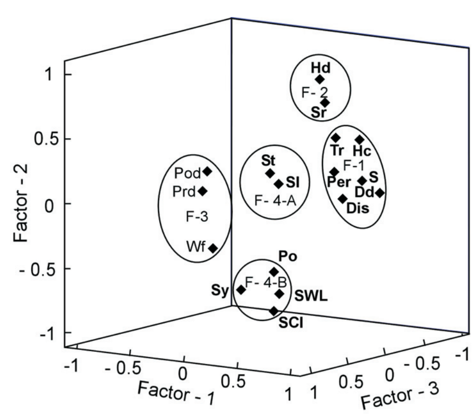

Fig.2. Three dimensional plot of factors 1, 2 and 3 showing distribution of hydrogeological parameters. Abbreviations: Sl - Ground slope, St - Thickness of soil zone, Prd - Pre-monsoon depth of water table, and Pod - Post-monsoon depths of water table, Wf - Water table fluctuation, Po - Porosity, Sy - Specific yield, Sr - Specific retention, Per - Permeability, SWL - Static water level, Dis - Discharge, Dd- Drawdown, SCI - Specific capacity Index, S – Storativity, Hc - Hydraulic conductivity, Hd - Hydraulic diffusivity and Tr – Transmissivity.

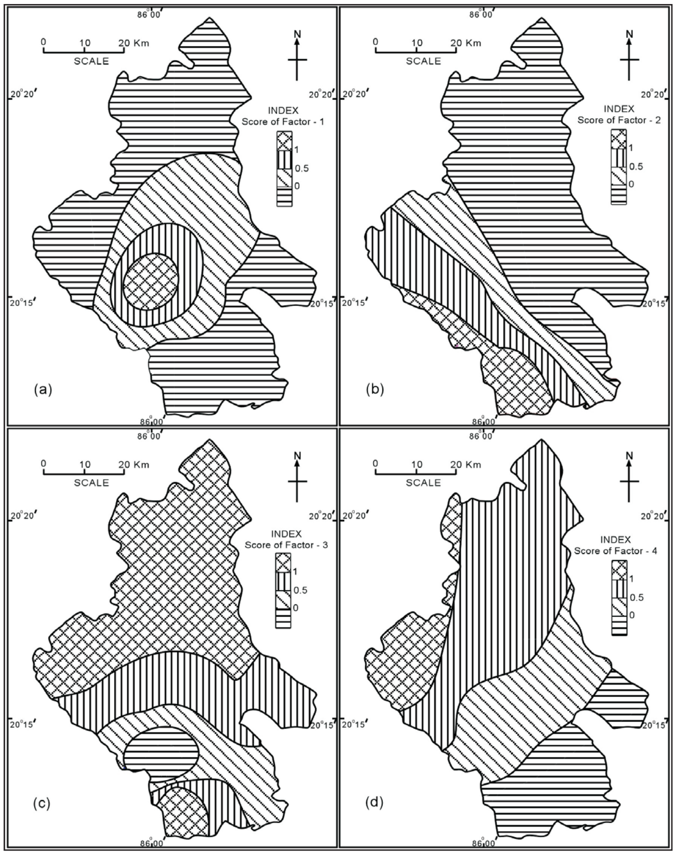

Fig.3. Spatial influences of (a) Factor-1, (b) Factor-2, (c) Factor-3 and (d) Factor-4

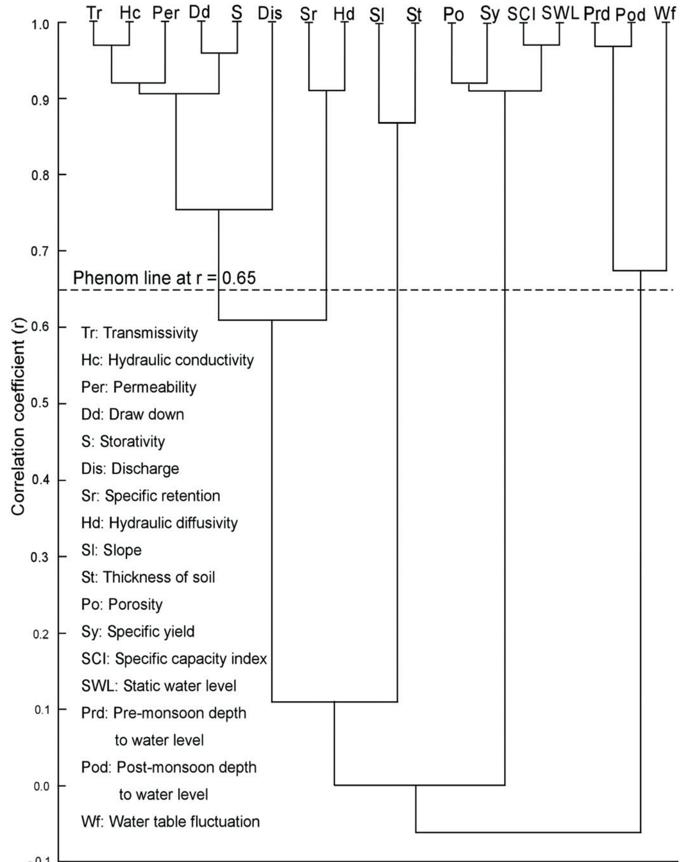

Fig. 4. Dendrogram showing clusters of hydrogeologic parameters.

The ground slope and soil thickness grouped under factor 4A are surfacial properties, which control groundwater recharge while porosity, specific yield, static water level and specific capacity index grouped under factor 4B are properties related to groundwater withdrawal. Withdrawal of groundwater from the subsurface is a measure of water yield, which is directly related with porosity where as static water level and specific capacity index are the consequences of water withdrawal. The spatial influences of these four factors in term of factor scores are shown in Fig. 3. Factor-1 is positive in central part (Fig.3a), Factor-2 is positive in southwestern part (Fig.3b), Factor-3 is positive in northern and southern parts (Fig.3c) and Factor-4 is positive in northwestern part (Fig.3d) of the Kantapara block.

Cluster Analysis

The correlation coefficients were used to group the hydrogeological parameters into distinct clusters (Fig.4; Davis, 2002). High cophenetic correlation (0.81) among the actual and apparent correlation coefficients (Table 2) testifies the statistical significance of the cluster analysis. The phenom line at 0.65 divides the dendrogram into five clusters. Cluster - 1 comprises transmissivity, hydraulic conductivity, permeability, draw down, storativity and groundwater discharge. These six parameters are the members of Factor - 1 (Table 3; Fig. 2). Cluster - 2 consisting of specific retention and hydraulic diffusivity match well with Factor - 2 (Table 3; Fig. 2). Cluster - 3 comprising ground slope and thickness of soil zone matches with Factor - 4A (Fig.2) while cluster - 4 with porosity, specific yield, specific capacity index and static water level matches with Factor - 4B (Fig.2).

Hydrogeologic parameters like pre- and post-monsoon depths to water table and water table fluctuation are grouped under cluster – 5, which matches well with Factor - 3 (Table 3; Fig. 2). Though, ground slope, thickness of soil zone, porosity, specific yield, static water level and specific capacity index are constrained to belong to a single factor (factor – 4 in Table 3), their segregation into two subfactors is accomplished in three dimension factor plot and cluster analysis. Thus, the hydrogeological parameters with distinct characteristics are properly classified by multivariate statistical techniques of factor and cluster analyses.

Conclusions

Different hydrogeological parameters show mutual sympathetic and antipathic relationships depending on their characteristics. Sympathetic relationship exists between slope and thickness of soil zone; pre- and post-monsoon water table depths; specific yield, specific capacity index and static water level; specific retention, transmissivity, hydraulic diffusivity and hydraulic conductivity; permeability, drawdown, storativity, transmissivity and hydraulic conductivity; discharge and drawdown; specific capacity index and static water level as well as between drawdown, storativity, transmissivity and hydraulic conductivity. Significant antipathic relationship exists between porosity and post-monsoon water depth; specific yield and specific retention; specific yield and transmissivity; specific yield and hydraulic conductivity. Factor and cluster analyses classify the seventeen hydrogeological parameters into five groups (factors and clusters). These are (i) transmissivity, hydraulic conductivity, permeability, draw down, storativity and groundwater discharge, which control well performance (ii) specific retention and hydraulic diffusivity, which control groundwater storage (iii) ground slope and thickness of soil zone, which control groundwater recharge (iv) porosity, specific yield, specific capacity index and static water level, which are related to groundwater withdrawal and (v) pre- and post-monsoon depths of water table and water table fluctuation, which are the quantitative measures of groundwater recharge and discharge.

Authors' Contributions

MN: Visualization, Investigation, Methodology, Validation, Reviewing and Editing. **RNH**: Conceptualization, Data curation, Software, Writing of original draft manuscript, Supervision.

Conflict of Interest

The authors declare that they do not have any conflict / competing of interest in this study.

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