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ROLE OF EFFECTIVE GRAIN SIZE d10 VALUES IN CONTROLLING VARIATION IN HYDRAULIC CONDUCTIVITY OF INDIVIDUAL AQUIFER ZONES AND COMPREHENDING REDUCTION IN YIELDS OF TUBE WELLS IN PARTS OF DHANSIRI BASIN IN GOLAGHAT DISTRICT, ASSAM, INDIA

KEYWORDS Dhansiri basin, grain size, hydraulic conductivity, deep tube well, aquifer.

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ABSTRACT *Knowledge of hydraulic conductivity is essential for addressing many problems involving groundwater flow and transportation of water soluble pollutants in aquifers. A variety of field and laboratory techniques have been developed to directly measure unsaturated hydraulic conductivities. Direct measurement of hydraulic conductivity is costly, difficult and time-consuming either in field or in laboratory. Therefore, indirect methods as a way to partially address this issue are developed. Methods of predicting hydraulic conductivity by empirical formulae based on particle-size distribution properties have been developed in the recent past. Various studies indicate that hydraulic conductivity is dependent on grain size and particle size distribution in porous media. Several empirical formulae were used to determine hydraulic conductivities of aquifers. Many different relationships have been developed based on particle-size distribution. Research findings show that values of hydraulic conductivity calculated using USBR and Slitcher's equation are less than that calculated by other methods. However, Breyer's equation is found to be very suitable for aquifer materials with low uniformity coefficient. A case study has been carried out in parts of Dhansiri valley in Golaghat district of Assam, India on grain size analysis of the samples collected from the exploratory wells constructed by Central Ground Water Board located at Chetiagaon, Kamargaon and Rajabahar. The study area even though has a rich aquifer system down to the depth of 300 m, witnesses problem in development of groundwater owing chiefly to fine to very fine nature of the aquifer materials. Deep tube wells constructed in the area reportedly undergo reduction in their yield with time and in some cases have to be abandoned. Results of the analysis indicate that owing to presence of fine sands, there occurs significant variation in hydraulic conductivities of individual aquifer zones within the aquifer system in the area. These point towards the role played by effective grain size i.e. d10 values in controlling hydraulic conductivity.*

1.0 INTRODUCTION

Saturated hydraulic conductivity is one of the most important physical characteristics of aquifer materials which is very important in terms of groundwater studies, water infiltration, leaching, design of drainage systems and hydrological studies. Direct measurement of hydraulic conductivity is costly, difficult and time-consuming either in field or in laboratory. Therefore, indirect methods as a way to partially address this issue are presented. A number of methods of predicting hydraulic conductivity by empirical formulae based on properties of particle-size distribution have been developed. Various studies indicate that hydraulic conductivity is dependent on grain size and particle size distribution in porous media.

In recent years, many studies have been carried out to predict hydraulic functions of aquifer materials based on grain size distribution. Hydraulic properties have a high spatial variation and its measurement is difficult and costly. Therefore, the empirical formulae have been developed.

Many different relationships have been established on particle-size distribution. Research findings show that values of hydraulic conductivity calculated using USBR and Slitcher's equation are less than that calculated by other methods. However, Breyer's equation is found to be very suitable for aquifer materials with low uniformity coefficient.

Carrier (2003) noted that hydraulic conductivity values calculated by Kozeny-Carman equation have high accuracy compared to Hazen equation. Odong (2007) has elaborated application of several empirical equations for prediction of hydraulic conductivity. Jarvis et al. (2002) presented the functions based on relative frequency of particle and geometric mean of particle diameters. Huang and Zhang Evaluated soil water retention curve.

Heuvelmans et al. (2005) stated the parameters of a hydrological model with artificial neutral networks and linear regression model. Regression transport functions are suitable method for modelling of soil hydraulic properties.

Vukovic and Soro (1992) noted that the applications of different empirical formulae to the same porous medium material can yield different values of hydraulic conductivity which may differ by a factor of 10 or even 20.

2.0 DESCRIPTION OF THE STUDY AREA

The study has been carried out in parts of Dhansiri valley in Golaghat district of Assam, India on grain size analysis of the lithological samples collected from the exploratory wells constructed by Central Ground Water Board located at Chetiagaon, Kamargaon and Rajabahar. The area of these three wells lies approximately between North Latitudes 26 30/ & 26 45/ and East Longitudes 93 45/ & 9400/ and is covered by Survey of India Topographic map 83F/14. The area has a well developed communication network. In the northern part, the National Highway-37 passes through the area connecting Guwahati with Dibrugarh. Major parts of the study area are well connected with the district headquarters by metalled roads.

Physiographically, the study area is an alluvial plain within the vast Brahmaputra Valley Alluvium with an altitude from 60 m at downstream to 100 metre at upstream. The slope of the area is very gentle. Landforms of river terraces are dominant in the area. The general slope of the area is towards north-west to which the drainage pattern of the area also conforms. The drainage texture in this area is very fine, the reason for which might be attributed to the low permeability of the subsurface sediments.

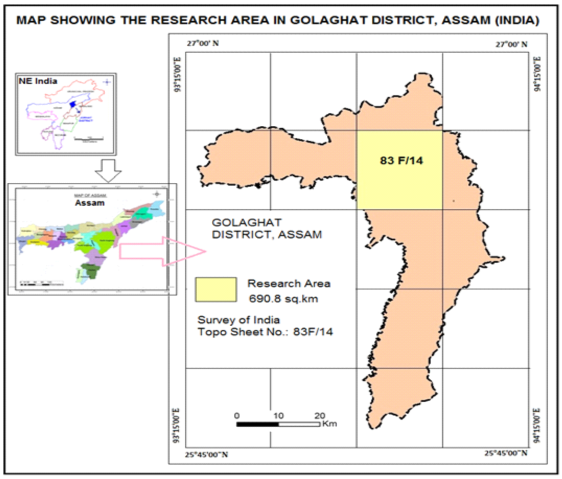
The study area enjoys sub-tropical humid climate. The mean annual rainfall is 1458.2 mm which is received mostly between May to August. Annual mean maximum and minimum temperature are 32°C and 18°C respectively. About 60 to 65% of the annual precipitation is received during south-west monsoon from June to September. Annual average temperature during winter period varies from 6 to 140C and during summer, it varies from 29 to 360C. The relative humidity varies from 93 to 95% during morning hours and during afternoon hours it varies from 53 to 75%.

Geomorphologically, the study area shows a monotonous plain topography towards north and southeast, while the south-western part of the area represents an undulating topography.

The River Brahmaputra flowing in an east-west direction in the extreme northern part of the study area and its tributaries flowing in a northerly direction, control the entire drainage system and plays an important role in ground water occurrence and control of the area. Important Rivers in the study area are Dhansiri, Daigurung, Kaliyani and Gelabil. These rivers have meandering courses with abandoned channels in the form of bils and ox-bow lakes along their courses.

Geologically, the study area is underlain by Quaternary Formation followed by Archaean Group of rocks. Quaternary Formation comprises Younger and Older Alluvial deposits consisting of different grades of sands, pebbles, cobbles, gravels and clays in the area. Major parts in the north of National Highway -37 passing in an east-west direction in the study area show Younger Alluvial deposits. The Older Alluvial deposits occur mainly towards southern parts of the National Highway-37. Hard crystalline rocks of Achaean age are found to expose in the south-western boundary of the study area bordering Karbi-Anglong district. The rock types are granite, granite gneiss and quartzite.

Sub-surface geology as evidenced from available data infers that potential aquifers pertaining to Quaternary Formation exist down to the explored depth of 300 m. Cumulative thickness of aquifer zones has a tendency to increase towards north.



Map1. Map showing the Research area in Golaghat District, Assam (India)

Table 1. Hydraulic conductivity as determined using Breyer's equation

Sl. No	Location	Depth Drilled (m)	Depth constructed (m)	Thickness of Aquifers Zones for which mechanical analysis done (m)			Effective Size (d10) mm	(d60) mm	Uniformity Co-efficient	Hydraulic Conductivity (k)	Average Hydraulic Conductivity for different depth ranges	
1	Chetiagaon 26°35′ 50″ 93° 59′ 24″	305.5	55	18.8	21.9	3.1	0.17	0.39	2.29	30.15	(18.8 to 21.9)m	30.15
				31	40.2	9.2	0.16	0.36	2.25	26.80	(31 to 49.3) m	23.98
				40.2	46.3	6.1	0.155	0.34	2.19	25.27		
				46.3	49.9	3.6	0.12	0.32	2.67	14.60		
2	Kamargaon 26°41′ 14″ 94° 00′ 45″	212.2	204	76.2	80.77	4.57	0.135	0.325	2.41	18.84	(76.2 to 91.44) m	25.19
				82.9	91.44	8.54	0.165	0.365	2.21	28.60		
				105.15	112.2	7.02	0.155	0.285	1.84	26.09	(105.15 to 125) m	25.13
				113.69	125	11.27	0.15	0.27	1.80	24.53		
				134.72	148.7	14.02	0.15	0.335	2.23	23.59	(134.72 to156.8)m	20.73
				149.96	156.8	6.81	0.12	0.295	2.46	14.83		
				167.03	177.7	10.67	0.108	0.25	2.31	12.15	(167.03 to 204.2)m	12.87
				184.1	190.4	6.3	0.105	0.22	2.10	11.69		
				191.41	204.2	12.8	0.115	0.24	2.08	14.05		
3	Rajabahar 26°41′ 19″ 93° 57′ 50″	300	151	28.4	34.5	6.1	0.23	0.875	3.80	50.00	(28.4 to 83.3)m	31.51

				34.5	43.6	9.1	0.215	0.61	2.84	46.32		
				43.6	52.8	9.2	0.142	0.32	2.25	21.10		
				52.8	58.9	6.1	0.158	0.36	2.28	26.07		
				58.9	65	6.1	0.17	0.39	2.29	30.15		
				65	68	3	0.18	0.465	2.58	33.05		
				68	74.1	6.1	0.17	0.37	2.18	30.44		
				74.1	83.3	9.2	0.14	0.39	2.79	19.71		
				110.7	119.9	9.2	0.09	0.38	4.22	7.49	(110.7 to 129)m	12.04
				119.9	129	9.1	0.14	0.875	6.25	16.64		
				138.2	147.3	9.1	0.115	0.66	5.74	11.45	(138.2 to156.5)m	12.30
				147.3	156.5	9.2	0.12	0.54	4.50	13.14		

3.0 MATERIALS AND METHODS

Field work for this study was conducted in several phases covering the entire area of study (Figure 1) and finally representative lithological samples were collected from three prime localities during exploratory drilling operations in 2013 & 2014 (under permission & guidance of CGWB, NER). The lithological samples were collected and described at intervals of 3 m. These samples were subjected to mechanical sieve analysis in order to construct grain-size distribution curves as shown in Figure 2a & 2b. Grain-size diameters of d_{10}, d_{20}, d_{30}, d_{50} and d_{60} were read off from the grain-size distribution curves. Statistical grain-size methods were then employed to determine hydraulic conductivity values as presented in Table 1.

3.1 GRAIN SIZE ANALYSIS

Porosity, hydraulic conductivity and permeability are hydrogeological parameters that all greatly depend on size of sediment grains and percentage of various sediment fractions. Laboratory Sieve analysis is the most widely used method for determining grain size distribution. Lower limit of applicability of sieve analysis is for grains up to 0.075 mm (which is also the boundary between sand and "fines" i.e. silt and clay according to engineering classification of sediment grain sizes adopted by American Society for Testing Materials. Uniformity Co-efficient (U) which is a measure of the range of grains present is expressed by $U= d_{60}/d_{10}$

Where

d_{60}= sieve opening size (diameter) which allows 60 % of the sample by weight to pass.

And d_{10}= sieve diameter which allows 10% of the samples to pass.

The lower the uniformity Co-efficient (U), the more uniform the materials are (i.e. well graded or well sorted) whereas large values of U represent a wide range of grain sizes and generally poorly graded porous materials. A somewhat arbitrarily set criterion for well sorted material is U < 5. There are few empirical formulae for calculating the hydraulic conductivity using grain size analysis. All these formulae have various limits of application and they give approximate values of hydraulic conductivity for different experimental materials and conditions. In this case, Breyer's equation given by the following relation:

$K= g/ C_b d_e^2$ ....Eqn. (1)

Where $C_b = 6x\,10^{-4} \log 500/U$

g = acceleration due to gravity (i.e.9.807m/s^2)

= kinematic viscosity (1.14x 10^{-6} m^2/s for ground water at 15C) has been used.

Breyer's empirical formula is applicable for $1<U<20$ and $0.06mm<d_{10}<d_{60}$, thus making it useful for analyzing heterogeneous porous media with poorly sorted grains.

Breyer's empirical formula has been used for lithological samples of three exploratory wells drilled by Central Ground Water Board located at Chetiagaon, Kamargaon and Rajabahar in the study area. Records of laboratory sieve analysis of these samples were studied and Breyer's empirical formula has been applied to depict the variations, if any, in the hydraulic conductivity of the individual aquifer zones within the aquifer system encountered in the study area. Details of the 3 exploratory wells and sieve analysis data along with the worked out hydraulic conductivity values have been shown in Table 1.

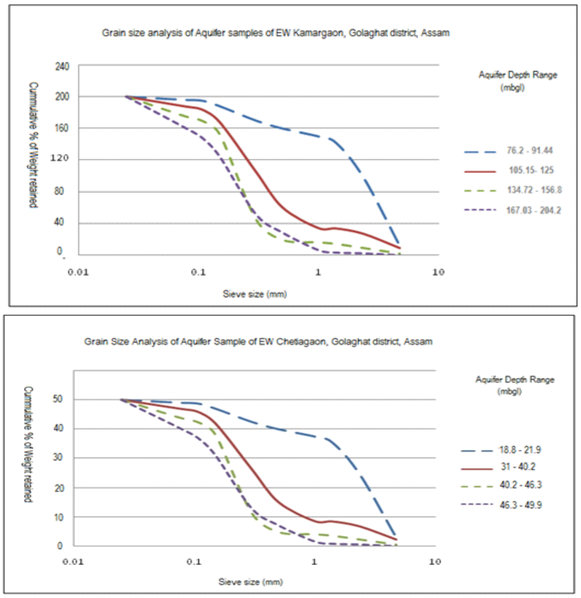


Fig.2a Grain size analysis of EW sites Kamargaon and Chetiagaon

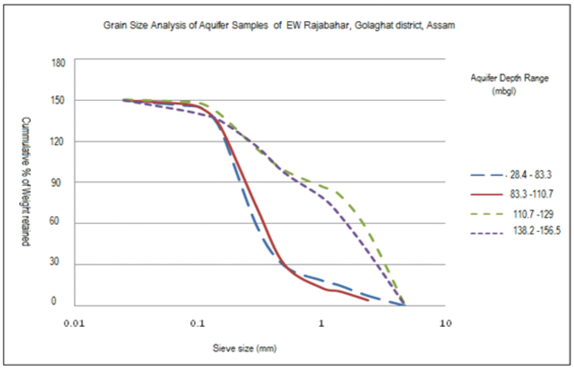


Fig.2b Grain size analysis of EW site Rajabahar, Golaghat district, Assam

4.0 RESULTS AND DISCUSSION

From the interpretation of grain size analysis as presented in table 1, following observations have been made for the study area.

U values for majority of the samples studied from the area are below 3.0 indicating a reasonably well sorted material. Even though U values for majority of the samples point towards good sorting of the aquifer materials, significant variation in hydraulic conductivity has been observed in the individual aquifer zones of the multi-aquifer system. These point towards the role played by effective grain size i.e. d_{10} values in controlling hydraulic conductivity of seemingly well sorted materials. d_{10} values for the samples studied show variation between 0.09 and 0.215mm. Based on observations made for d_{10} values for all the samples, the following four groupings of hydraulic conductivity have been made for the study area.

Group 1: For d_{10} between 0.09 and 0.1mm, the K value is invariably less than 10m/day
Group 2: For d_{10} between 0.1 and 0.15mm, the K value is between 10 and 20m/day
Group3: For d_{10} between 0.151 and 0.2mm, the K value stands between 20 and 35m/day
Group4: For d_{10} >0.2mm, the K value is more than 35m/day

For practical purposes, however, it can be considered that for $d_{10} < 0.15$, the K value is less than 20m/day and for $d_{10} > 0.15$, the K value is more than 20m/day in the study area.

Proper placement of slotted pipes against the aquifer zones is of much importance in determining overall service lives of the wells. From the results of grain size analysis, it is noticed that presence of fine grained particles significantly reduce hydraulic conductivities of the aquifers. It is clear from the analytical results that for d_{10} between 0.09 mm and 0.1 mm, the K value is invariably less than 10 m/day. Care should be taken while tapping individual zones and the zone with K value less than 10m/day should be avoided. To ensure this, one requires to tap the aquifer with $d_{10} > 0.1$mm. This can be done by making use of standard sieve of 0.106 mm. If less than 10% of the representative samples of the aquifer pass through this standard sieve size, it can be assumed that the hydraulic conductivity of the aquifer zone is more than 10m/day and the zone may be tapped. This approach can be employed when precise demarcation of the aquifer zones cannot be done.

The design aspects of ground water abstraction structures have been computed and suggested as follows:

- **Shallow/medium tube well :**
- Hydraulic properties of shallow aquifers generally do not vary much and as such, the depths of shallow tube wells may vary from 30 to 50 m and depth range of medium duty tube wells may vary from 50 to 70 m tapping 5 to 10 m of aquifer zones. A well assembly of 102 mm diameter with agricultural strainers made up of PVC pipe can be lowered in 150 mm diameter annular space. Such a tube well is expected to yield 25 to 30 m^3/hr for a drawdown of 3 to 5 m. On an average, such a tube well is expected to command 2.5 to 3.0 hectares of land.

- **Deep tube well :**
- Hydraulic properties of aquifer zones along with availability of thick granular formations permit construction of deep tube wells of varied designs. Based on available data of exploratory tube wells in the area, design of deep tube wells have been determined for the benefit of user agencies. The hydraulic and hydrogeological parameters utilized are hydraulic conductivity, aquifer thickness to be tapped, optimum screen entrance velocity and well efficiency. The available thickness of aquifer zones in the study area varies horizontally as well as vertically from southern to northern parts. As such, average thickness of aquifer zones is taken as 60 to 80 m in the southern and central parts while in the northern parts, it is more than 100 m near river Brahmaputra. These productive aquifer zones can be tapped by lowering 200 mm dia casing pipe with 10% open area of varying slot sizes depending upon variability of grain sizes of the aquifers. For discharges varying from 100 to 200m^3/hr, the screen lengths have been computed depending upon the optimum screen entrance velocities and for calculating the slot lengths, hydraulic conductivities of the aquifers are utilized as follows:

$$SL = \frac{Q}{A_o V_o} \qquad \text{Eqn. (2)}$$

Where
SL= Optimum length screen in m
Q= Discharge of production well in m^3/min
A_o= Effective open area per meter of screen in sq m
V_o= Optimum screen entrance velocity in m/min
(Walton – 1962)

The matrix for determining the lengths of slotted pipes for different discharges based on the above formula has been prepared for different parts of the study area and given in table 2:

Table 2. Matrix of determining the lengths of slotted pipes for different discharges

Sectors	K (m/day)	Q (m^3/hr)	Optimum screen entrance velocity (m/min)	Effective open area (m/sq m)	Open area of screen diameter of productive casing (m)	Slot length (m)
Northern part	80	50 100 150	1.80 1.80 1.80	0.05024 0.05 0.05	16%	10 20 30
Central part	60	50 100	1.20 1.20	0.05024 0.05024	18%	14 28
Southern part	20	50 100	0.60 0.60	0.05024 0.05024	18%	30 55

The slot sizes of the productive casings of aquifer zones based on grain sizes would vary from 0.199 to 0.875mm. As such, while constructing the wells, proper lowering of the slot pipes after carrying out mechanical analysis of the lithological samples is required to be done. Based on draw down, interference effect and long term seasonal fluctuation, lengths of the housing pipes for different parts in the study area are worked out to be in the range of 30 to 40 m. Further, the diameter of the housing pipes should be 5.0 cm larger than that of the pumps to be lowered so as to facilitate easy operation of pumping. Thus, designs of the tube wells for different discharges varying from 50 to150 m3/hr have been worked out and presented in the table 3:

Selection of Filter Pack

Ahrens (1957a) stated that the common usage of the term 'gravel pack' is misleading because such packs may range in particle size from fine sand to coarse gravel depending upon gradation of the aquifer materials. Therefore, the term 'filter pack' is preferred to 'grave pack' in this paper. It is generally known that optimum well design should start with an analysis and interpretation of the aquifer properties including particle size distribution of the aquifer materials (E. E. Jhonson, 1963).

The U.S. Corps of Engineers (1941, 1942) explained that the filter pack design depends upon the following criteria for filtering stability:

Table.3 Design of tube wells in the study area

Area	Discharge(m3/hr)	Depth of tube well (m)	Well Assembly (m)
Northern Part	50	75	20 cm dia housing =40 15 cm dia slotted = 10 15 cm dia blank pipes= 25
	100	100	30cm dia housing = 45 15cm dia slotted = 20 15cm dia blank = 35
	150	110	30cm dia housing =45 15 cm dia slotted = 30 15 cm dia blank = 35
Central Part	50	85	20 cm dia housing = 50 15 cm dia slotted = 14 15 cm dia blank = 25
	100	108	30 cm housing = 50 15 cm dia slotted = 28 15 cm dia blank = 30
Southern parts	50	140	20 cm dia housing = 60 15 cm dia slotted = 30 15 cm dia blank = 50
	100	180	30 cm housing = 60 15 cm slotted = 55 15 cm blank = 65

$$\frac{\text{15\% finer size of the filter pack}}{\text{85\% finer size of the finest aquifer material}} \leq 4$$

And for maximum permeability:

$$\frac{\text{15\% finer size of the filter pack}}{\text{85\% finer size of the coarsest aquifer material}} \geq 4$$

Later laboratory studies by the Corps of Engineers (1948) determined that following additional criteria were needed for greater stability of filter pack:

$$\frac{\text{15\% finer size of the filter pack}}{\text{15\% finer size of the coarsest aquifer material}} < 20$$

And,

$$\frac{\text{50 \% finer size of the filter pack}}{\text{50 \% finer size of the aquifer material}} < 25$$

Bieske, 1962 deduced the following formula for very fine nature of aquifer materials where filter pack used should consist of two or three standardized grain sizes, the grain sizes of successive packs becoming progressively larger towards the well screen.

Filter pack standard grain size = (Aquifer standard grain size) x (Screening factor)

The screening factor is defined as the increase in grain size required to prevent entry of the associated formation through the gravel pack. The thickness of the finest pack should be greater than the thickness of the adjoining pack. Total minimum thickness should not be less than 3 inches. The following graded pack size may be adopted

- Outer layer : 1 to 1.5 mm
- Central layer: 4 to 6 mm
- Inner layer : 16 to 25 mm

These indirect methods have definite applicability in enhancing well efficiency in the study area.

5.0 CONCLUSION

Breyer's empirical equation to calculate hydraulic conductivity based on grain size distribution in the study area has been evaluated. The results assure success in predicting hydraulic conductivity from analysis of data on particle diameters. The following relationship obtained from Beyer's equation has been used.

$K = g / C_b \, d_e^2$

Where $C_b = 6 \times 10^{-4} \log 500/U$

g = acceleration due to gravity (i.e.9.807m/s^2)

= Kinematic viscosity (1.14x 10^{-6} m^2/s for Ground Water at 15C)

The Breyer's empirical formula is applicable for $1<U<20$ and $0.06\text{mm}<d_{10}<d_{60}$, thus making it useful for analyzing the heterogeneous porous media with poorly sorted grains. Empirical equation of Breyer has been applied to depict the variations in the hydraulic conductivity of the individual aquifer zones within the aquifer system, encountered in the study area. Four groups have been categorized for d_{10} values corresponding K values in the study area.

Lengths of slotted pipes required in the study area for different K values & discharges have been calculated. Thus, designs of the tube wells with nature of filter packs have been predicted.

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