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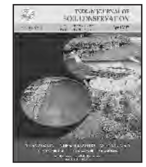

Investigation of variability in drainage properties of saline soils at village Mudlana in Sonepat district of Haryana

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ABSTRACT

A study was conducted for determining and analyzing depth wise variability in drainable porosity and depth wise and spatial variability in hydraulic conductivity of saline soils. The field data on drain discharge and water table drawdown from at an already installed subsurface drainage system at village Mudlana in Sonepat district of Haryana state were used in this study. The hydraulic conductivity values estimated at multiple locations at the experimental site were also collected. The study revealed that the point measurements of hydraulic conductivity at multiple locations in the experimental area resulted in great variability (0.27-5.30 m day^{-1}), making it difficult to select field representative value. Hydraulic conductivity as determined from drain discharge and water table drawdown measurements showed depth-wise variability, ranging from 0.96 m day^{-1} near soil surface to 0.39 m day^{-1} at deeper layer. Similarly, drainable porosity as determined from drain discharge and water table drawdown measurements was also found varying from 5.5% near soil surface to 10.8% at deeper layer. Skaggs (1976) method of determining K/u ratios (ratio of hydraulic conductivity and drainable porosity) has also been presented which resulted in a variation of 17.41 near soil surface to 3.69 at deeper layers. The measurements of the two drainage properties from drain discharge and water table drawdown measurements gave field representative values with lumped effect of soil heterogeneity, non uniformity and anisotropy.

1. INTRODUCTION

The effective sub-surface drainage system is characterized in terms of soil-drainage properties, drainage system parameters and drainage boundary conditions. The two prominent drainage properties namely, saturated hydraulic conductivity (K) and drainable porosity or effective porosity (u) are the most important soil properties having great influence on sub-surface movement of water to drains. Most of the subsurface drainage design equations use the two soil properties often to describe the flow media. Measurements of K, u or K/u ratio taken in the field both under steady state and unsteady state drainage conditions are used in determining the drainage methods best suited to existing field conditions. So far, drainable porosity has been excluded from analysis under steady state drainage process (Ernst, 1956 and Ernst, 1962). Scientists/researchers/ academicians, who assumed unsteady state drainage flow into drains, have included drainable porosity in their analysis. Later on, hydraulic conductivity-drainable porosity ratio has been used in drainage design under unsteady state condition (Skaggs 1976).

The conventional method of subsurface drainage design has mostly used constant values of K and u or K/u ratio. However, field investigations indicate a strong dependence of drainable porosity on the soil depth especially in alluvial soils. The same is true for hydraulic conductivity also, which may have spatial as well as depth-wise variations due to the nature of soil formation processes (Pali, 1986). In several drainage design investigations, the soil mass is treated as having layers of different hydraulic conductivities. Many research workers, such as Ernst (1956, 1962), have developed drainage design formulae considering variable hydraulic conductivity values for different layers but in the field, such stratification of different hydraulic conductivity layers is seldom found because the soil properties usually vary in a gradual way. In certain drainage studies, the drainable porosity has been treated to be curvilinear to water table depth and the types of relations were different for different soil types. The basis of such considerations has been that drainable porosity is a function of suction (Pandey and Tyagi, 2003). The more the water table recedes, the larger is the volume of water that is drained. Various researchers have reported that the theoretical results by drainage design formulae significantly differ from field performance results. This variation may be attributed to the fact that these design formulae use constant hydraulic conductivity and drainable porosity values under specific field conditions, but great heterogeneity usually exists in drainage properties especially of alluvial saline soils, this results in variation of theoretical and field results.

With these facts in view, a study was conducted on a representative saline and waterlogged soils at village Mudlana in Sonipat district, where, a horizontal subsurface drainage system has been installed by Haryana Land Reclamation and Development Corporation. The study was aimed at determining and analyzing the variability of K, u and K/u ratio for saline soils.

2. MATERIALS AND METHODS

Study Area

The study village Mudlana is located at a distance of about 29 km from Panipat at $29^0$10''N latitude and $76^0$43''E longitude at an altitude of 226 m above msl. The study area is nearly flat with gentle slope and forms a part of vast alluvial plain in the catchment of river Yamuna. The peripheral higher elevations form a closed basin which restricts the surface and subsurface natural drainage resulting in inundation of the area for a few weeks by Yamuna flood-waters during heavy rainfall periods.

Climate Conditions

The climate of the study area is subtropical semiarid with high evaporation rates. The area receives an average annual rainfall ranging from 500 to 600 mm, 83% of which precipitates from July to September. From October to June end, the weather remains dry excepting for a few showers received from western depressions. Pan evaporation generally exceeds precipitation throughout the year except in rainy season. High evaporation rates (114-170 mm month^{-1}) just after the rainy season cause accumulation of salts from saline groundwater, which usually remains high. The average annual evaporation is about 2086 mm. Summer season is very hot and in winter temperature drops down 3-4^{0}C.

Soil Conditions

The soils are slightly heavier in nature. Surface 25 cm soils are compacted with bulk density of 1.75-1.78 g cm^{-3} and in lower layers; it is about 1.55 g cm^{-3}. The soils chiefly contain chlorides and sulphate salts of Na, Ca and Mg. Due to predominance of sodium salts, The SAR of the soil solution is invariably high (69.9) in top 15 cm depth. The top 15 cm soil has a pH of 9, an EC_e of 13.1 mmhos/cm and an ESP of 69.2. The soils have about 21.3% clay, 17.4% silt and 61.3% sand, falling under textural class S_1.

Groundwater Conditions

The groundwater of the study area is highly saline with EC_e (Salinity of the saturation extract) reaching up to 21.5 mmhos cm^{-1}, making it not fully fit for irrigation and drinking purpose. The water table almost reaches the ground surface during monsoon season and its recession begins from October to June falling to a depth of 1.5-2.0 m below ground surface in summer season in the study area. This really demanded the drainage works in the waterlogged study area. The trend of water table decline is similar to the loss of water through evaporation during January to May.

Experimental Drainage System

The existing subsurface drainage system is installed in sandy loam soils with three drain spacing as 50, 67 and 84 m, each at a depth of 1.6 m below ground surface. The impermeable layer is situated at 3.4 m below drain centre. The internal diameter of lateral is 75 mm and that of collector drain is 140 mm with a total length of 310 m. Perforated PVC pipes with 3 mm circular perforations were used for lateral drains, laid at a grade of 0.1%. The present study was conducted on 50 m drain spacing only. The observation wells and piezometers were installed between lateral drains at an average depth of 2 m below ground surface to monitor hydraulic heads between the drains.

Methodology

The two drainage properties *viz.,* drainable porosity and hydraulic conductivity of the soil were estimated from drain discharge and hydraulic head measurements in 50 m drain spacing of the subsurface drainage system. The concepts and methodology is described as follows:

Drainable porosity (u)

Drainable porosity is the volume fraction of pore-space water which can be drained from a soil mass under prescribed conditions and is defined as the volume of water that is drained (or taken up) by a unit volume of soil when the water table drops (or rises) over a unit distance.

The drainable porosity is not usually a constant but, besides other things, it is a function of water table depth (Taylor, 1960). The time of drawdown and shape of the water table depend on the particular way in which drainable porosity is related to water table depth. Thus, it is convenient and often necessary in drawdown studies to express drainable porosity as a function of water table depth. Therefore,

$u = f(z)$

Where, z is water table depth.

During drawdown under dynamic conditions, the drainable porosity at any point in the soil is not solely a function of water table depth z but also is determined by the time t during which drainage is permitted before the water table falls to a new position. Therefore,

$u = f(z, t)$

Evaluation of f(z, t) is difficult. So an average drainable porosity, as required in most drawdown equations, can be computed either for the entire depth of drawdown, say 0 to z_n or for prescribed intervals within this range. In the former situation, the drainable porosity may be given by the expression as:

$$u(z) = \frac{V}{z} \quad ...(1)$$

Where, u(z) = Net cumulative volume drained per unit area of plot in time t/Net drop in water table; V is cumulative drain outflow volume in mm, when water table has receded to depth z in mm.

The drain discharge can be obtained from continuous outflow measurements or from outflow rate-time curves, while the water table depth can be measured by piezometers or observation wells. It is desirable to obtain the values of z and V after the water table is initially established near ground surface and during a rainless period. If an appreciable quantity of artesian water or seepage from surrounding areas is entering the drainage field, the reliable estimate of drainable porosity is possible only after deducting the volume of seepage from drain discharge. Graphical evaluation of u(z) can also be made from the plotting of u(z) versus z data.

In the present study, the volume of outflow drained per unity area of plot in a particular duration was determined by measuring the drain outflow volume in time t and then dividing it by net surface area enclosed between two drains. The net outflow volume was computed by subtracting the average seepage flow of 2.07 mm day^{-1} (Pali, 2015) entering the study area from surrounding fields. The measured values of drain discharge, hydraulic heads and computed drainable porosity corresponding to different depths are given in Table 1 with standard symbols and notations.

Hydraulic conductivity-Drainable Porosity Ratio (K/u)

The hydraulic conductivity-drainable porosity ratio, K(z)/u(z) was determined from water table drawdown measurements with the help of the method suggested by Skaggs (1976), which states that after making Dupuit-Forchheimer assumptions, the equation governing water movement through soil towards drains may be written as:

$$u(z)\frac{dH}{dh} = -K(z)\frac{d(H.dH/dx)}{dx} \quad ...(2)$$

Where, H is the elevation of water table above impermeable layer, t is time, x is horizontal distance from one of the drains and u(z) and K(z) denote drainable porosity and hydraulic conductivity, respectively.

For parallel drains, eq. (2) may be changed in non dimensional form by introducing the variables H' = H/H0, ξ = x/S and ζ = KH0t/uS2 where, H0 is the initial maximum elevation of water table above impermeable layer and H is elevation of water table at time t. Therefore, eq (2) may then be written as:

$$dH'/d\zeta = d/d\xi.(H'dH'/d\zeta) \quad ...(3)$$

Table: 1
Computed drainable porosity (u) at different depths

Drainage period (t) (days)	Water table depth (z) from soil surface (m)	Drop in water table (Δh) (m)	Drain outflow per unit area × 10-3 (m)	Drainable porosity (u)
0	0.88	-	-	-
1	0.21	0.13	7.20	0.06
2	0.28	0.20	13.85	0.07
3	0.34	0.26	19.97	0.08
4	0.39	0.31	25.47	0.08
5	0.42	0.34	30.65	0.09
6	0.46	0.38	35.60	0.09
7	0.49	0.41	40.32	0.10
8	0.53	0.45	44.80	0.10
9	0.57	0.49	48.97	0.10
10	0.59	0.51	52.95	0.10
11	0.26	0.54	56.75	0.10
12	0.65	0.57	60.30	0.11
13	0.66	0.58	63.70	0.11
14	0.70	0.62	66.95	0.11

For the case of falling water table, boundary conditions may also be written in non dimensional form as:

$H' = 1, \zeta = 0 , 0 \leq \zeta \leq 1 ; H' = B = de/H0, \zeta = 0, \xi = 0 ; H' = B, \zeta > 0, \xi = 1.$

Solutions of eq. (3) for falling water table have been obtained and plotted by Skaggs (1976) for x/S values up to 0.50 (Fig. 1). These graphical solutions are used to estimate values of K/u ratio for different water table drawdown at corresponding time periods.The computation of K/u ratio values at different water table depths, as determined by the Skaggs (1976) method, are given in Table 3.

Hydraulic Conductivity (K)-Point Measurement

The field measurements and estimation of saturated hydraulic conductivity were made at the experimental site. Hydraulic conductivity of the soil below water table was determined *in-situ* by single auger hole method. It was measured at various randomly selected locations covering whole study area. The measured values of saturated hydraulic conductivity are given in Table 2.

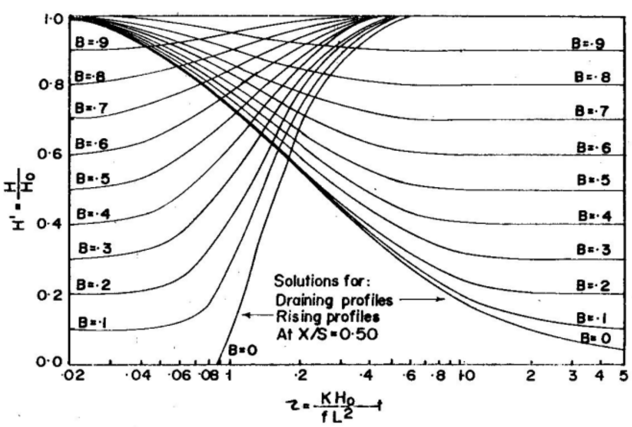

Fig. 1. Nomograph for determining K/u ratio (Skaggs, 1976)

Hydraulic Conductivity (K)-Skaggs (1976) Method

Since the point measurements of hydraulic conductivity at different locations exhibit a lot of spatial variability, the variable hydraulic conductivity can be determined from the relation of K/u ratio as obtained above. The Skaggs (1976) method for estimation of K/u ratio presents an excellent procedure for estimating the hydraulic conductivity values at different water table depths, if corresponding values of drainable porosity are known. The K value may be obtained by multiplying the K/u ratio values with u values at corresponding water table depths and time periods. The computation of K values at different water table depths are given in Table 3.

3. RESULTS AND DISCUSSION

The drainage properties including drainable porosity, hydraulic conductivity and hydraulic conductivity-drainable porosity ratio were determined from drain discharge and water table drawdown data. The method of estimating

Table: 2
Measured values of K at multiple locations by point measurements

Location	K (m day^{-1})	Location	K (m day^{-1})
1	4.12	11	0.42
2	5.30	12	1.05
3	0.92	13	0.27
4	0.68	14	2.67
5	0.63	15	1.15
6	0.51	16	3.95
7	3.51	17	1.62
8	1.20	18	2.87
9	1.00	19	3.60
10	0.56	20	4.23

Table: 3
Estimation of K/u ratio and K by Skaggs (1976) method

Drainage period (t) (days)	Water table height above impermeable layer (H=h+de) (m)	Depth (z) from soil surface (m)	H' =H/H0	ζ =KH0t/uS2	K/u=ζS2/H0t	K=(K/u)*u (m day^{-1})
0	4.02 (H0)	0.98	1.00	-	-	-
1	3.89	1.11	0.97	0.03	17.41	0.96
2	3.82	1.18	0.09	0.04	13.37	0.93
3	3.76	1.24	0.93	0.05	10.78	0.83
4	3.71	1.29	0.92	0.05	8.39	0.69
5	3.68	1.32	0.91	0.06	7.21	0.65
6	3.64	1.36	0.91	0.06	6.32	0.59
7	3.61	1.39	0.90	0.07	6.04	0.59
8	3.57	1.43	0.89	0.07	5.36	0.53
9	3.53	1.47	0.88	0.08	5.37	0.54
10	3.51	1.49	0.87	0.08	4.97	0.52
11	3.47	1.53	0.86	0.08	4.40	0.46
12	3.45	1.55	0.86	0.09	4.11	0.44
13	3.435	1.57	0.85	0.09	3.87	0.42
14	3.40	1.6	0.84	0.09	3.69	0.39

For B=de/H0 = 2.5/4.02 = 0.62 in nomograph (Fig. 1) drainage properties from observed drain discharge and water table drawdown offers the advantage of integrating the effects of spatial heterogeneity in drainage properties and also provides depth-wise representative values of the drainage properties of soil. The variability of the two drainage properties is discussed here.

Variability in Drainable Porosity (u)

Depth-wise drainable porosity as determined in the study have been given in Table 1 and the relation of drainable porosity with soil depth is shown in Fig. 2. It is clear from the figure that drainable porosity is a function of water table depth expressed as follows:

$$y = 32.02\,x^{1.761} \qquad (R^2 = 0.970) \qquad \text{...(4)}$$

Where, y and x are representing dependent and independent variable, respectively.

A gradual variation in drainable porosity was found to range from 5.5% for the upper soil layer to 10.8% for deeper soil layers. The texture of the soil being sandy loam, these values of drainable porosity correspond well to the values in the range of 6 to 9% for medium textured soils as found by Dieleman and Trafford (1976). The drainable porosity was low near the soil surface and increased gradually in deeper soil depths. The lower values of drainable porosity near the soil surface was responsible for severe drainage problem leading to water logging condition in the study area, because with lower values of drainable porosity near soil surface, addition of even small amount of rainfall or irrigation leads to large rise of water table due to slow infiltration and percolation resulting in impeded natural drainage of soil profile (Gupta 2015).

Variability in Hydraulic Conductivity-Drainable Porosity Ratio (K/u)

Depth-wise hydraulic conductivity-drainable porosity ratio values as computed from nomograph given by Skaggs (1976) have been given in Table 3 and the relation with soil depth is shown in Fig. 3. From the figure it is observed that K/u ratio is large near soil surface and gradually decreases with increasing depths and the functional relation of K/u ratio with soil is denoted as:

$$y = 2.148\,x^{-0.23} \qquad (R^2 = 0.985) \qquad \text{...(5)}$$

Variability in Hydraulic Conductivity (K) with Soil Depth

The hydraulic conductivity values at different water table depths as computed by Skaggs (1976) method are given Table 3 and its relation with depth is plotted in Fig. 4. It is clear from Fig. 4 that the hydraulic conductivity also decreases with depth as denoted by the following relation:

$$y = 1.128\,x^{-0.38} \qquad (R^2 = 0.975) \qquad \text{...(6)}$$

Near soil surface it was found as 0.96 m day^{-1} and gradually decreased in lower soil layers reaching up to 0.39 m day^{-1} at H = 3.40 m. Apparently, it looks that with increasing drainable porosity, the hydraulic conductivity must also increase. But, this is not the case here for saline soils of Haryana, because the hydraulic conductivity is controlled by the relative distribution of different pore sizes in the soil mass not by the porosity alone. Thus in this case even with increasing drainable porosity values, the hydraulic conductivity values for the lower depths were found to be low

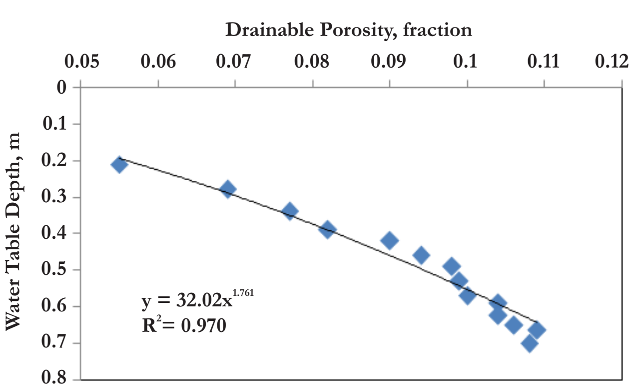

Fig. 2. Variation of Drainable Porosity with Water Table Depth

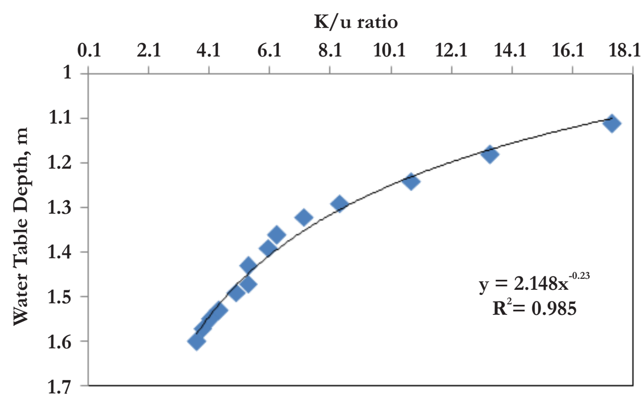

Fig. 3. Variation of K/u ratio with Water Table Depth

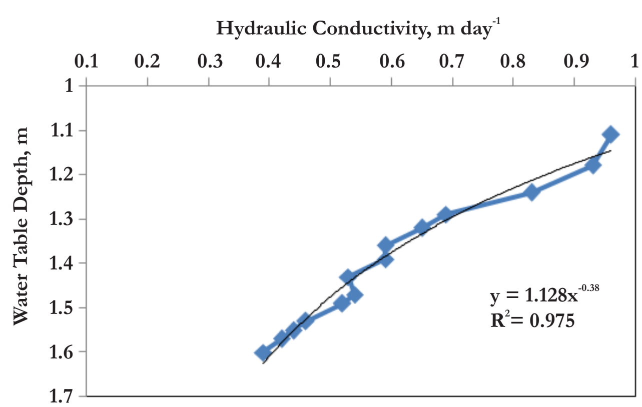

Fig. 4. Variation of Hydraulic Conductivity with Water Table Depth

due to changing inherent nature of saline soils. The low hydraulic conductivity of lower soil layers caused the prolonged discharge flow from the drainage system as also observed during the operation of the drainage system. The depth-wise variability of hydraulic conductivity indicates that depth-wise heterogeneity exists in the soils of the study area.

Spatial Variability in Hydraulic Conductivity

The point measurements of K values by single auger hole method at multiple locations within the experimental area have been given in Table 2. It is seen that the soils of the study area show a great spatial variability in hydraulic conductivity values. The range of variation is from 0.27 m day^{-1} to 5.30 m day^{-1}. It is also observed that at maximum number of locations, K values falls in low range indicating an skewed distribution, the value corresponding to 50% probability being 1.2 m day^{-1}. The large variation in K values offers difficulty in selection of a design value of hydraulic conductivity to be used in drain spacing formulae. The large variability in K values reflects the great heterogeneous nature of the alluvial saline soils present in the study area. The nature of fluvial deposits from floods varying in texture, shifting position of river channels, ever-changing depositional velocities, source of the sediments and climatic variation can be thought as the main factors responsible for large spatial heterogeneity in the hydraulic and hydrologic properties of these soils which ultimately affect the performance of the drainage systems. The spatial variability in K values also indicates that the point measurements, which involve only a small quantity of soil volume, may not give field representative values of hydraulic conductivity. Moreover, the point measurements do not incorporate the integrated effects of soil profile heterogeneities, non-uniformities and anisotrophy.

In the light of the above, it can be said that the soil drainage properties determined from drain discharge and water table drawdown measurements in existing subsurface drainage systems offer the advantage of integrating the effects of spatial heterogeneity observed in the drainage parameters and at the same time, provide the depth-wise representative values of the drainage properties of the soil.

4. CONCLUSIONS

The drainable porosity of saline soils was found low near soil surface which gradually increased with increase in depth of soil. Lower drainable porosity near soil surface is the reason behind severe drainage problem as low drainable porosity makes the intake and percolation rates of water slow. This results in undesirable increase in water table height from even small addition of water from rainfall or irrigation, which brings salts present in groundwater to crop root zone. Hydraulic conductivity of saline soils showed large spatial variation even within the same field. Depth-wise variation in hydraulic conductivity was also found, which is a typical characteristic of alluvial saline soils. Determination of drainable porosity and hydraulic conductivity of saline soils from drain discharge and water table drawdown measurements gives more reliable and field representative values due to lumping of the effects of soil profile heterogeneity, non uniformity and anisotrophy. These drainage properties exhibited an exponential relation and high degree of correlation with soil depth. Thus, it is concluded that in the absence of drainage installation (incurring high investment), these relations may be of great use for estimating field representative values of hydraulic conductivity and drainable porosity of the soil.

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