SOIL MOISTURE RETENTION CHARACTERISTICS AND HYDRAULIC CONDUCTIVITY FOR DIFFERENT AREAS IN INDIA IN SELECTED STATES

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ABSTRACT

Mathematical models of hydrologic and agricultural systems require knowledge of the relationships between soil moisture content (θ), soil water pressure (h) and unsaturated hydraulic conductivity (K). This study involved field and laboratory determination of soil moisture characteristics in different areas of India – Hindon, Kolar, Narsinghpur, Ghataprabha and Lokapavani. Saturated hydraulic conductivity was measured either through Guelph Permeameter in the field or through ICW Permeameter or Jodhpur Permeameter in the laboratory. Retention curve data was obtained through pressure plate apparatus. These have been used to develop empirical relationships to derive the approximate soil moisture retention curve at the places where only saturated hydraulic conductivity data is available.

Key Words : Soil Moisture, Hydraulic Conductivity, Retention Curve, Soil Water Pressure, Unsaturated Zone.

INTRODUCTION

The water movements in the unsaturated zone, together with its water holding capacity are very important for assessing the water demand of the vegetation, as well as for the recharge of the ground water storage. A fair description of the flow in the unsaturated zone is also crucial for predictions of the movement of pollutants into ground water aquifers.

For analytical studies on soil moisture regime, critical review and accurate assessment of the different controlling factors is necessary. The controlling factors of soil moisture may be classified under two main groups viz. climatic factors and soil factors. Climatic factors include rainfall intensity, storm duration, inter-storm period, temperature of soil surface, relative humidity, radiation, evaporation, and evapotranspiration. The soil factors include soil

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matric potential and water content relationship, hydraulic conductivity and water content relationship of the soil, saturated hydraulic conductivity and effective porosity. Besides these factors, the information about depth to water table is also required.

Saturated and unsaturated hydraulic conductivity are related to the degree of resistance from soil particles when water flows through soil pores. In addition, unsaturated hydraulic conductivity is affected markedly by the volumetric water content of soil.

The relation between matric potential and volumetric water content in a soil is termed as the soil moisture characteristic curve. The differences among soil moisture characteristic curves are attributed primarily to the differences in pore size distribution among soils. These curves are sensitive to the changes in bulk densities and disturbances of soil structures. In addition, the curves generally show hysteresis according to the degree of wetting or drying of soils.

In the present study, field and laboratory investigations have been carried out to determine the soil moisture characteristics (saturated hydraulic conductivity and soil moisture retention curve) in different areas of the country and empirical relationships have been derived for each study area to obtain the soil moisture retention characteristic from saturated hydraulic conductivity.

STUDY AREA

The following areas have been considered for the present study. The locations of theses areas have been marked in figure 1.

Hindon Sub-Basin

The study area is a part of Gangetic plain and lies in the upper part of Hindon basin, located between 29º55' - 30º6' NL, and 77º35' - 77º46' EL (Kumar et al., 1999). The area is located within Saharanpur district of Uttar Pradesh (India), appearing in the Survey of India topographic sheets 53 F/12, 53 F/16, 53 G/8 and 53 G/13 in the scale of 1:50,000. The investigated area covers around 24 km. along the Hindon river in its upstream reach. The study is confined to a stretch of Hindon river in between Aurangabad and Dudhil Bukhara villages.

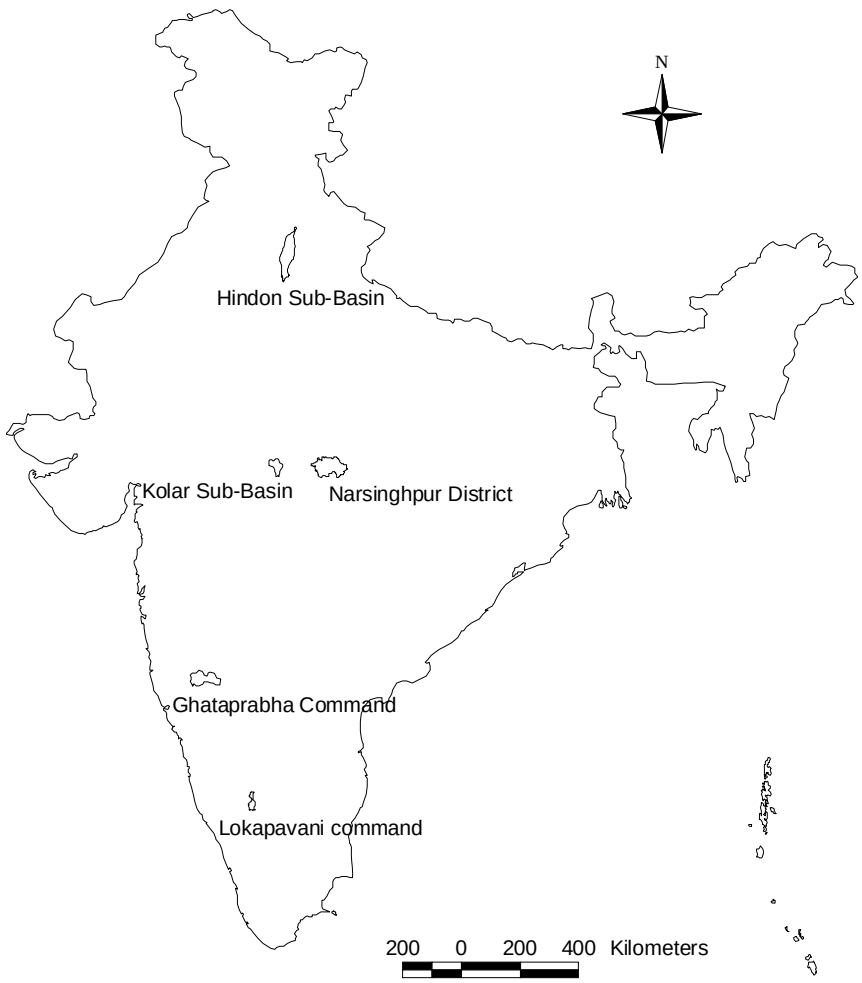

Figure 1 : Location of Diifferent Study Areas in Selected States

Kolar Sub-Basin

The Kolar sub-basin is located between 22º40' to 23º08' NL and 77º01' to 77º29' EL (Seth et al., 1990). The Kolar river originates in the Vindhyachal mountain range at an elevation of 550 metres above MSL in the Sehore district of Madhya Pradesh. The river during its 100 km. course first flows towards east and then towards south before joining the Narmada river near Neelkanth. During its course, the Kolar river drains an area of about 1350 sq. km. The entire basin lies in the Sehore and Raisen districts.

Narsinghpur District

Narsinghpur district is located in the Jabalpur division of Madhya Pradesh (Shukla et al., 1995 and Soni et al., 1996). Narsinghpur city is around 100 km. away from Jabalpur city. This area comes under the command area of Bargi irrigation project, which is a multipurpose project. The Bargi dam is constructed on Narmada river. The selected area for the present study is the doab of river Sher, Barau and left bank canal of Bargi irrigation project.

Ghataprabha Command

The command area of Ghataprabha lies between 16º00'08" to 16º88'09" NL and 74º26'43" to 75º56'33" EL (Soni et al., 1992 and Chandramohan et al., 1996). The entire area is undulating with elevation ranging from 524 metres to 768 metres. The left branch canal runs along the ridge line west to east, almost dividing the area between the river Krishna in the North and Ghataprabha in the South in two parts. The project envisages irrigation of 3180 km^2 in Belgaum, Bijapur and Dharwad districts. Out of the total geographical area of 1597 km^2, an area of about 536 km^2 come under Kharif and 1208 km^2 under Rabi. Mainly cotton, jower, wheat, bajra, maize, groundnut and pulses are grown.

Lokapavani Command

The study area lies in the Pandavapura taluk of Mandya district in Karnataka state (Singh et al., 2001). It lies between 12º28' to 12º32' NL and 76º40' to 76º45' EL. It falls in Krishnarajasagar command, which consists of two contour canals, Vishveshwaraiah canal (V.C.) and Chikkadeveraya Sagar canal (CDS). Total command area in this study area is 68 sq.km., of which 20.7 sq.km. comes under CDS canal command and 47.3 sq.km. under VC

canal command. The lengths of the CDS and VC canals are 31 km. and 42.2 km., respectively. The study area is mostly agricultural land without any forest. Forest lies beyond the 24 distributary in the East of study area. The main crops grown in the area are sugarcane and paddy. Crops are sown on rotation basis.

FIELD AND LABORATORY INVESTIGATIONS

Augers were used to obtain undisturbed soil cores at different depths. Saturated hydraulic conductivity was measured at various locations in the study area either in the field through Guelph Permeameter or through ICW Permeameter or Jodhpur Permeameter in the laboratory. Retention curve data were generated in the laboratory for all the soil samples collected from various sites of all the study areas.

Soil Moisture Retention Curves

The graph giving the relation between soil moisture tension and soil moisture content is called moisture retention curve or soil moisture characteristic. If the tension is expressed as the logarithmic value of cm water, the graph is referred to as a pF-curve. Moisture retention curves are used:

(a) to determine an index of the available moisture in soil (the portion of water that can be readily absorbed by plant roots) and to classify soils accordingly, e.g. for irrigation purposes,

(b) to determine the drainable pore space (effective pore space, effective porosity, specific yield) for drainage design,

(c) to check changes in the structure of a soil, e.g. caused by tillage, mixing of soil layers etc.,

(d) to ascertain the relation between soil moisture tension and other physical properties of a soil (e.g. capillary conductivity, thermal conductivity, clay and organic matter content).

In order to construct the moisture retention curve of a soil, the moisture content of the sample is measured by putting the moist soil sample at a succession of known pF values till attainment of equilibrium and each time determining the amount of moisture that is retained. If the equilibrium moisture content (expressed preferably as volume percentage) is plotted against the corresponding tension (pF), the moisture retention curve (pF-curve) can be drawn. There is no single method of inducing the whole range of tensions from $pF = -\infty$ (total

saturation) to pF = 7 (oven dry).

The ceramic plates equipment is suitable for determination of pF-curves in the pF range of 2.0-4.2 (0.1-15 bar of suction). For each soil type, the characteristic pF-curve may be developed. These curves relate the soil suction to its moisture content. This relationship is important in studies of soil moisture movement and quantity and availability of soil moisture for plant growth.

Saturated Hydraulic Conductivity

The hydraulic conductivity depends upon the attributes of the soil and the fluid together. The soil characteristics, which have bearing on the hydraulic conductivity are the total porosity, the distribution of pore sizes and the tortuosity – in short, the pore geometry of the soil. The fluid attributes, which affect the hydraulic conductivity are fluid density and viscosity.

The simplest technique to measure the saturated hydraulic conductivity (K_s) in the laboratory is to take an 'undisturbed' cylindrical sample of the soil, saturate it, and let water flow through it. From the rate of outflow, the hydraulic gradient and the cross-sectional area observed on the sample, K_s can be calculated with Darcy's equation. Because truly undisturbed samples are difficult to obtain and the sample size is relatively small, laboratory methods have limited usefulness and direct measurement of K_s in the field is usually preferred.

The saturated water permeability can be determined in the field through Guelph Permeameter or in the laboratory with a laboratory permeameter. *Guelph Permeameter* is a constant head device which operates on the Mariotte siphon principle and provides a quick and simple method for simultaneously determining field saturated hydraulic conductivity, matric flux potential and soil sorptivity. The *ICW Permeameter* is used for measuring the saturated permeability of. undisturbed soil samples stored in soil sample rings. Determination of the permeability of undisturbed soil samples is a simple matter. By creating a difference in water pressure on both sides of a well saturated soil sample, water flow passes through the sample. This flow is measured and forms the essential data together with pressure difference and sample dimensions for permeability calculations. The *Jodhpur Permeameter* (Singh, 1958) may be used to determine permeability by constant head as well as falling head method.

RESULTS AND DISCUSSION

To model the retention and movement of water and chemicals in the unsaturated zone, it is necessary to know the relationships between soil water pressure, water content and hydraulic conductivity. The measurements of $\theta(h)$ from soil cores (obtained through pressure plate apparatus) can be fitted to the desired soil water retention model e.g. van Genuchten model (1980). Once the retention function is estimated, the hydraulic conductivity relation, $K(h)$, can be evaluated if the saturated hydraulic conductivity, K_s, is known.

However, in India, soil water retention data is only sparsely available. In order to have a quick derivation of soil water retention curve without detailed laboratory investigations, an attempt has been made to derive the same from saturated hydraulic conductivity.

The following functional relation was assumed for characterizing the soil moisture retention characteristics:

$$\theta = a\ [\log |h|]^{b}\ [K_s]^{c} \qquad \ldots (1)$$

where,

θ = volumetric water content (cm^3/cm^3);

h = soil water pressure (relative to the atmosphere) expressed in cm of water;

K_s = saturated hydraulic conductivity; and

a, b, c = constants.

A total of 445 sets of data (θ, h, K_s) were available from the laboratory investigations of soil samples from the five study areas. The constants a, b, c of the above function were obtained through non-linear regression analysis carried out for each sub-basin/command separately. All the available 445 data sets were also considered for regression analysis to find the average relationship. Table 1 presents the constants a, b, c of empirical function (equation 1) for different areas.

Table 1: Constants of empirical function for different areas

S. No.	Sub-Basin / Command	Number of Data Sets (θ, h, K_s)	Constant a	Constant b	Constant c	Proportion of Variance Explained (%)
1	Hindon Sub-basin	90	0.944	-2.123	-0.268	74.17
2	Kolar Sub-basin	60	0.733	-1.034	-0.062	80.78
3	Narsinghpur district	147	0.870	-1.072	-0.025	66.38
4	Ghataprabha Command	71	0.423	-1.026	-0.215	59.75
5	Lokapavani command	77	0.552	-1.360	0.002	65.41
6	All considered	445	0.584	-1.103	-0.106	50.48

The ‘proportion of variance explained’ indicates the quality of prediction in individual areas than just using the mean value of the dependent variable. This is also known as the ‘coefficient of multiple determination’.

It can be observed from Table 1 that good correlation for the empirical relationship was found for Kolar sub-basin with 'proportion of variance explained' as 80 per cent. It varied between 60 to 80 per cent for other areas which can also be considered as reasonable. For the average relationship, it was found to be 50 per cent.

Thus, equation (1), after substituting the parameter values for different study areas may be applied to obtain soil moisture retention characteristics from saturated hydraulic conductivity in the respective basins.

CONCLUSION

Water relations are among the most important physical phenomena that affect the use of soils for agricultural or engineering purposes. During the recent years, advanced theories of transport in porous material have been proposed. To take advantage of such theories, elaborate experimental data are needed. The proposed model (Eq. 1) uses a fixed property, saturated hydraulic conductivity and the variable property of soil moisture tension to determine volumetric soil moisture content. This results in the soil moisture characteristic curves. However, it is to be emphasized that these functional relations have been developed for specific areas and applicability of the average relationship for other regions needs to be further explored.

REFERENCES

Chandramohan, T., Purandara, B. K. and Chandra Kumar, S. (1996). Measurement of Surface Soil Hydraulic Properties for Ghataprabha Command Area, Case Study Report No. CS(AR)-214, National Institute of Hydrology, 1995-96, 63 p.

Kumar, C. P., Arora, Manohar, Singh, Digamber, Mittal, Sanjay, Srivastava, S. L. and Rao, P. R. (1999). Variation of Soil Moisture Characteristics in a Part of Hindon River Catchment, Case Study Report No. CS(AR)-4, National Institute of Hydrology, Roorkee, 1998-99, 61 p.

Seth, S. M., Srivastava, S. L., Mittal, Sanjay, Vatsa, Rajan, Garg, Pankaj and Vijay T. (1990). Laboratory Analysis of Soil Samples from Kolar Sub-basin of River Narmada, Technical Report No. TR-82, National Institute of Hydrology, 1990, 122 p.

Shukla, M. K., Soni, B. and Srivastava, S. L. (1995). Estimation of Hydrological Soil Properties of Narsinghpur District, Case Study Report No. CS(AR)-167, National Institute of Hydrology, 1994-95, 55 p.

Singh, Alam (1958). Jodhpur Pattern (J.P.) Permeameter, Current Engg. Practice, Vol. 1, No. 3, Sept. 1958, Bombay, pp. 19-21.

Singh, Vivekanand, Mittal, S., Srivastava S. L. and Lakhera, N. K. (2001). Estimation of Hydrological Properties of Soil in Lokapavani Area of K. R. Sagar Command in Mandya District, Karnataka, Case Study Report No. CS(AR)-15, National Institute of Hydrology, 2000-2001, 37 p.

Soni, B., Srivastava, S. L., Purandara, B. K. and Varadarajan, N. (1992). Estimation of Hydrological Soil Parameters for Malaprabha and Ghataprabha Subbasins, Technical Report No. TR-130, National Institute of Hydrology, 1991-92, 93 p.

Soni, B., Srivastava, S. L. and Singh, Dhanpal (1996). Comprehensive Hydrological Study of Narmada River Basin - Estimation of Hydrological Soil Properties of Narsinghpur District, Case Study Report No. CS(AR)-208, National Institute of Hydrology, 1995-96, 98 p.

van Genuchten, M. Th. (1980). A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils, *Soil Sci. Soc. Am. J.*, Volume 44, 1980, pp. 892-898.