SOIL MOISTURE CHARACTERISTICS IN UPPER PART OF HINDON RIVER CATCHMENT

C. P. Kumar[*] *Vijay Kumar*[**] *Vivekanand Singh*[***]

ABSTRACT

Knowledge of the physics of soil water movement is crucial to the solution of problems in watershed hydrology, for example, the prediction of runoff and infiltration following precipitation, the subsequent distribution of infiltrated water by drainage and evaporation, and estimation of the contribution of various parts of a watershed to the ground water storage. Convenient and reliable techniques for estimating the soil hydraulic properties are required for prediction of soil water flow.

This paper presents the field and laboratory determination of soil moisture characteristics and their variation along the Hindon river in its upstream reach. A total of 38 soil samples were collected from 14 sites in Aurangabad, Kamalpur, Budhakhera, Gagalheri and Dudhil Bukhara comprising around 24 km reach, upstream of Hindon river. Extensive laboratory measurements were made for each soil sample collected. Porosity was obtained for each soil sample. Saturated hydraulic conductivity was measured through ICW Permeameter in the laboratory. Retention curve data was obtained through pressure plate apparatus. Unsaturated hydraulic conductivity function was indirectly derived through van Genuchten retention parameters by non-linear regression analysis.

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

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* Scientist 'E1' and Head, Hard Rock Regional Centre, National Institute of Hydrology, Belgaum - 590 001 (Karnataka)

** Scientist 'C', Western Himalayan Regional Centre, National Institute of Hydrology, Jammu - 180 003 (J & K)

*** Scientist 'B', National Institute of Hydrology, Roorkee - 247 667 (Uttaranchal)

1.0 INTRODUCTION

Water relations are among the most important physical phenomena that affect the use of soils for agricultural or engineering purposes. During the recent years, mathematically sophisticated theories of transport in porous material have been proposed. However, the difficulties of making reliable field measurements at an appropriate scale and using them in physically realistic predictive models are undiminished.

The water movements in the unsaturated zone, together with the water holding capacity of this zone, are very important for 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 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 precipitation data containing rainfall intensity, storm duration, interstorm period, temperature of soil surface, relative humidity, radiation, evaporation, and evapotranspiration. The soil factors include soil matric potential and water content relationship, hydraulic conductivity and water content relationship of the soil, saturated hydraulic conductivity, and effective medium porosity. Besides these factors, the information about depth to water table is also required.

Saturated hydraulic conductivity and unsaturated hydraulic conductivity are related to the degree of resistance from soil particles when water flows in pores. These resistances are affected by the forms, sizes, branchings, jointings, and tortuosities of pores as well as viscosity of water. 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 because the curve is characteristic of each soil. 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 wetting or drying of soils.

The present study aims at field and laboratory investigations to determine the soil moisture characteristics (parameters of hydraulic conductivity function and soil moisture retention function) at various locations along the uppermost part of Hindon river.

2.0 STUDY AREA

The study area is a part of the Gangetic plain, which has been divided into three belts: Bhabhar belt, Terai belt and Alluvial plain. In the foothill region of the Himalaya, the hills are fringed towards the south by talus fans. The upper portion of talus fans is composed of rock fragments, gravel and soil which support thick forests. This zone, known as the Bhabhar, has a thickness of about 200 m. The Bhabhar formation is chiefly made up of unconsolidated boulders. The zone is characterized by steep ground slope and deep water table lying between 5 to 37 m depths below the ground surface. The southern limit of the Bhabhar generally forms a spring line that also defines the northern limit of the Terai tract.

The Terai tract lies immediately south of the Bhabhar zone. It is a transition zone between the Bhabhar and the Alluvial plain. It is composed of alternate layers of clay and sand often having marshy conditions covered with grass and thick forest. In the Terai, ground slope varies from mild to steep and the water table is at very shallow depth. The width of the belt varies from 5.5 to 8 km. The study area lies in the Alluvial plain, which is almost a level country with gentle slope from NW to SE. Lithologically, the Gangetic plain has thick alluvial deposits consisting of unconsolidated sands, clay and kankar.

The study area lies in the upper part of Hindon basin, bounded between latitude $29^{o}55'$ and $30^{o}6'$ N and longitude $77^{o}35'$ and $77^{o}46'$ E (figure 1). The area is located within Saharanpur district of Uttar Pradesh (India) and included in the Survey of India topographic sheets 53 F/12, 53 F/16, 53 G/9 and 53 G/13 in the scale of 1:50,000. The investigated area covers a reach of 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.

The climate in the Hindon basin is moderate to subtropical monsoon type. Thus, there exists a well-marked seasonal variation in precipitation, temperature, and relative humidity. The average annual monsoon rainfall in Saharanpur town is 886 mm and the temperature variation is from $8^{o}C$ in winter to $40^{o}C$ in summer. The drainage of the area comprises of the Hindon river, which is an ephemeral river flowing towards south. The river finally meets the Yamuna river (a tributary to the river Ganges) near Ghaziabad (latitude $28^{o}28'N$) outside the study area.

The soil is alluvial type deposited by Hindon river system. Lithologically, it mainly consists of clay, silt and fine to coarse sand. The soils are very fertile for growing wheat, sugarcane and vegetables. However, along the sandy river course, fruit orchards are also common.

3.0 SOIL MOISTURE CHARACTERISTICS

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. It is often convenient to represent these functions by means of relatively simple parametric expressions. The problem of characterizing the soil hydraulic properties then reduces to estimating parameters of the appropriate constitutive model. The following typical functional relations, as reported by Haverkamp et al. (1977), were used for characterising the hydraulic properties (unsaturated hydraulic conductivity and moisture retention curve) of soil.

$$K = K_S \frac{A}{A + |h|^{\beta_1}} \qquad \ldots (1)$$

and

$$\theta = \frac{\alpha(\theta_s - \theta_r)}{\alpha + |h|^{\beta_2}} + \theta_r \qquad \ldots (2)$$

where K is the hydraulic conductivity of the soil (cm/h); h the soil water pressure (relative to the atmosphere) expressed in cm of water; θ the volumetric water content (cm^3/cm^3); and A, α, β_1 and β_2 the parameters for the soil. Subscript s refers to saturation, i.e. the value of θ for which h = 0, and the subscript r to residual water content.

The measurements of θ(h) from soil cores (obtained through pressure plate apparatus) can be fitted to the desired soil water retention model. Once the retention function (e.g. equation 2) is estimated, the hydraulic conductivity relation, K(h), can be evaluated if the saturated hydraulic conductivity, K_s, is known. In the present study, parameters of hydraulic conductivity function (A and β_1 in equation 1) were indirectly derived through the van Genuchten retention parameters. For the van Genuchten model, the water retention function is given by

$$S_e = (\theta - \theta_r)/(\theta_s - \theta_r) = [\,1 + (\alpha_v |h|)^n\,]^{-m} \quad \text{for } h < 0$$
$$= 1 \quad \text{for } h \geq 0$$

$$\ldots (3)$$

and the hydraulic conductivity function is described by

$$K = K_s S_e^{1/2} [1 - (1 - S_e^{1/m})^m]^2 \quad \ldots (4)$$

where, α_v and n are van Genuchten model parameters, m = 1 – 1/n.

The parameters of soil moisture retention function (including θ_r) and hydraulic conductivity function were obtained through non-linear regression analysis. The saturated moisture content (θ_s) was assumed to be equal to (0.93*soil porosity). The porosity for each soil sample was measured in the laboratory.

Table 1 presents the location and depth of soil samples collected from uppermost part of the Hindon river catchment. Table 2 presents the parameters of Haverkamp h-θ function (equation 2) and "proportion of variance explained" for all the soil samples. Table 3 presents the saturated hydraulic conductivity obtained through I C W Permeameter, van Genuchten retention parameters, Haverkamp K-h function (equation 1) parameters, and "proportion of variance explained" for all the soil samples. The depth-averaged characteristics were also determined at each site.

It may be observed that soil moisture characteristics vary widely along the Hindon river in its upstream reach. The "proportion of variance explained" was found to be more than 90% in most of the cases.

4.0 CONCLUSION

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). Hence, a sustained research effort towards the parameterisation of K(h) and h(θ) has resulted in the development of several laboratory, field and theoretical methods.

Field and laboratory based soil investigations were carried out for the uppermost part of Hindon river catchment. Soil characteristics such as soil moisture retention curve and saturated hydraulic conductivity were measured at various locations along the Hindon river. The parameters of soil moisture retention function were obtained through non-linear regression analysis. The parameters of hydraulic conductivity function were indirectly derived from the van Genuchten model. Soil characteristics were found to vary widely both spatially as well as along the depth.

Table 1 : Location of Soil Sampling Sites

S. No.	Soil Sample Code	Village	Normal Distance from Centre of River (m)	Bank	Depth Range (cm)
1	A11	Aurangabad	200	Left	90 – 110
2	A12	Aurangabad	200	Left	150 – 180
3	A21	Aurangabad	100	Left	0 – 40
4	A22	Aurangabad	100	Left	100 – 120
5	A23	Aurangabad	100	Left	160 – 180
6	A31	Aurangabad	100	Right	0 – 30
7	A32	Aurangabad	100	Right	90 – 110
8	A33	Aurangabad	100	Right	160 – 180
9	A41	Aurangabad	200	Right	0 – 30
10	A42	Aurangabad	200	Right	90 - 110
11	A43	Aurangabad	200	Right	170 - 190
12	K11	Kamalpur	100	Left	0 - 100
13	K12	Kamalpur	100	Left	100 – 150
14	K13	Kamalpur	100	Left	150 - 200
15	K21	Kamalpur	200	Left	0 – 70
16	K22	Kamalpur	200	Left	70 – 110
17	K23	Kamalpur	200	Left	110 – 180
18	K31	Kamalpur	400	Left	0 - 100
19	K32	Kamalpur	400	Left	100 – 180
20	K33	Kamalpur	400	Left	180 – 220
21	K41	Kamalpur	100	Right	40 – 60
22	K42	Kamalpur	100	Right	105 – 125
23	K51	Kamalpur	200	Right	40 – 60
24	K52	Kamalpur	200	Right	100 – 120
25	K53	Kamalpur	200	Right	160 – 180
26	K61	Kamalpur	400	Right	45 – 65
27	K62	Kamalpur	400	Right	100 – 120
28	B11	Budhakhera	100	Right	35 – 55
29	B12	Budhakhera	100	Right	70 – 90
30	B13	Budhakhera	100	Right	120 – 140
31	G11	Gagalheri	100	Right	35 – 55
32	G12	Gagalheri	100	Right	70 – 90
33	G13	Gagalheri	100	Right	130 - 150
34	G21	Gagalheri	100	Left	70 – 90
35	D11	Dudhil Bukhara	100	Right	5 - 15
36	D12	Dudhil Bukhara	100	Right	30 – 50
37	D13	Dudhil Bukhara	100	Right	85 – 95
38	D14	Dudhil Bukhara	100	Right	110 - 120

Table 2 : Parameters of Haverkamp h - θ Function

Sample No.	Porosity	θ_s	α	β_2	θ_r	Proportion of Variance Explained (%)
A11	0.4466	0.415	28.980	0.565	0.072	94.23
A12	0.4722	0.439	46.762	0.681	0.088	96.85
A1 (Average)	0.4594	0.427	18.689	0.486	0.050	95.41
A21	0.4687	0.436	171.510	0.952	0.077	99.36
A22	0.4388	0.408	452.927	1.054	0.101	98.24
A23	0.4652	0.433	28.143	0.552	0.037	94.19
A2 (Average)	0.4576	0.426	156.978	0.897	0.086	91.38
A31	0.4051	0.377	1997.722	1.360	0.095	99.43
A32	0.4520	0.420	430.479	1.060	0.117	98.26
A33	0.4520	0.420	60.843	0.800	0.076	99.39
A3 (Average)	0.4364	0.406	340.197	1.062	0.098	82.98
A41	0.5040	0.469	38.176	0.834	0.039	99.45
A42	0.4476	0.416	13.688	0.473	0.055	99.68
A43	0.4846	0.451	47.788	0.750	0.045	99.23
A4 (Average)	0.4787	0.445	24.264	0.680	0.058	59.14
K11	0.4082	0.380	4.176	0.608	0.008	98.77
K12	0.4020*	0.374	22.611	0.848	0.015	99.68
K13	0.3959	0.368	6.747	0.628	0.014	99.04
K1 (Average)	0.4020	0.374	15.771	0.807	0.015	94.02
K21	0.4163	0.387	119.900	1.033	0.026	99.48
K22	0.3551	0.330	1.534	0.493	0.002	98.89
K23	0.3673	0.342	8.945	0.675	0.006	98.62
K2 (Average)	0.3796	0.353	17.220	0.753	0.009	57.86
K31	0.5061	0.471	135.006	0.921	0.042	99.69
K32	0.5102	0.474	122.687	0.916	0.034	99.63
K33	0.5082*	0.473	24.258	0.903	0.011	99.82
K3 (Average)	0.5082	0.473	27.306	0.686	0.013	70.07
K41	0.3747*	0.348	2.123	0.594	0.006	99.79
K42	0.3747	0.348	1.835	0.513	0.006	98.63
K4 (Average)	0.3747	0.348	1.491	0.489	0.005	95.40
K51	0.5061*	0.471	9.928	0.802	0.018	99.01
K52	0.5061*	0.471	59.769	0.937	0.048	98.60
K53	0.5061	0.471	34.853	0.673	0.075	98.55
K5 (Average)	0.5061	0.471	17.438	0.704	0.048	43.32
K61	0.4082	0.380	190.938	1.043	0.059	99.96
K62	0.4204	0.391	39.309	0.704	0.076	99.63
K6 (Average)	0.4143	0.385	88.275	0.872	0.064	93.73
B11	0.4400	0.409	690.350	1.600	0.010	99.66
B12	0.4700	0.437	20.166	1.068	0.007	97.22
B13	0.4300	0.400	3.701	0.626	0.004	96.88
B1 (Average)	0.4467	0.415	34.558	1.076	0.008	83.31
G11	0.4200	0.391	499.356	1.085	0.127	99.53
G12	0.4450	0.414	686.994	1.184	0.109	98.81
G13	0.4200	0.391	49.309	0.986	0.023	97.29
G1 (Average)	0.4283	0.398	115.747	0.944	0.083	50.17
G21	0.4450	0.414	12.314	0.991	0.004	97.42
D11	0.5800	0.539	10.324	0.522	0.016	97.38
D12	0.5450	0.507	15.953	0.805	0.007	97.91
D13	0.4500	0.418	10084.52	1.698	0.036	99.39
D14	0.5000	0.465	1.986	0.588	0.003	96.04
D1 (Average)	0.5188	0.482	24.504	0.780	0.018	56.39

* Assumed

Table 3 : Parameters of Haverkamp K – h Function

Sample No.	θ_r	θ_s	K_s (cm/hour)	van Genuchten Retention Parameters			Haverkamp K-h Function Parameters		
				α_v	n	Proportion of Variance Explained	A	β_1	Proportion of Variance Explained
A11	0.072	0.415	0.041	0.0142	1.3884	93.67	7.645	1.255	99.32
A12	0.088	0.439	0.010	0.0112	1.5193	97.12	17.530	1.270	99.28
A1 (Average)	0.050	0.427	0.026	0.0185	1.3284	95.65	5.029	1.316	99.43
A21	0.077	0.436	0.080	0.0088	1.7714	99.18	86.035	1.435	99.48
A22	0.101	0.408	0.022	0.0058	1.8370	98.60	176.590	1.420	99.64
A23	0.037	0.433	0.588	0.0134	1.3812	94.62	7.345	1.230	99.31
A2 (Average)	0.086	0.426	0.230	0.0078	1.7100	91.61	63.324	1.342	99.48
A31	0.095	0.377	0.058	0.0057	2.1278	99.60	1196.988	1.747	99.79
A32	0.117	0.420	0.080	0.0063	1.8294	97.76	156.263	1.425	99.63
A33	0.076	0.420	0.036	0.0124	1.6643	99.42	38.729	1.426	99.29
A3 (Average)	0.098	0.406	0.058	0.0074	1.8622	82.87	169.768	1.492	99.61
A41	0.039	0.469	1.884	0.0207	1.7457	99.41	48.347	1.688	99.32
A42	0.055	0.416	0.175	0.0273	1.3312	99.22	5.006	1.488	99.60
A43	0.045	0.451	0.412	0.0138	1.6006	99.14	26.279	1.406	99.27
A4 (Average)	0.058	0.445	0.824	0.0210	1.5725	59.22	20.685	1.552	99.37
K11	0.008	0.380	33.753	0.1728	1.5520	98.59	9.731	2.925	100.00
K12	0.015	0.374*	16.157	0.0479	1.7156	99.61	40.794	2.190	99.84
K13	0.014	0.368	17.785	0.1089	1.5384	98.69	14.323	2.606	99.99
K1 (Average)	0.015	0.374	22.565	0.0591	1.7022	94.05	39.957	2.357	99.91
K21	0.026	0.387	0.677	0.0200	1.7937	98.99	61.501	1.716	99.30
K22	0.002	0.330	24.984	0.8721	1.4431	98.80	0.120	3.054	100.00
K23	0.006	0.342	14.430	0.0867	1.5714	98.22	19.504	2.495	99.97
K2 (Average)	0.009	0.353	13.364	0.0536	1.6099	57.31	24.870	2.163	99.88

Table 3 (continued) …

Sample No.	θ_r	θ_s	K_s (cm/hour)	van Genuchten Retention Parameters			Haverkamp K-h Function Parameters		
				α_v	n	Proportion of Variance Explained	A	β_1	Proportion of Variance Explained
K31	0.042	0.471	0.303	0.0142	1.6234	99.06	29.492	1.436	99.27
K32	0.034	0.474	0.350	0.0151	1.6272	98.94	29.537	1.461	99.27
K33	0.011	0.473*	4.603	0.0486	1.7927	99.91	57.832	2.284	99.85
K3 (Average)	0.013	0.473	1.752	0.0311	1.4824	69.47	12.565	1.678	99.62
K41	0.006	0.348*	84.992	0.4259	1.5619	99.71	1.486	3.269	100.00
K42	0.006	0.348	48.204	0.6204	1.4641	98.43	0.339	3.076	100.00
K4 (Average)	0.005	0.348	66.598	0.7309	1.4639	95.27	0.214	3.092	100.00
K51	0.018	0.471*	20.196	0.0910	1.7243	99.07	46.113	2.799	99.98
K52	0.048	0.471*	0.421	0.0269	1.7350	98.34	43.189	1.808	99.47
K53	0.075	0.471	0.245	0.0246	1.4396	97.51	9.976	1.523	99.50
K5 (Average)	0.048	0.471	6.954	0.0474	1.5506	43.19	18.148	2.006	99.83
K61	0.059	0.380	0.845	0.0148	1.7622	99.74	60.798	1.576	99.28
K62	0.076	0.391	0.230	0.0242	1.4583	98.92	11.109	1.529	99.49
K6 (Average)	0.064	0.385	0.538	0.0178	1.5956	93.20	23.988	1.499	99.30
B11	0.010	0.409	14.937	0.0219	2.4113	99.69	1108.457	2.396	99.43
B12	0.007	0.437	5.493	0.0781	1.9931	97.11	178.926	3.077	99.98
B13	0.004	0.400	17.588	0.2128	1.5754	96.61	8.015	3.084	100.00
B1 (Average)	0.008	0.415	12.673	0.0519	1.9764	83.26	128.839	2.547	99.89
G11	0.127	0.391	17.270	0.0079	1.7607	98.88	86.032	1.397	99.52
G12	0.109	0.414	0.177	0.0088	1.8348	97.86	126.838	1.503	99.53
G13	0.023	0.391	8.519	0.0334	1.8370	97.53	65.564	2.026	99.62
G1 (Average)	0.083	0.398	8.655	0.0164	1.6898	49.91	39.859	1.546	99.27
G21	0.004	0.414	N.A.	--	--	--	--	--	--
D11	0.016	0.539	0.207	0.0594	1.3853	96.55	6.634	1.960	99.89
D12	0.007	0.507	66.640	0.0597	1.6970	97.50	39.022	2.360	99.92
D13	0.036	0.418	70.013**	0.0070	2.2241	99.66	1712.531	1.892	99.81
D14	0.003	0.465	89.857	0.3957	1.5793	95.83	1.971	3.298	100.00
D1 (Average)	0.018	0.482	56.679	0.0392	1.6279	56.19	26.398	1.950	99.73

* Assumed

** From Guelph Permeameter (ICW Permeameter result not available)

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NOTATIONS

A	=	Soil Parameter
h	=	Soil Water Pressure
m	=	van Genuchten Model Parameter
n	=	van Genuchten Model Parameter
K	=	Hydraulic Conductivity
K_s	=	Saturated Hydraulic Conductivity
S_e	=	Effective Saturation
α	=	Soil Parameter
α_v	=	van Genuchten Model Parameter
β_1	=	Soil Parameter
β_2	=	Soil Parameter
θ	=	Volumetric Water Content
θ_r	=	Residual Water Content
θ_s	=	Saturated Water Content