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Physico-chemical properties and hydrological behavior of soils of Nilona micro watershed of Maharashtra

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Abstract
The present investigation was carried out in Nilona micro watershed of Darwha block, Yavatmal district, Maharashtra to study the physico-chemical properties of soils and also predict the hydrological behavior i.e. saturated hydraulic conductivity *(K_s)*. 118 surface soil samples were collected from grid points located at regular interval of 325 m. The results showed that the bulk density of 1.25 to 1.68 g cm^{-3} and particle density 2.40 to 2.81 g cm^{-3}. Porosity of 32.86 to 52.30%**.** In soils of the Nilona micro watershed, the amount of sand, silt and clay content varied from 37.90 to 60.70%, 10.70 to 25.30% and 25.90 to 37.60%. The saturated hydraulic conductivity (K_s) of the studied soil positively correlated with sand. The soils of Nilona micro watershed were saline in nature and were within safe limit of salinity. The organic carbon content of surface soils ranged from low to high and available nitrogen under low category. The present study helps to prepare a comprehensive watershed development plan to understand the topography, erosion status and drainage pattern of the region. The need of such information is important in estimating soil hydrological model that assumes particular importance for Yavatmal district, a drought prone region of Maharashtra.

Keywords: Nilona, Yavatmal, saturated hydraulic conductivity, hydrological model, watershed development

Introduction

The watersheds are natural hydrological entities that cover a specific aerial expanse of land surface from which the rainfall runoff flows to a defined drain, channel, stream or river at any particular point. The terms region, basin, catchment, watershed, etc. are widely used to denote hydrological units. In the last two decades, watershed management has gained the top most priority in water resources sector.

Watershed delineation is one of the most commonly performed activities in hydrologic and environmental analyses. A number of studies used soil water simulation models to evaluate the performance of estimated soil hydraulic characteristics through the simulation of different aspects of soil behaviour [15]. Hydraulic conductivity and available water holding capacity are some of the key parameters that are important in soil and water management practices for sustainable and improved agricultural production [6]. The parameter is important for both, modeling the hydrology of segments of the landscape and for evaluating field soil water regimes in relation to the potential of soil for various uses [16].

Although soil hydraulic parameters are increasingly needed for crops as well as land use planning, they are not routinely determined by soil surveyors partly because of the difficulties to measure them [14]. Direct measurements of soil water retention capacity are expensive, time consuming and labour intensive [6, 16]. However, the parameters can alternatively be estimated using available soil data such as particle size distribution, organic matter content, bulk density and soil porosity [10].

Material and Methods

The study area Nilona micro watershed is located between 20° 15’ 43” to 20° 17’ 39” N latitude and 77° 38’ 41” to 77° 41’ 10” E longitude, covering an area of 1297.35 ha in Darwha tehsil of Yavatmal district, Maharashtra (Fig 1). The elevation of the area ranges from 360 to 467 m above MSL. The study area falls under North Deccan (Maharashtra) Plateau and is agro-climatically placed under hot moist to semi-arid eco-sub-region.

The climate of the area is subtropical, dry sub-humid with well-expressed summer (March-May), rainy season (June-October) and winter season (November-February). The mean maximum temperature varies from 33 °C to 46 °C in summer season, mean daily minimum temperature is 13 °C to 15 °C with a mean annual temperature of 29 °C.

Site selection – traversing of the study area
Nilona micro-watershed was delineated. 118 surface soil samples were collected from grid points located at regular interval of 325 m presented in Fig 2. The soil-site characteristics such as landform, location, slope, runoff, drainage, erosion, stoniness, land use and natural vegetation were studied.

Soil sample processing
The soil samples were air dried at room temperature. The samples were ground using wooden mortar and pestle and sieved through 2 mm sieve. The processed samples of <2 mm size was labeled and stored in polythene bags for subsequent physical and chemical analyses.

Analysis of soil samples
Physical properties
Bulk density (BD)
The bulk density (dry clod) was determined by clod coating method [1]. Soil clods of about 20-25 g in weight were tied with a fine thread and weighted in air. The clods were coated with molten paraffin wax (55-60 °C) and the volume of soil clod was determined using 'Archimedes' principle and bulk density was determined.

Particle density (PD)
The determination of Particle density of soil was done as per the pycnometer method [3].

Porosity
It was calculated by following formula:
% Porosity = {1-Bulk density/ Particle density} x 100

Particle-size distribution
The particle size distribution of a soil were determined by Hydrometer method [2] based on the Stokes`s Law. The soil samples were treated with H_2O_2 (30%) to remove organic matter, chemically dispersed by adding 15 ml of 5% sodium hexametaphosphate (40 g sodium hexametaphosphate liter^{-1} of water) solution and 300 ml of distilled water was added followed by mechanical dispersion under the stirring machine. The whole dispersed sample was carefully transferred to a sedimentation cylinder of 1 liter using a squirt bottle to make sure all of the soil gets into the cylinder; distilled water was added to make up the volume to 1000 ml. The textural class was determined by using USDA textural triangle [13].

Saturated Hydraulic Conductivity (*Ks*)
The hydraulic conductivity of a soil is a measure of its ability to transmit water. The soil samples (< 2 mm) were fully saturated and then leached with deionized water. The saturated hydraulic conductivity was determined by constant head method described by [8] and calculated on the basis of Darcy's law as mentioned below :-

$$K = \frac{Q \times \Delta L}{T \times A \times \Delta H}$$

where,
K = Saturated hydraulic conductivity (cm d^{-1}.)
Q = Water discharge per hr.
ΔL = Length of soil column (cm)
ΔH = Hydraulic head drop (cm)
A = Cross section area of soil (sq.cm)
T = Time

Coefficient of Linear Extensibility (COLE)
The determination of COLE was done as per the method of [11]. The COLE has been defined as the ratio of the difference between the moist length and dry length of clod to its dry length.

$$COLE = \frac{Lm - Ld}{Ld}$$

where,
Lm = Length of moist clod
Ld = Length of dry clod

Soil moisture retention characteristics
The soil moisture retention characteristics were determined by pressure plate apparatus (Soil Moisture Equipment Corporation, USA) [5]. The basic theory behind this method is that a saturated soil, when subjected to increased vapor pressure, will lose a portion of its water. If the original mass of the soil is known, the amount of water remaining in the soil after subjected to a given pressure can be measured gravimetrically. By repeated measurement of the water content at different suctions of 0.33 (field capacity), 1, 3, 5, 10 and 15 (permanent wilting point) bars, respectively. The sieved soil samples in duplicate were filled in rubber soil retainer rings of 6 cm diameter and 1 cm height on ceramic plate of requisite capacity. The soil in the ring was allowed to saturate for 24 hr with an excess of water and the requisite pressure from a source of compressed air was applied on the next day. Moisture was determined gravimetrically after the soils have attained equilibrium at a particular pressure [8].

Chemical properties
Soil reaction (pH)
Soil reaction was determined by pH meter using glass/calomel electrode after equilibrating soil: water suspension in the ratio of 1:2 for 30 minutes as per method described by [4].

Electrical conductivity (EC)
A mixture of 20 gram air dry soil and 40 ml distilled water are stirred at regular interval at one hour. The soil water suspension (1:2) supernatant liquid was used to the electrical conductivity using ELICO Conductivity Bridge [8].

Organic Carbon
Organic Carbon content was determined by Walkley and Black method [1]. Ground soil samples of 80-100 mesh were used for estimating organic carbon. Soils were oxidized by 1N potassium dichromate solution in presence of sulphuric acid. The amount of dichromate remaining was determined by back titration with 0.5 N freshly prepared ferrous ammonium sulphate solution using ferroin indicator.

Available nitrogen (N)
Available nitrogen was determined by modified alkaline permanganate method as described by [9].

Results and Discussion
Physical properties of soils
The physical properties of the studied soils are presented in table 1 and discussed in following sections.

Bulk density

The bulk density (BD) is the ratio of the mass of dry soil to the total volume of the soil including pore spaces [3]. It is an index of workability of soil, availability of soil moisture, aeration and root penetration. The BD values range from 1.25 to 1.68 g cm^{-3}, with the mean value 1.49 g cm^{-3}.

Particle density

Particle density is the mass per unit volume of soil solid particles and it is expressed as the total mass of soil (solid) particles to their total volume excluding pore's space volume. The results indicate that the particle density of soils ranged from 2.40 to 2.81 g cm^{-3}, with mean value 2.56 g cm^{-3}.

Porosity

The amounts of pores per unit volume of soil constitute the porosity of the soil. The total porosity depends on the texture and aggregation of the soil. Porosity of these soils varied from 32.86 to 52.30 per cent with mean value 41.56 per cent.

Soil texture

The distribution of sand, silt, clay and their amounts provide information on texture of the soil which is permanent in nature (not altered by agro-management) and partly controls air, water and nutrient availability to the plant mainly.

The data (Table 1) show that soils developed on different physiographic units vary in their content of soil separates. This may be attributed to various geomorphic processes operating under different physiographic conditions. The soil textural data presented in table no. 4.7 reveal that the sand, silt and clay contents varied from 37.90 to 60.70%, 10.70 to 25.30% and 25.90 to 47.30%, respectively.

Out of 118 soil samples, sand content of 37 samples ranged from 35 to 45%, 58 samples ranged between 45 to 55%, 22 samples from 55 to 60% range and only 1 sample (60.75%) had above 60% sand content. The silt content of 45 soil samples range between 10 to 15%, 56 samples range from 15 to 20% of silt content remaining 21 samples ranged from 20 to 26% of silt content. 65 samples of clay content ranged between 25 to 35%, 21 samples ranged from 35 to 40% and remaining 32 samples were above 40% clay content.

Saturated hydraulic conductivity

Hydraulic conductivity is the measure of quantum of water that can flow through horizons in cm/day. The saturated hydraulic conductivity of soils is a good indicator of internal drainage conditions of the surface as well as sub surface. It is influenced by texture, structure, BD and pH of soils. It affects movement of water in the soils and hence affects crop growth.

The data presented in table no. 1 reveals that the saturated hydraulic conductivity of the studied soil samples varied from 1.60 to 15.60 cm d^{-1}, with the mean value of 7.95 cm d^{-1}.

COLE (Coefficient of Linear Extensibility)

Certain soils have the capacity to swell significantly when wet and to shrink and crack when dry. If the value of COLE exceeds 0.09, significant swelling and shrinkage of the soil is expected. The value of COLE higher than 0.3, indicates the presence of significant amount of smectite mineral in soil. In the present study, the COLE value ranges from 0.12 to 0.23, with a mean value of 0.19, which means all soil samples have below the value of COLE 0.3, indicates the absence of significant amount of smectite mineral in all soil samples.

Chemical properties of soils

Important chemical characteristics of soils are discussed here and the data was presented in table no. 1.

Soil pH

Soil pH is an indicator of nutrient availability to the plants that also controls activities of micro-organisms and quantum of nutrient availability in soils. It is partly controlled by nature of parent material and the climate in which the soil is developed and modified by physiography. The pH (1:2 soil water suspensions) ranged from 6.35 to 8.69, with a mean value of 7.68. Out of 118 soil samples, 47 samples were neutral (6.55 - 7.48), 62 samples were saline (7.62 - 8.50), 7 samples were sodic (8.52 - 8.69) and only 2 samples were acidic in reaction.

Electrical conductivity

Electrical conductivity gives an insight about the presence of total soluble salts. Higher number of salts in soils restrict the nutrient uptake due to increase in zeta potential of nutrient ions thus restricting nutrient transport and affecting plant growth.

The electrical conductivity of 1:2 soil water suspensions ranged from 0.11 to 0.42 dSm^{-1}, with a mean value of 0.25 dSm^{-1} at 25 ^{o}C. However, EC has been found within safe limit <1 dSm^{-1} in all the soil samples.

Organic carbon

The soil organic carbon (OC) is an indicator of soil fertility. The organic fraction in soils is formed from the microbial decomposition of organic residues. In addition to this, it also improves soil structure, infiltration rate, water and nutrient storage capacity and reduces soil erosion [12]. The nature and quantum of organic fraction formation depends on the type and quality of organic matter.

The data presented in table no. 1 indicates that, organic carbon content in 118 surface soils range from 0.20 to 1.90% with a mean value of 0.81%. Out of 118 soil samples, 28 samples were < 0.5% of organic carbon content, 21 samples in between 0.5 - 0.75% and 69 samples were > 0.75% organic carbon content.

Available nitrogen (N)

Nitrogen is the most vital major nutrient required by the plants for proper growth and development. The available nitrogen data of 118 soil samples ranged from 125.44 to 275.96 kg ha^{-1}, with a mean value of 172.10 kg ha^{-1}. All soil samples were below low level of available nitrogen, because all soils have below 280 kg ha^{-1} of available N. [7] reported low available N in shrink-swell soils of Maharashtra.

Table 1: Descriptive statistics of soil characteristics

Sl. No	Soil parameters	Range	Minimum	Maximum	Mean	SE	SD	CV
1	pH	2.34	6.35	8.69	7.68	0.06	0.65	8.57
2	EC	0.31	0.11	0.42	0.25	0.00	0.07	30.65
3	OC	1.70	0.20	1.90	0.81	0.03	0.36	45.41
4	Avail. N	150.53	125.44	275.96	172.10	2.59	28.16	16.36
5	BD	0.43	1.25	1.68	1.49	0.00	0.10	6.90
6	PD	0.40	2.40	2.81	2.56	0.00	0.06	2.66
7	Porosity	19.43	32.86	52.30	41.56	0.41	4.54	10.93
8	COLE	0.10	0.12	0.23	0.19	0.00	0.02	11.25
9	Sand	22.80	37.90	60.70	48.67	0.53	5.82	11.96
10	Silt	14.70	10.70	25.30	16.47	0.30	3.32	20.18
11	Clay	21.4	25.90	47.30	34.84	0.53	5.76	16.53
12	K_s	14.00	1.60	15.60	7.95	0.26	2.90	36.52
13	FC	0.26	0.36	0.63	0.48	0.00	0.05	10.48
14	PWP	0.14	0.20	0.35	0.28	0.00	0.02	9.33
15	AWC	0.15	0.14	0.29	0.20	0.00	0.03	15.86

Table 2: Pearson correlation among different soil properties

	pH	EC	OC	N	BD	PD	Porosity	COLE	Sand	Silt	Clay	K_s	Log K_s	FC	WP	AWC
pH	1															
EC	.571**	1														
OC	-.252*	-0.072	1													
N	-0.042	0.042	0.175	1												
BD	-0.16	-.262*	-0.077	-.237*	1											
PD	0.177	0.091	-0.024	0.2	-0.192	1										
Porosity	0.2	.263*	0.055	.271*	-.950**	.487**	1									
COLE	-0.093	0.128	0.034	0.192	-0.128	.214*	0.182	1								
Sand	0.019	-0.024	-.255*	-.392**	.272*	-.283**	-.331**	-0.144	1							
Silt	-0.155	-0.091	-0.118	-0.078	0.184	-.217*	-.231*	0.043	-.260*	1						
Clay	0.068	0.075	.318**	.431**	-.372**	.401**	.456**	0.117	-.839**	-.307**	1					
K_s	.741**	.502**	-.501**	-0.145	0.003	0.049	0.019	-0.115	.305**	0.062	-.336**	1				
Log K_s	.779**	.527**	-.519**	-0.156	-0.02	0.063	0.043	-0.11	.280**	0.058	-.308**	.980**	1			
FC	0.075	-0.03	0.19	.300**	0.226*	.351**	-0.002	0.049	-.444**	-.440**	.686**	-.291**	-.274**	1		
WP	-0.061	-0.126	0.167	0.16	.366**	0.19	-.267*	-0.03	-.452**	-.234*	.577**	-.329**	-.320**	.819**	1	
AWC	0.162	0.052	0.161	.335**	-0.092	.391**	0.205	0.099	-.329**	-.492**	.602**	-0.189	-0.171	.895**	.477**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

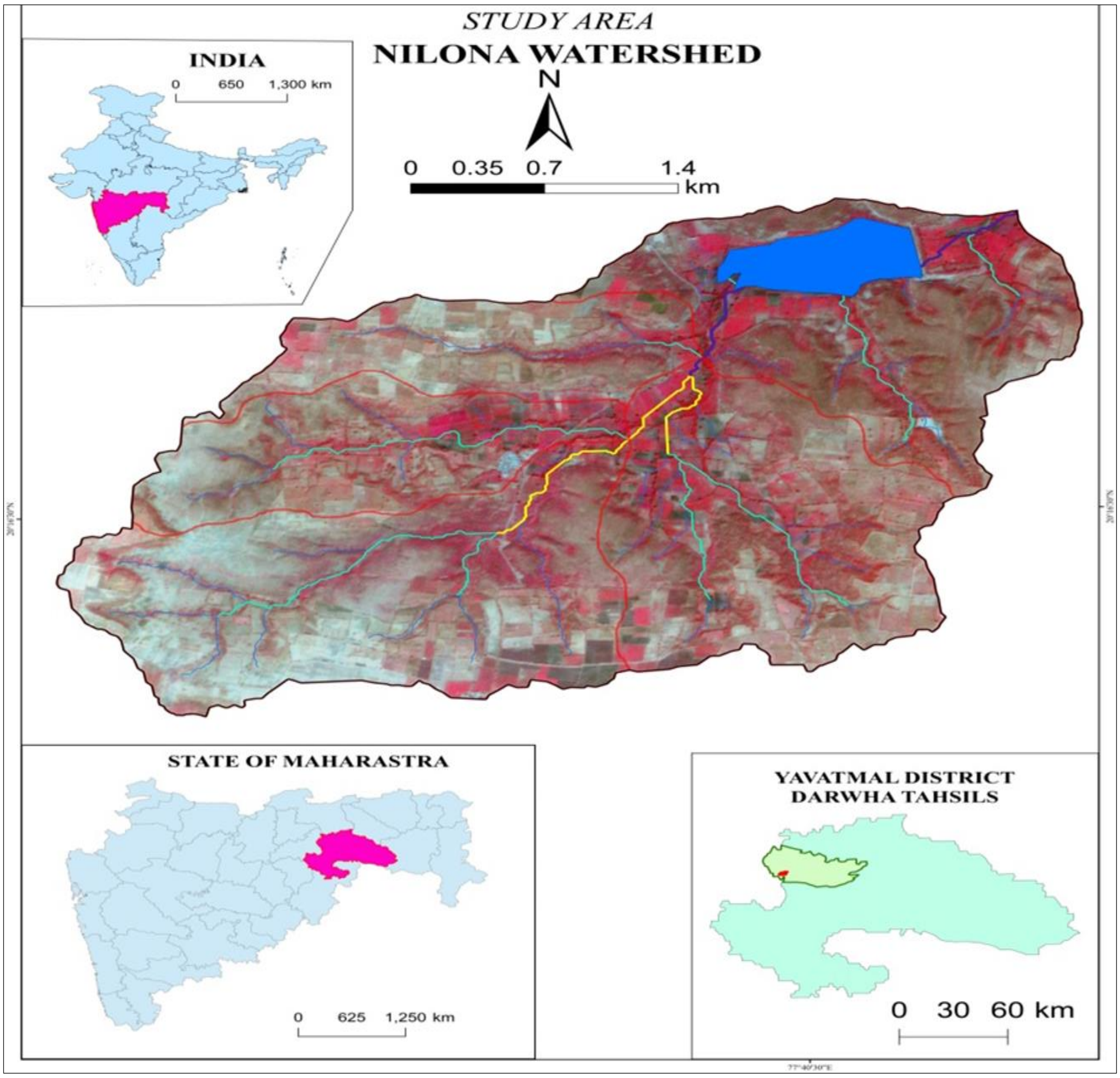

Fig 1: Location map of Nilona micro watershed, Darwha block, Yavatmal district

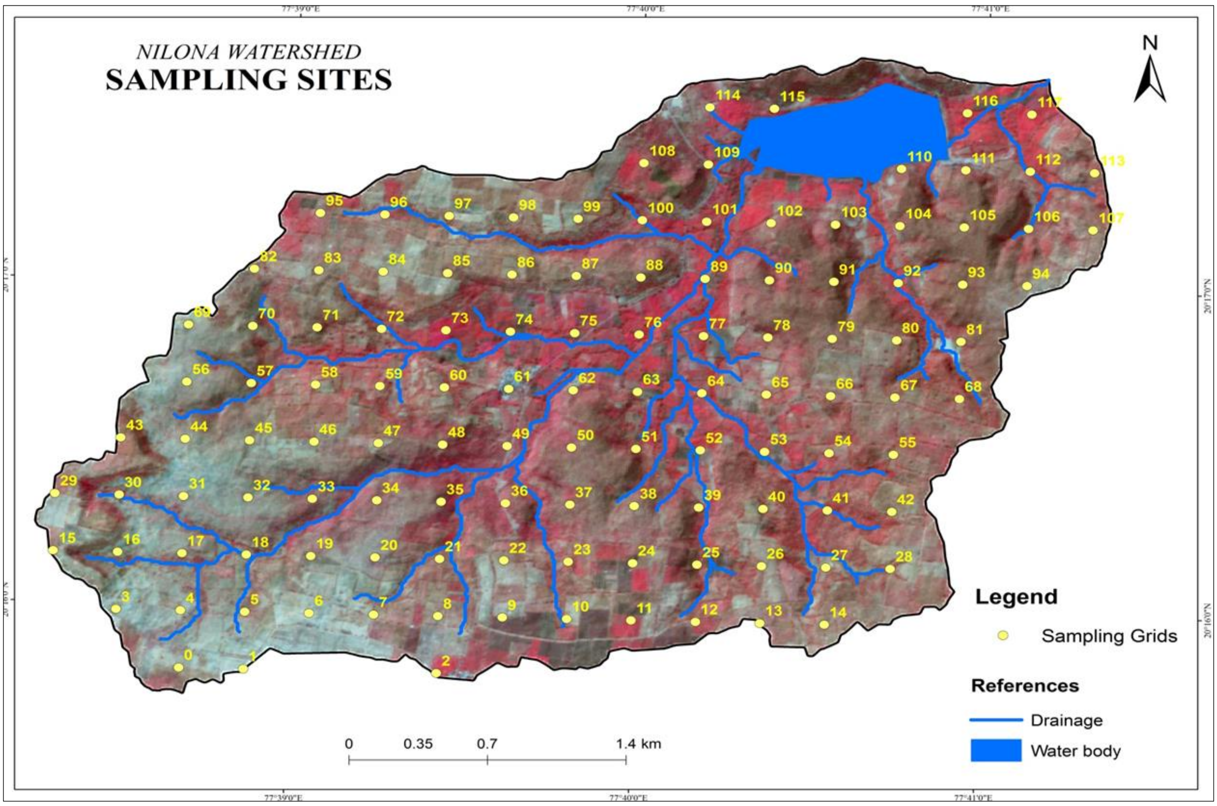

Fig 2: Soil sampling sites map of Nilona micro watershed, Darwha block, Yavatmal district

Conclusions

The soils of Nilona micro watershed showed the bulk density of 1.25 to 1.68 g cm^{-3}. The particle density of soils ranged from 2.40 to 2.81 g cm^{-3}. Porosity of these soils varied from 32.86 to 52.30**.** In soils of the Nilona micro watershed, the amount of sand, silt and clay content varied from 37.90 to 60.70%, 10.70 to 25.30% and 25.90 to 37.60%. The saturated hydraulic conductivity (K_s) of the studied soil positively correlated with sand. The soils of Nilona micro watershed were saline in nature and were within safe limit of salinity i.e., EC <1 dSm^{-1}. The organic carbon content of surface soils ranged from low to high and available nitrogen under low category. The data is available in spatial and digital format so that the land resources can be monitored on a regular basis. Similarly, this information can be utilized to prepare water management plan for the area.

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Conflict of interest

All the authors declared that they do not have any conflicts of interest in publishing this research article.

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