STUDIES OF INFILTRATION OF SOIL IN SHER-UMAR RIVER, DOAB IN NARMADA BASIN

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Abstract*—Infiltration is an important component of the hydrologic cycle and is defined as the process of entry of water through the soil surface. Earlier, the term infiltration was used to denote the difference between rainfall and runoff in small areas. Hydrological importance of the infiltration process is to be seen from the fact that it marks the transition from fast moving surface water to slow moving soil moisture and groundwater. In this paper infiltration tests were carried out at twelve locations in the Sher-Umar doab in Narmada basin during to assess the infiltration capacity of the soils in that area. The top soils of Sher-Umar doab area are mostly dark colored and are clayey in texture. These soils normally form a layer of about 1-2 meter thickness. At few places, underlying coarse calcareous yellow coloured soil are also exposed. Black clayey soils have been derived from Deccan Trap rocks, which are abundant in the nearby areas. Both the black clayey soils and yellow calcareous soils have low infiltration rate, ranging from 0.1 cm/hr to 4.8 cm/hr. In the initial period of water application the infiltration rate is very high which reduces very rapidly with time.

***Index Terms*—Infiltration of Soil, Infiltrometer, Narmada Basin, Umar River Doab**

I. INTRODUCTION

Infiltration is the process by which water on the ground surface enters the soil. Infiltration rate in soil science is a measure of the rate at which soil is able to absorb rainfall or irrigation. It is measured in inches per hour or millimeters per hour. The rate decreases as the soil becomes saturated. If the precipitation rate exceeds the infiltration rate, runoff will usually occur unless there is some physical barrier. It is related to the saturated hydraulic conductivity of the near-surface soil. The rate of infiltration can be measured using an infiltrometer. Infiltration is caused by two forces: gravity and capillary action. While smaller pores offer greater resistance to gravity, very small pores pull water through capillary action in addition to and even against the force of gravity.

The rate of infiltration is determined by soil characteristics including ease of entry, storage capacity, and transmission rate through the soil. The soil texture and structure, vegetation types and cover, water content of the soil, soil temperature, and rainfall intensity all play a role in controlling infiltration rate and capacity. For example, coarse-grained sandy soils have large spaces between each grain and allow water to infiltrate quickly. Vegetation creates more porous soils by both protecting the soil from raindrop impact, which can close natural gaps between soil particles, and loosening soil through root action. This is why forested areas have the highest infiltration rates of any vegetative types.

The top layer of leaf litter that is not decomposed protects the soil from the pounding action of rain; without this the soil can become far less permeable. In chaparral vegetated areas, the hydrophobic oils in the succulent leaves can be spread over the soil surface with fire, creating large areas of hydrophobic soil. Other conditions that can lower infiltration rates or block them include dry plant litter that resists re-wetting, or frost. If soil is saturated at the time of an intense freezing period, the soil can become a concrete frost on which almost no infiltration would occur. Over an entire watershed, there are likely to be gaps in the concrete frost or hygroscopic soil where water can infiltrate. Once water has infiltrated the soil it remains in the soil, percolates down to the ground water table, or becomes part of the subsurface runoff process.

The process of infiltration can continue only if there is room available for additional water at the soil surface. The available volume for additional water in the soil depends on the porosity of the soil and the rate at which previously infiltrated water can move away from the surface through the soil. The maximum rate that water can enter a soil in a given condition is the infiltration capacity. If the arrival of the water at the soil surface is less than the infiltration capacity, it is sometimes analyzed using hydrology transport models, mathematical models that consider infiltration, runoff and channel flow to predict river flow rates and stream water quality.

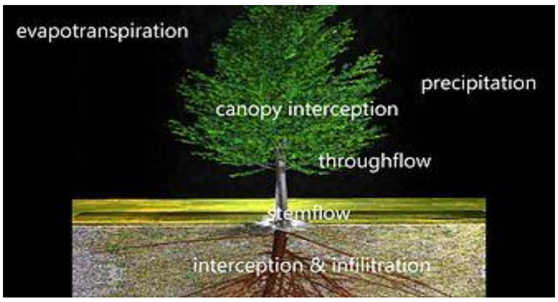

Figure 1 Process of Infiltration

Narmada basin extends over states of Madhya Pradesh, Gujarat, Maharashtra and Chhattisgarh having an area of 98,796 Sq.km which is nearly 3% of the total geographical area of the country with maximum length and width of 923 & 161 km. It lies between 72°38’ to 81°43’ east longitudes and 21°27’ to 23°37’ north latitudes. It is bounded by the Vindhyas on the north, by the Maikala range on the east, by the Satpuras on the south and by the Arabian Sea on the west. The hilly regions are in the upper part of the basin, and lower middle reaches are broad and fertile areas well suited for cultivation. Narmada is the largest west flowing river of the peninsular India. It rises from Maikala range near Amarkantak in Anuppur district of Madhya Pradesh, at an elevation of about 1057 m. The total length of the river is 1,312 km and for the first 1079 km it flows in Madhya Pradesh and thereafter forms the common boundary between Madhya Pradesh and Maharashtra for 35 km, and Maharashtra and Gujarat for 39 km. In Gujarat State it stretches for 159 km. Its important tributaries are the Burhner, the Banjar, the Sher, the Shakkar, the Dudhi, the Tawa , the Ganjal, the Kundi, the Goi and the Karjan which joins from left whereas the Hiran, the Tendoni, the Barna, the Kolar, the Man, the Uri, the Hatni and the Orsang joins from right. Narmada drains into the Arabian Sea through the Gulf of Khambhat. The major part of basin is covered with agriculture accounting to 56.90%. Water bodies cover 2.95% of the total basin area. The basin spreads over 20 parliamentary constituencies (2009) comprising 15 of Madhya Pradesh, 3 of Gujarat, and 1 each of Chhattisgarh and Maharashtra.

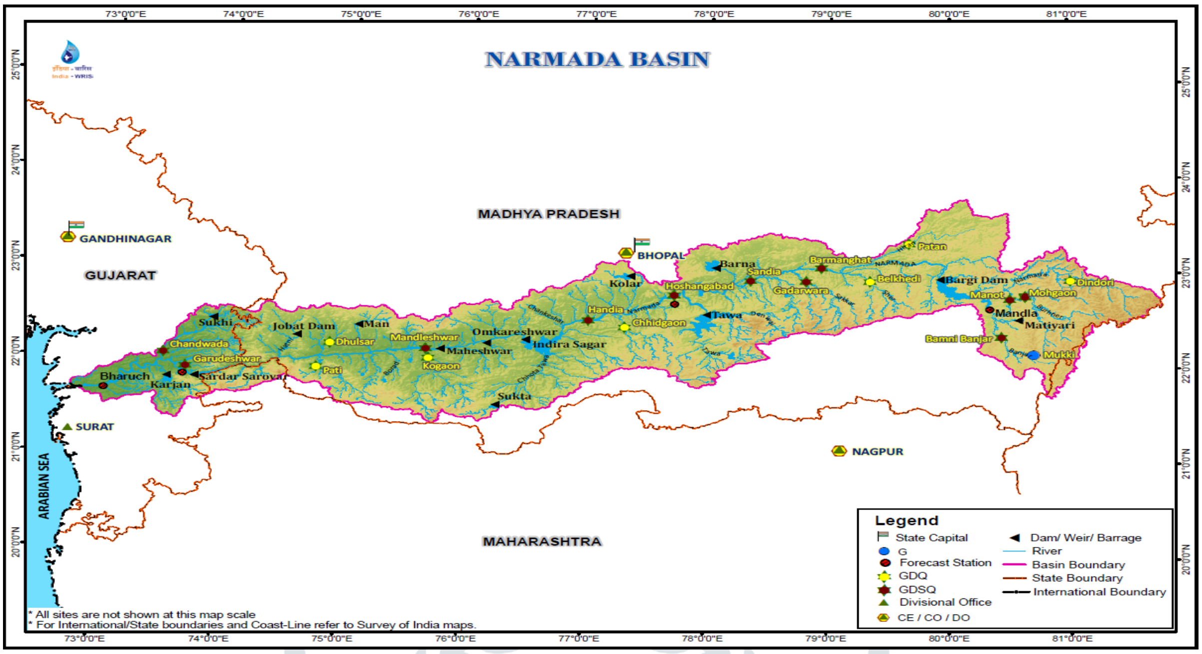

Figure 2 Map of Narmada Basin

Keeping in the view the importance of infiltration studies, infiltration studies have been initiated in the Bargi Left Bank Canal Command area. Infiltration tests were conducted in the Sher – Umar doab falling under the command area of Bagri Left Bank Canal in Narsinghpur district of Madhaya Pradesh.

II. Study Area

The Bargi multi-purpose project, renamed as Rani Avanti Bai Sagar Project, is one of the major river valley project on Narmada River by the Government of Madhya Pradesh as a part of the Narmada Valley Development Plan. On completion of the project, irrigation facilities will be available for 157,000 hectares in Jabalpur and Narsinghpur districts through Left Bank Canal system and 46,000 hectares in Jabalpur district through Right Bank Canal system.

The study area is a part of the Left Bank Canal Command of Bargi Multi-purpose Project. The canal is 132.2 kilometer long and has a discharge capacity of 124.65 cumecs. This canal has Culturable Command Area of 95,000 hectares.

Location

The study area is a part of Narsinghpur District, Madhya Pradesh and occupies the central part of Bargi Dam command area in Narmada river basin. The area lies between latitudes 22º53' N to 23º03' N and longitudes 79º10' E to 79º32' E and falls under Survey of India toposheets no. 55M/4, 55M/8 and 55M/9. The area is bound by the Sher River in west, by the Umar River in east and north, and by the Bargi Left bank canal in south (under construction). This is one of the most fertile and populous part of Narsinghpur.

The study area lies in the east of narsinghpur town and is traversed by State Highway No. 22 from Jabalpur to Hoshangabad. The main broadgauge railway line from Hawrah to Bombay also passes through the study area.

Physiography

The study area occupies a part of the southrn part of the Narmada Valley which is most fertile and populous part of Narsinghpur district. The general level of the study area lies between 338m to 360m above MSL. The general topography of the area appears to be flat except in the vicinity of the river, where deep gullies and ravines have formed giving rise to undulating to rolling topography. At few places, gravel mounds are also present.

The general slope of the area is towards north and northwest. In the plain areas, the slope is upto 3%, whereas in the undulating areas the slope is upto 15%. The drainage pattern in the areas is dendritic type. Small rivulets are confined to the southern and northern part of the study area. In southern area, the drainage is mainly in the hilly area and in the northern part it is along the two major rivers, that is, Sher and Umar. The landscape of the area is such that most of the surplus rain water drains through rivers and streams, but poor to moderate drainage conditions occur in the flat areas creating drainage problem in the central part of the doab.

Climate

The study area falls in sub-zone-2c based on hydrometeoroligical classification of the country (Kaushal and chaudhary, 1975; WAPCOS, 1986). The climate in the region is subtropical.

The rainy season extends from June to October under the influence of south-west monsoon. Normally the rainfall ceases by the end of September, but in quite a large number of years, the area receives good rainfall during October. The area also receives some rainfall during January and February. There is considerable variation in rainfall from year to year. As per the rainfall data of Narsinghpur meterological station, annual rainfall varied from 563.3mm (1965) to 1893.6mm (1977), with average annual rainfall of 1162mm (1965-89). Mean monthly rainfall of Narsinghpur meteorological station is given in Table 1.

The temperature in the area varies from 45ºC in summers to 2ºC in the winters. The temperature begins to rise rapidly from March till May, which is generally the hottest month of the year. With the onset of the monsoon in the second week of June, there is an appreciable drop in the day temperature. From mid-November onwards, both day and night temperature decreases rapidly. December and January are the coldest months of the year.

Table 1 Mean monthly rainfall at Narsinghpur meterological station for the period 1965-89

S.No.	Month	Mean monthly rainfall (mm)	Year 1989
1.	January	18.74	0.00
2.	February	19.40	0.00
3.	March	10.36	38.00
4.	April	1.68	0.00
5.	May	7.05	0.00
6.	June	166.70	231.80
7.	July	314.95	93.40
8.	August	422.50	603.60
9.	September	155.58	120.80
10.	October	22.30	0.00
11.	November	11.30	0.00
12.	December	11.40	0.00
	TOTAL	11161.96	1087.60

Soil

The soils of the area are alluvial in nature. The thickness of alluvium increases towards north. Rocks are exposed on the southern periphery of the study area. Kankars have been observed at a depth of 80 cm to 150cm.

The top soils of the area are normally heavy and dark colored and are derived from Deccan Trap rocks. The top black soil is variable in thickness with average thickness of about 1 meter with a maximum thickness of 9 meters. This soil is clayey in texture and has high moisture retaining capacity. The black soil is underlain by light textured yellow soil. This yellow soil has low water retaining capacity as compared to black soil.

In some places, the soil have been formed from sand stone parent material in which a lot of textural variation is found. It varies from sandy loam to clay. The soil crust is deep and has a fair amount of gravel or kankar (impure form of nodular calcium carbonate) along the depth of profile.

The soil survey of the area had been carried out by soil survey unit Jabalpur under department of agriculture, Government of Madhya Pradesh. In study area, there are only three types of soil that is clay, clay loam, silty clay loam in which clay and silty clay loam are predominant.

Towards the banks of river, the texture of the soil changes from heavier to lighter grade that is from clay to clay loam, loam, sandy loam and finally sandy. The colour of the soil also changes from dark greyish brown to brown, yellowish brown and finally yellow grey.

Ground Water

The entire study area is covered with alluvium of recent age. Alluvium consists mainly of clay and fine to medium grained sand. The thickness of alluvium varies from place to place ranging from 15 to 180m. Groundwater is mostly present under confined conditions and gives yield of 75-150 m3/hr for 6m drawdown.

Water table is guiding factor which control the movement of water through soil, though by physical character, a soil may have different drainability.

Agriculture and Irrigation

The study area is normally agriculture area with no forest land. Forested area lies beyond Bargi canal in the South. The main crops grawn in the area are Soyabean, Gram, Arhar, Masoor, Moong, Jwar, Wheat and Sugar Cane. In some low lying areas, Rice is also cultivated. Fruit bearing trees are Mango and Jamun.

"The old Haveli" system of cultivation is practiced in rabi. The preference to rabi cultivation is due to the high clay content of the soil which is difficult to work in rainy season. Broadly speaking, under Haveli system a large area is bunded and utilized for collecting rain water during the monsoon and is left fallow during Kharif season. The rain water stored as soil moisture helps to grow rabi crops.

III. Infiltration Process and Methods of Measurement

Infiltration characteristics of a soil is an important parameter for hydrological modeling. It is essential to know the rates at which different soils will take in water under different conditions. Infiltration rates are affected by a number of factors of which soil moisture, soil texture and vegetal cover are most important. It's a basic parameter for developing an integrated crop, soil and water management plan. The knowledge of infiltration is of great importance to a hydrologist in estimating rate of runoff and peak flow with time, to a soil scientist/agronomists in estimating the availability of the soil moisture, to irrigation and drainage engineer in planning and design of various water resources development projects.

Factors Affecting Infiltration Rate

Once the importance of study of infiltration rate has been established, it is useful to understand the effect of various soil and climatic factors on the infiltration rate. Some of the most common factors affecting infiltration rate are:

- Soil properties (including structures, texture and distribution, porosity and compactness of soil grains),

- Soil moisture,
- Landuse characteristics,
- Rainfall (duration and intensity),
- Surface slope, and
- Climate

Infiltration Estimation and Measurement Techniques

The three step sequence, that is, surface entry, transmission and exhaustion on storage presents difficulties in the measurement of infiltration. For the most part, hydrologists determine the rate and amount of in-soak and attempt to correlate this with various combinations of soil, vegetation and antecedent soil moisture. There are two general approaches to determine the infiltration capacity of a soil cover and soil moisture complex. One of these is the analysis of hydrographs of runoff from natural rainfall on plots and watersheds. The other is the use of infiltrometers with artificial application of water to enclosed sample areas.

Maximum infiltration rates are measured in the field by applying water to the soil surface either by ponding or as natural or artificial rain at rates sufficient to cause some runoff. Maximum infiltration rates are very high in the beginning of water application, but diminishes in time to much lower, nearly constant values.

In India many type of infiltrometers (as discussed below) are used to determine the infiltration characteristics of the soils. Where infiltrometer data are not available, phi index or empirical formulate are used.

Infilrometers can be grouped into two general groups; (i) Rainfall Simulators, with the water applied in the form and at the rate comparable with natural rainfall and (ii) Flooding type with the water applied in a thin sheet upon an enclosed area and usually in a manner to obtain a constant head. In India only flooding type infiltrometers are used, which may vary in size, in the quantity of water that is required, and in the methods of measuring the water. In flooding type two, mainly double ring infiltrometers are used, but sometimes single ring infiltrometers are also used.

Single Ring Infiltrometer

It consists of a metal cylinder which is driven into the soil to a short distance (nearly 15cm). The time pattern of infiltration is obtained by monitoring the change in supply to the surface. Refinement to the technique involve the introduction of an outer ring has a buffer and devices for monitoring a constant head of supply.

Changes in the supply are monitored by recording the water level in the graduated coloum above the infiltrometer at selected times.

Figure 3 Single Ring Infiltration

Double Ring Infiltrometer or Concentric Ring Infiltrometer

The most common type consists of two shallow concentric rings of sheet metal, usually ranging from 22.5 to 19cm diameter are placed with their lower edges a few centimeters below the ground surface and with the upper portion projecting above in figure 4.

Water is now applied in both apartments ‘a’ and ‘b’ and is always kept at same level in both. The function of the outer ring is to prevent the water within inner space from spreading over a larger area after penetrating below the bottom of the ring. From the rate at which water must be added to the inner ring in order to maintain the constant level, the infiltration capacity and its manner of variation are determined.

Figure 4 Double Ring Infiltration

IV. METHODOLOGY

Normally, three steps are involved in any field investigation, that is, pre-field preparations, field investigations and post-field analysis.

Pre-Field Preparations

Reconnaissance soil survey of the Bargi Left Bank Canal Command area has been carried out by the soil survey unit, Department of Agriculture, Government of Madhya Pradesh. The soil texture map of the Narsinghpur District was collected from the department of agriculture, Narsinghpur in figure 5. A base map, indicating road network of the area, was prepared using survey of the India toptsheets. The soil texture map was transferred on the base map for location of tests sites. The sites were tentatively chosen in such a way that different type of soil found in the area are covered and the sites are easily approachable. Twelve sites were identified for the infiltration tests, well distributed all over the area in figure 6 and covering two soil types. The area covered by third soil type (clay loam) was small, hence no test could be conducted in that type.

Field Investigations

During the field work, infiltration tests were carried out at twelve locations and soil samples were collected for soil texture analysis. Information about ground water level was also collected from local survey is shown in table 2.

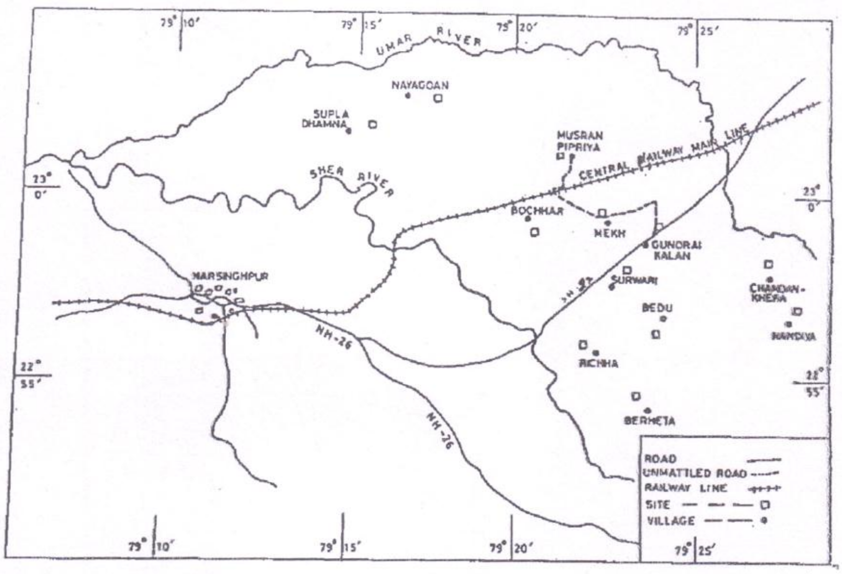

Figure 5 Location of Infiltration test sites

Table 2 Groundwater table depth in Sher-Umar River Doab in October 1996.

S.No.	Name of village	Depth to water table (m)
1.	Nayagaon	6.6
2.	Supla	6.8
3.	Bedu	9.6
4.	Gundrai Kalan	9.4
5.	Berheta	6.5
6.	Survari	7.8
7.	Bochhar	6.9
8.	Mekh	8.4
9.	Musran Piparia	9.2
10.	Pachauri (Nadiya)	1.3
11.	Chandankhera	7.4
12.	Richha	7.5

Infiltration tests were carried out using micro-processor based double ring infiltrometer. The inner and outer rings used for the test were of 22.5cm and 35cm diameter, respectively. The rings were inserted into the ground upto a depth of 25-30cm. The tests were carried out using constant head method with a head of 10cm. Each test was conducted for such a duration (2 to 4 hrs.) during which the infiltration rate became constant.

Post Field Analysis

After the field work was over, the samples were brought to the National Institute of Hydrology, Roorkee for laboratory analysis, that is particle size analysis and saturated hydraulic conductivity excreta.

Textural Analysis

The samples collected from the field were tested in the soil water laboratory, National Institute of Hydrology, Roorkee, for the particle size distribution. Partical size distribution of the soils was by sieve and sedimentation analysis. Soil samples were washed were distilled water to remove the soluble salts. The washed sample were separated in to two fractions that is, +75 micron and -75 micron through wet sieving. Sieve analysis was performed for the fraction of soil retained on 75 micron sieve (+75 micron). The portion passing through the 75 micron sieve (-75 micron) was analysed by sedimentation analysis using hydrometers. The test results of the analysis are given in table 3.

Table 3 Particle size distribution in soils of Sher-Umar River Doab

S.No.	Name of village	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Texture
1.	Nayagaon	4.9	5.4	62.1	27.6	Silty clay loam
2.	Supla	0.0	8.9	61.7	29.4	Silty clay loam
3.	Bedu	0.5	13.9	37.7	47.9	Clay
4.	Gundrai Kalan	2.4	16.4	20.3	60.9	Clay
5.	Berheta	2.4	20.2	24.8	52.6	Clay
6.	Survari	0.0	6.0	26.8	67.2	Clay
7.	Bochhar	1.6	10.3	34.7	53.4	Clay
8.	Mekh	1.0	14.0	21.8	63.2	Clay
9.	Musran Piparia	0.0	12.5	19.3	68.2	Clay
10.	Pachauri(Nadiya)	0.6	24.3	26.0	49.1	Clay
11.	Chandankhera	0.4	4.6	22.7	72.3	Clay
12.	Richha	0.0	12.8	12.3	74.9	Clay

The table 3 shows that the soils are mostly clayey in texture, except at two places were sand percentage is a bit higher.

Preparation of infiltration Map

Raw data obtained from the field was processed to find the infiltration capacity of the soils in table 4. This soil infiltration capacity was transferred to soil series map of the area and infiltration capacity map was prepared in figure 6.

Table 4 Infiltration capacity of the soils of Sher-Umar River Doab

S.No.	Name of village	Infiltration Capacity (cm/hr)
1.	Nayagaon	4.80
2.	Supla	2.40
3.	Bedu	0.40
4.	Gundrai Kalan	0.12
5.	Berheta	0.10
6.	Survari	0.60
7.	Bochhar	2.40
8.	Mekh	3.00
9.	Musran Piparia	0.24
10.	Pachauri (Nadiya)	2.40
11.	Chandankhera	0.20
12.	Richha	0.20

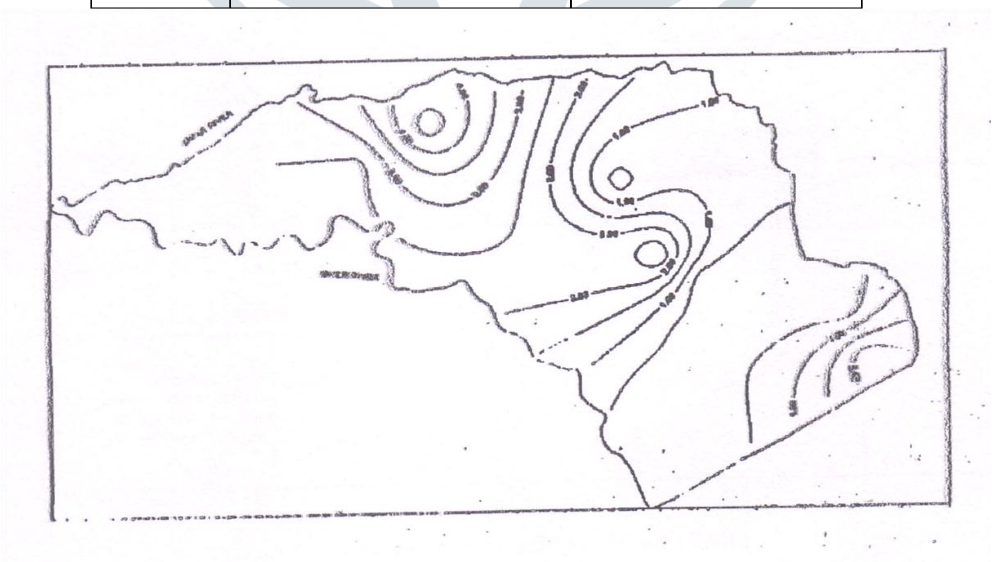

Figure 6 Infiltration Map of the Sher-Umar Doab

V. Conclusions

The top soils of Sher-Umar doab area are mostly dark colored and are clayey in texture. These soils normally form a layer of about 1-2 meter thickness. At few places, underlying coarse calcareous yellow coloured soil are also exposed. Black clayey soils have been derived from Deccan Trap rocks, which are abundant in the nearby areas. Both the black clayey soils and yellow calcareous soils have low infiltration rate, ranging from 0.1 cm/hr to 4.8 cm/hr. In the initial period of water application the infiltration rate is very high which reduces very rapidly with time.

Initial high infiltration rate may be because of the presence of cracks in the soils. As the time of water application increases, the infiltration rate reduces very quickly, may be. Due to the presence of swelling clays. The soils derived from basic rocks (like Deccan Trap) generally contain clay minerals montmorilonite. These clay minerals have the property of expanding in the presence of moisture. This expansion of minerals causes the reduction in pore space as well as the connectivity of pores and hence reduces the infiltration rate. The light coloured soils are rich in CaCo3, as is evident from the presence of kankers in this layer of soils. The low rate infiltration rate may be due to cementation of mineral particles by the calcareous material present.

Till now, limited water is available for irrigation in the form of groundwater. There is no source of surface water except rainwater. Therefore, agriculture in the area is mainly rainfed. In the irrigated field, water is applied through sprinklers, from the water derived from ground water source. Ground water in the area is present mainly in confined conditions and very few dug wells are present.

During rainy season, in the areas having some slope, excess water runs away through small rivulets, but in flat areas or small/shallow depressions the water stands for long periods as the infiltration capacity of the soils is low. This renders the land waterlogged and thereby unusable for quit some time. Only way of removal of this water is through evaporation.

Based on the infiltration tests carried out in the Sher-Umar doab, following conclusions can be derived:

- The soils present in the Sher-Umar doab are mainly black clayey soil (black cotton soils) with very low infiltration capacity ranging from 0.1cm/hr to 4.8cm/hr.
- The soils are not suitable for flooding method of irrigation. If this practice of irrigation is used (after the completion of the Bargi Left Bank Canal), then proper drainage should be provided.
- Excess irrigation with canal water may lead to waterlogging and salinisation.

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