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SPATIAL VARIATION OF SOIL AND HYDROLOGICAL CHARACTERISTICS OF SELECTED WATERSHEDS IN HARD ROCK REGION

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Preface

One of the major problems in hydrological modelling is accounting for spatial and temporal heterogeneity of soil hydraulic properties. Since the 1970s, there has been an upsurge in studies connected with the spatial heterogeneity of hydraulic properties connected with agricultural and forest lands. In contrast, temporal variability of soil hydraulic properties such as infiltration parameters have received only limited attention under field conditions In catchment hydrology, the spatial and temporal variations in rainfall intensity and the properties of the soil make simple application of soil physics difficult. With respect to temporal variation in rainfall intensity it is reported that prediction of time of occurrence can be made from an estimate of the infiltrated volume. The spatial variation of infiltration parameters determines the patterns of surface and subsurface flow. Ponding begins from preferred locations with a low values of infiltration parameters due either to intrinsic soil properties or to high moisture contents resulting from subsurface flow.

It is believed that detailed prediction of infiltration in catchment hydrology will depend on the prediction of time and space locations of occurrence of ponding and hence the location and magnitude of overland flow and interflow source areas. The algorithms which incorporate these predictions will be based on soil physical principles and use information from detailed field observations. Therefore, the present study is taken up to understand the spatial variability of soil hydrological properties under varied land use conditions and also to characterize the watershed based on the above parameters determined from field investigations which will be useful in unsaturated flow modelling.

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1.0 Introduction

Knowledge of the infiltration process and in turn, the storm runoff generation process, requires a physical understanding of soil water behaviour. In the context of hydrological modelling, the application of classical theory of soil water movement with confidence is fraught with difficulties. For example, the collection of accurate soil hydraulic property data at different length scales (Dagan, 1986) requires a very careful assessment of the limitations of available methodologies. The choice of methodologies (theoretical and measurement) for application in field studies also depends on the scale of the problem and the questions being addressed. In addition, the classical soil water theory has been mostly developed at the scale of laboratory column under controlled conditions. In the continuum approach to soil water movement, as embodied in Darcy's Law and Richards equation, in which the macroscopic soil-water movement is considered and not the microscopic flow pattern in the complex pore network. Under field conditions, soil hydraulic properties exhibit heterogeneity, both in time and space, from natural and man-induced disturbances. This produces non-uniformity of soil water flow which violates the stable flow conditions assumed by the classical Richards flow theory. Swelling and shrinking of soils induce the formation of fissures within the soil matrix. Also, large channels are created by roots and soil fauna activity (Beven and Germann, 1982). Both these situations may lead to preferential flow through the non-capillary macropores which are not amenable to one-dimensionless flow models. Instability of flow also occurs where there are abrupt changes in hydraulic conductivity with depth; commonly resulting from either surface compaction or layering of superficial deposits. Water repellency of the solid phase (Wallis et al., 1991) and compression of air ahead of an wetting front during infiltration (Raats, 1973; Philip, 1975; Colis-George and Bond, 1981) also causes unstable flow. In areas where the compressed air cannot escape, such as flat lands, further entry of water into pores is impeded and therefore this mechanism becomes an overriding control over infiltration. Under these circumstances, water entry is greatly reduced or ceases (Youngs, 1988).

The preceding conditions of heterogeneity lead to unstable infiltration flows in the field which can be explained by the theory of viscous fingering (Philip, 1975; White, 1988). For example, a surface crusted soil underlain by preferential flow paths means that not all the soil will be wetted uniformly and `fingers' of infiltrated water may occur below the crust.

Movement of water by way of infiltration under unsaturated conditions is dependent on two basic soil hydrological properties viz. K(θ) and D(θ). Beginning with research efforts made by Richards (1931) and his several associates (e.g. Richards et al 1943; Richards and Gardner, (1936); Ogata and Richards, 1957 and Richards et al, 1956) and latter on unsaturated water movement studies have been continued by Philip (1957), Bruce and Klute (1956), Gardner (1956, 1962), Davidson et al (1963), Jackson et al (1965), Nielsen and Biggar (1961), Green and Corey (1971), Van Bavel et al (1968), Nielsen et al (1973), Vachud et al (1982) among many others attempting to devise and test laboratory and field methods for determining and/or predicting K(θ) and D(θ). In recent years number of investigations have been carried out to understand the spatial variability of hydrological properties. However, such studies, in India are very limited particularly in hard rock areas which constitutes about 65% of our country. Even with the available literature, it is noted that, systematic studies on a catchment/watershed scale had lot of limitations due to various constraints in carrying out field experiments and therefore, the results cannot be generalized on large scale to provide appropriate answers for various questions. In the field, however, and catchment hydrology deals essentially with field situations, the process description is complicated both by highly variable conditions of water supply to the infiltrating surface and by soil characteristics that vary in both time and space. This variation is difficult to reproduce faithfully, either in the laboratory or in computer models. In addition, the initial and boundary conditions necessary to use the models predictively are often difficult to define the soil water movement in an unsaturated zone.

1.1 Theory of Soil Water Movement

Owing to the slow movement of water through the soil matrix, the kinetic energy of soil water is negligible small as compared to the various forms of (hydraulic) potential energies (viz., pressure, gravitational, osmotic etc.) to which the water is subjected. The potential energy concept was introduced by Buckingham (1907) and its dependence on soil water content (or vice versa) was worked out by Gardner (1920). The various forms of hydraulic potential energies are associated with external and internal force fields/forces viz., gravitational, cohesive, adhesive etc. Under normal conditions, water moves through the soil under the combined influence of matric, pressure and gravitational potential gradients. The hydraulic potential, ϕ, the term applied to this combined influence, is related to the hydraulic potential head, H, such that

$$H\ (\mathrm{cm}) = \phi / \rho g = (\rho\, g\, h \pm \rho g z) / \rho g = h \pm z \ \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

A theoretical differential equation for unsaturated flow is obtsined by combining Darcy's equation with the continuity equation. This equation is referred to as the diffusion equation or Richard's equation (Swartzendruber, 1969). The equation is expressed as;

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial}\left(D(\theta)\frac{\partial\theta}{\partial z} \right) - \frac{\partial K(\theta)}{\partial z} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where D(θ), the soil water diffusivity, is defined as K (θ). The difficulty with solving the equation is the nonlinear relationship between hydraulic conductivity, pressure head, and soil water content.

Several solutions of the equation can be developed based on the boundary conditions for the system being evaluated. For a saturated soil, K(θ) reaches a constant and the pressure head becomes positive.

In recent years many researchers have examined solutions of Richard's equation. Most of these solutions are only defined for a particular aspect of the infiltration process or are approximate solutions obtained by using finite difference or finite element methods.

1.2 Spatial and Temporal Heterogeneity of Soil Hydraulic Properties

The hydrological functioning of the watershed is influenced by the type of vegetation, its extent and management. Forests may occupy smaller or greater fraction of watersheds. The upland watersheds have relatively more area under forests which have influence the hydrological behaviour of watersheds.

The systematic studies carried out in India to study the effect of land use pattern on the hydrological behaviour of a catchment are largely confined to small watersheds. It has been observed by many investigators abroad that the size of the catchment is one of the most important aspects for consideration while evaluating the effect of land use cover and the management practices on the hydrologic response of a catchment. In small watersheds, the contribution to water yield (runoff) is mainly from overland flow which, in turn, is largely influenced by the land use cover. In case of medium and large watersheds total runoff (i.e. stream flow) is however, dependent upon subsurface flow (base flow) also in addition to overland flow and it is influenced by the channel system. In forested catchments effect of watershed size may be more important a factor to be considered because increased forest cover is associated with more and deeper roots which help in longer and deeper percolation as evidenced by the result of lower surface runoff (i.e. overland flow) and less water available for flow in smaller stream. The portion of water which is induced to go into deeper profile on the smaller watersheds (within the medium and large watersheds), as subsurface flow. To sum up, it could be mentioned that in the small catchments forests decrease to a great extent the overland flow and the runoff while in medium and large catchments the total runoff (i.e. annual water yield) may however be increased due to forests because of dry weather flow.

One of the major problems in hydrological modelling is accounting for spatial and temporal heterogeneity of soil hydraulic properties. Since the 1970s, there has been an upsurge in studies connected with the spatial heterogeneity of hydraulic properties connected with agricultural and forest lands (e.g. Rogowski, 1972; Nielsen et al., 1973; Baker, 1978; Sharma et al., 1980; Talsma and Hallam, 1980; Bonell et al., 1987). In contrast, temporal variability of soil hydraulic properties such as infiltration parameters have received only limited attention under field conditions (e.g. Tricker, 1981; Gish and Starr, 1983; Smetten, 1987; Whitle and Perroux, 1989), although the general nature of the problem is well known (Skaggs and Khaleel, 1982; ASAE, 1983).

Disruptions to the soil fabric by such factors as biological activity, various managment practices and intense rainfall compacting the surface (producing crusts over bare soil), combined with the change in hydraulic status influence temporal heterogeneity of hydraulic properties at a point (Mc Intyre, 1958a, b: Beven and Germann, 1982; Skaggs and Khallel, 1982; Tarchitzky et al., 1984). Bonell and Williams (1986a) monitored changes in the "S" (sorptivity) and "A" (transmission) parameters related to the Philip infiltration equation (Philip, 1957a, b; 1969) over three wet seasons in a tropical, semi-arid environment of Queensland, Australia. They showed stastically that temporal heterogeneity in these parameters is atleast significant as spatial variability. Temporal variability a sampling point was attributed to biological activities (both fauna and flora), raindrop impact and the subsequent desiccation and cracking of thin (1 mm) surface crusts between storms. This highlights the problem of using measurements as representative estimates of soil hydraulic parameters as inputs to infiltration models.

Whilst the work of Bonell and Williams (1986a) was undertaken in a tropical semi-arid environment, such conclusions should also be relevant to areas within the humid tropics where bare soil is exposed. The exceedingly high surface permeabilities associated with tropical rain forests (Nortcliff and Thornes, 1981; Bonell et al., 1983b), however, indicates that any temporal heterogeneity should have little impact on the infiltration and drainage process unless disturbed by management practices.

For a comprehensive description of hydraulic properties, knowledge, therefore, is of both their temporal and spatial variability required, especially in agricultural and degraded areas. It also comments apply to the hydraulic properties of subsoil's with high clay content when there are drastic changes in structure resulting from swelling and shrinkage.

Various techniques have been developed to address the problem of characterizing heterogeneity over space. One approach is to apply scaling theory that is based on the similar media concept (Miller and Miller, 1956). It assumes that internal geometry of soil differs only by the characteristic size. Such material is assumed to have identical porosities, and the same relative particle and pore size distributions. Scaling theory is concerned with microscopic dimension, viz. particle, pore or aggregate size or some average of one of these parameters for a particular soil sample. If λ is the microscopic dimension and λ_M be some reference value, such as the microscopic dimension characterizing a reference soil, then a dimensionless scaling factor a is defined as

$$a = \lambda / \lambda_M \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Now, the objective is to express spatial variability in terms of a single, physically-based parameter. The scaling factor can also be used as a single parameter to approximate the $\theta(h)$, and infiltration curve of a soil from these characteristics of the reference soil. Various ways of using the scaling factor a are adopted e.g. $1/a$, a^2, a, $1/a^3$,depending on the soil hydraulic variable or time variable considered. Peck et al. (1977).

Initially, scaling theory was applied to soils, notably clean sands, under controlled laboratory conditions (Peck et al., 1977). Application and testing of such theory to field soils commenced in the late 1970s by several workers, with reasonable success (Warrick et al., 1977; Peck et al., 1977; Sharma and Luxmoore, 1979; Sharma et al, 1980). On the basis of "S" and "A" parameters of the Philip infiltration equation, Sharma et al., (1980) evaluated scaling factors by different methods and produced scaled, cumulative infiltration versus time, I(t), curve for an entire drainage basin. Field soils, however, do not fully satisfy all the conditions required by similar-media theory with respect to porosity, due to the consequences of shrinkage, swelling and preferential flow. Sharma et al, (1980) highlighted this problem in the context of scaling the sorptivity, "S"($lr^{-1/2}$), and transmission, "A"(lr^{-1}), parameters of the Philip infiltration equation. In addition, Warrick et al, (1977) noted that the scaling factors calculated from ψ(theta) were not the same as those calculated to scale $K(\theta)$ data referring to the same set of soils. Furthermore, scaling factors calculated form (θ) were more effective, in scaling the $K(\theta)$ data, than vice versa. Therefore, soil water properties based on scaling theory are only an approximation.

Nevertheless, they provide a framework for studying the effects of soil heterogeneity on the hydrological response of land surfaces.

The difficulty of transferring scale factors from one set of hydraulic properties to another in field soils prompted Youngs and Price (1981) to provide an alternative method for scaling soil water behaviour without the restrictions of similar geometry. Miller (1980) pointed out that scaling of macroscopic flow equations requires a macroscopic, as well as microscopic length. White (1988) noted that an inherent soils based scaling length, which could fulfill both macroscopic capillary (or sorptive) length, λ(L) introduced by Philip(1985). Philip's work was based on the quasi-linear analysis of steady unsaturated soil water flow, represented

$$K(\psi)= Ks\ e^{\alpha\psi}$$

$$\alpha > 0\ \psi < 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where α is called the "sortptive number" with dimensions α s -1 as the "sorptive length" and λ c = λ s -1 (White and Sully, 1987). The lambda c parameter is essentially a flow weighted mean soil-water potential and has a scaling length for both distance and soil water potential, and is not dependent on above equation (White et al., 1992). The relationship between λc and a characteristic microscopic, mean pore radius λm was provided by Philip(1987). White and Sully(1987) summarized relationship between λc and λm, and also showed that λc can be directly related to field measurable sorptivity and hydraulic conductivity using the disc permeameter (Perroux and White, 1988). The λ parameter was suggested as in situ measure of soil structure(White and Sully, 1987) which offers a hydraulic approach to study the impact of environmental and land-use changes. For example, with aid of the disk permeameter method, White and Perroux (1989) used λm to quantify changes in soil structure caused by intense drought breaking rains falling on a drought-exposed, unprotected soil surface. The results showed that the soil matrix remained essentially unchanged, but the larger pores had been infilled.

From the literature review as mentioned in the previous paragraphs indicated that the spatial variability of soil water content under field conditions are caused by a spatial heterogeneity of physical characteristics of soil layers, irregularities at the surface, artificial drainage structures and by heterogeneous root distributions. This spatial variability is difficult to include in the models. Therefore, it is essential to go for field investigations both on watershed scale and catchment scale. In the present study a preliminary attempt is made to address the spatial heterogeneity under various field conditions. The present investigations have been carried out with the following objectives

(i) To measure the hydrological soil properties such as infiltration, hydraulic conductivity, and soil physical properties.

(ii) Characterisation of the watershed based on hydrological and soil properties. Different types of watersheds within a catchment varying between 6 to 20 sq. km. have been selected, viz., Forested watershed, Urban watershed and Agricultural watershed. In addition to this, a representative basin has been selected for the study with a catchment area of 520 sq. km. The land use map of Malaparbha representative basin is prepared and investigations have been carried out in different land use covers of the drainage basin.

1.2.1 Infiltration

The phenomenon of infiltration deserves a special place in hydrologic study as the understanding of the same enables to estimate more effectively the amounts of runoff originated from precipitation and the results thereof can be applied more confidently to the design problems.

Infiltration is defined as the movement of water in to the soil through soil surface. The maximum rate at which water can enter the soil at a particular point under a given set of conditions is known as the infiltration capacity. This attribute of the soil, is expressed as a rate in inches or centimeters per hour, and is a function of surface soil conditions (e.g., occurrence of litter and surface horizon characteristics (texture and structure). It is further influenced by the rate at which the water is supplied to the soil and the antecedent soil moisture conditions. Stallings(1952) noted that as long as 1877 raindrops were observed to seal the soil surface and decrease infiltration by in-washing of fine particles.

The actual rate of infiltration may be equal to or less than the infiltration capacity. Generally, both infiltration capacity and infiltration are influenced by the rate at which water (precipitation, runoff, or snowmelt) supplied to the soil surface exceeds the infiltration capacity. They decline during a runoff event and tend to equilibrate after about an hour (Kane and Stein, 1983).

Research in India has shown that infiltration rate is markedly influenced by profile morphology (Gupta and Narain, 1971) and soil sodicity (Abrol and Acharya, 1975). Field infiltration rate has been shown to depend on initial water content also (Subramanyam and Kar, 1976). Joshi and Dass (1977) successfully applied Philip's theory to horizontal infiltration in the laboratory and demonstrated a decrease in infiltration rate as well as sorptivity with increase in bulk density and initial water content. Recent studies have been concentrated on infiltration in uniform and layered soils (Abaruah et al, 1985) with efforts to quantity influence of the management practices such as tillage on infiltration rate (Ambegankar et al., 1984 ; Jaggi et al., 1986; Bhagat and Acharya, 1988).

Hydrological processes involving soil-water interactions in the field, and particularly, the flow of water in the rooting zone of most crop plants, occur while the soil is in unsaturated condition. The ability of the soil to absorb, retain and transmit water gives rise to the notion of this zone behaving as a leaky reservoir. 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 groundwater storage (Lakshman, 1993). A fair description of the flow in the unsaturated zone is crucial for predictions of the movement of pollutants into groundwater aquifers. Input at the soil surface is in the form of precipitation or irrigation out of which a part is absorbed and the other runs off. The water that infiltrates into the soil is later partitioned between that amount which returns to the atmosphere by evapotranspiration and which seeps downward and recharges the saturated zone. Soil physicists, in the recent years have offered analytical solutions for describing water movement in the unsaturated zone and validated through several laboratory experiments. However, the natural conditions existing in the field soils are in no way comparable to the idealized and controlled laboratory conditions. Therefore, it is necessary to apply mathematical models to simulate the soil moisture profiles under field conditions.

Water in the rooted part of soil is quite mobile. Its distribution over time and depth is important because it determines the amount of water available to the crop. Water enters the soil as rain or irrigation water and also by capillary rise from the groundwater table. It leaves the soil by evaporation, drainage and is taken up by roots for their transpiration needs. Gravity and gradients in moisture suction cause water movement within the soil processes are the same for all layers, but the outcome is specific to each layer in view of varying parameter values.

1.2.2 Hydraulic Conductivity

When the soil is not saturated, soil moisture flows downward by gravity flow through interconnected pores that are filled with water. With increasing water content, more pores fill, and the rate of downward water movement increases. Darcy's law is valid for flow in the unsaturated zone, although the unsaturated hydraulic conductivity, $K(\theta)$, is not a constant. The unsaturated hydraulic conductivity is a function of the volumetric water content, θ. As θ increases, so does $K(\theta)$. The value of the moisture potential, ψ, is also a function of θ, often ranging over many orders of magnitude.

The moisture potential, ψ, is measured by a suction applied to a soil. The curve of ψ versus volumetric water content is a plot of the volumetric water content, starting with a saturated sample to which increased suction is gradually applied. A rather substantial problem occurs because of hyseteresis in the volumetric water content-moisture potential relationship. To use value of ψ, one must know the prioor moisture history of the sample.

Flow in the unsaturated zone is further complicated by the fact that both K and ψ may change as θ varies, and, by its very nature, unsaturated flow involves many changes in volumetric moisture content as waves of infiltrated water pass.

One important consideration in unsaturated flow is that at low volumetric water contents, the relations that hold true in saturated flow may be invalid. The best example is the fact that for coarse materials, such as sand and gravel, the pores are large and drain quickly. At lower volumetric moisture contents, there may be very few saturated pores. On the other hand, finer-grained soils may have most of the pores still saturated. Thus, at lower values of θ, the unsaturated hydraulic conductivity of a clay may be greater than that of a sand. A layer of sand in a fine-textured, unsaturated soil may retard downward movement of infiltrating water owing to its low unsaturated hydraulic conductivity.

1.2 .3 Soil Moisture Characteristics

The soil moisture characteristics, θ(h), is the functional relationship between volumetric water content, θ, of the soil and the corresponding pressure head, h. Early workers (e.g. Keen,1931; Baver, 1940) recognizing the importance of particle size and pore size distributions of soil in soil-water release and retention relationships, invested considerable efforts in developing suitable methods for their determination. Simultaneously, neutron meter and tensiometer are utilized for measures of θ and h respectively, at a given location in the field, to obtain in-situ θ(h). Sintered funnel water manometer and pressure-plate apparatus are used in the laboratory for this purpose. Nielsen et al., (1961) observed that θ (h) determined in the laboratory agreed well with such data obtained under field conditions. θ (h) can be determined by either absorption (wetting a dry soil) or desorption (drying a wet soil) methods but the results usually differ on account of a phenomenon known as hysteresis. Basic studies on this phenomenon have been done by several soil physicists (e.g. Topp, 1969). The magnitude of the hysteresis effect is likely to be greater in sand than clay.

Earliest work on θ (h) (the pF curves) has been reported in India by Subba Rao and Ramacharulu (1958) for surface soils belonging to several morphological groups. Later studies on profile water retention and release characteristics reported by a number of works (Khosla and Abrol, 1966; Ali et al., 1966; Talati et al., 1975), revealed the influence of textural constituents and the type of clay minerals on the nature of θ(h). Such work is still in progress (e.g. Gupta et al., 1983; Mohanty, 1985; Challa et al.,1987) with a view to discovering and confirm the simple and multiple regression relationships between soil water constants at specific values (e.g. field water capacity and wilting point) and the amount of silt plus clay, organic carbon, CEC and other such easily measurable properties for diverse soil groups.

The most popular empirical functional model of the whole range θ(h) is due to Brooks and Corey (1964);

$$\mathbf{Se = (\theta - \theta_r)/(\theta_s - \theta_r) = (h / h_b)^{\lambda}, h < h_b = 1 \quad h > h_b} \quad \ldots\ldots\ldots(5)$$

where θ_s is the saturated water content, θ_r is the residual water content, h_b is the air entry or bubbling pressure head, λ is the pore size distribution index. Further in modelling θ(h) was made through the works of Visser (1968), Laliberte (1969), Su and Brooks (1975) culminating in the closed form model proposed by van Genuchten (1980);

$$Se = [1+(\alpha \ h)^{n}]^{-m} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

where α , n and m are the empirical parameters.

The concern for developing analytical θ (h) models involving few key parameters such as in equation (3) was also extent in view of predicting K(θ), the unsaturated hydraulic conductivity function, which is often difficult to determine in practice in a closed form unlike the ones already available (e.g. Childs and Collis George, 1950; Millington and Quirk, 1961). In India, Gosh (1976) proposed a model for light textured soils.

$$h = h_b (\theta / \theta_s) \beta \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

where $\beta = 26.5 (Sd / St)^{1.786}$ where Sd and St are percentages respectively of sand and silt in the soil. A similar expression for theta (h)

$$\theta = \theta_s - b \log h \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

where b is an empirical constant, was developed and found to closely describe the entire theta (h) curve for various types of soils. From the above discussion, it is understood that soil water flow is, highly non-linear because both hydraulic conductivity and matric potential (or soil water pressure head) depend on soil water content.

2.0 Methodology

2.1 Measurement of Soil Hydraulic Properties

2.1.1 Water Content (Gravimetric method)

Measurements of water content are needed in hydrological studies for direct knowledge of the quantity of the available soil water for interpretation of physical and chemical measurements, and for determination of water retention and hydraulic conductivity curves. Soil water content can be expressed as a dimensionless mass or volume ratio. The gravimetric content is mass ratio.

$$\theta_m = M_w/M_s \qquad (9)$$

where, θ_m is gravimetric water content, M_w is water mass (mg) , and M_s is dry soil mass (mg) the volumetric water content is based on the volume ratio.

$$\theta = V_w/V \qquad (10)$$

where θ is volumetric water content, V_w is volume of water(cu. m) V is total soil volume. Gravimetric and Volumetric soil water content are related to each other as

$$\theta = r_s \, \theta_m \qquad (11)$$

where r_s is dry bulk density of the soil (mg/cu. m) soil water content can be measured by direct methods such as oven or microwave dry, or by indirect ones based on neutron thermalisation, gamma ray attenuation or electrical conductivity and capacitance.

2.1.2 Determination of Infiltration Characteristics

2.1.2.1 Double Ring Infiltrometers

Double ring infiltrometers are used for determining infiltration capacity curve in selected locations of the study area. Two rings made up of cast iron with a height of about 1 m and a diameter of 27.5 – 30 cm (inner ring) and 40—45 cm (outer ring). The inner ring is used for the measurement of infiltration depth and the outer ring is used as a buffer ring which will saturate the surrounding soil layer. Both the rings are inserted into the ground upto a depth 40 – 45 cm (fig 2). Initially the outer ring (the space between inner and outer ring)is filled with water till the soil layer gets saturated. Inner ring area is also filled with water and head should be maintained equal in both the rings. A float is attached to maintain head in both the rings. The depth infiltration may be measured by fixing scale to the rings. Initially the water infiltrates very fast and latter on it reaches the steady state. With time depth a graph can be drawn which will give the infiltration capacity of the soils.

2.1.2.2 Disc Permeameter

The disc permeameter has become a popular apparatus for measuring in situ the scptivity,S, and hydraulic conductivity, K, of the soil at some prescribed potential. Measurements of sorptivity, S, and hydraulic conductivity, K, are important for predicting how water will enter, redistribute within., and drain from soils. Methods that can rapidly and accurately measure S and K are valuable. The disc permeameter (Perroux and White 1988) is a relatively new method that has gained popularity because of its simplicity, the speed at which measurements can be made, and because it does not greatly disturb the soil surface being measured. (White and Sully 1987;) White and Perroux 1987 and 1989; Smettem and Clothier 1989; Ankeny et al 1991). Different methods have been devised for calculating S and K are compared using same set of data. These methods are all based on the approximate , but usefully accurate, solution of flow from a disc source found by Wooding (1968). This linearized solution uses a hydraulic conductivity (K) function of the exponential form (Gardner 1958):

$$K = Ks \exp (\psi / \lambda c \ ) \qquad (12)$$

where Ks is the saturated hydraulic conductivity (m s-1), λ c is the macroscopic capillary length scale (m) and ψ is the matric potential (m).

(i) Principles of Operation

When a source of water, such as a wet circular disc or shallow pond , is placed on the soil surface, the initial stages of flow into the soil are dominated by the soil's capillary properties. As time progresses, both the size or geometry of the water source and the force of gravity influence the water flow rate. For uniform soils a time is eventually reached where the flow rate from the source becomes steady. This steady state flow rate is governed by capillarity, gravity, the size of the disc and the pressure at which water is supplied to the soil surface.

In this technique we make use of both the initial and steady-state flow rates to separate the capillarity and gravity contributions to soil water flow. In addition, by selecting the water supply pressure we can dictate the sizes of pore sequences or fissures which participate in the flow process.

(ii) Hydraulic Conductivity

The method for determining soil hydraulic properties from disc permeameter measurements in the field is based on an analysis of the three-dimensional flow from a shallow circular pond or surface disc

For a pond or disc of radius r0 , on a homogeneous soil , Wooding showed that when water is supplied at a potential of ψ0 the steady state volumetric flow rate q is

$$q = \pi\ r02\ (K0 - Kn) + 4r\ 0\ \varphi \qquad (13)$$

The first term on the right essentially represents the contribution of gravity to the total flow from the surface disc and the second term contains the contribution due to capillarity. In the gravity term K0 is the hydraulic conductivity at the supply potential φ0, and Kn is the hydraulic conductivity at the initial soil water potential φn . For relatively dry materials Kn is much smaller than K0 and we can safely ignore its effect . The capillarity term contains the matric flux potential , which is related to the conductivity by φ = K0 λc

The macroscopic capillary length λc is related to the sorptivity, S0, and the hydraulic conductivity (White and Sully, 1987),

$$\lambda c = bSo2/\ (\theta o - \theta n) \qquad (14)$$

is the initial moisture content at θn is the moisture content at φn, θo is the moisture content at the supply potential, φ0, So is the sorptivity at φn with supply potential φ0 and `b' is a dimensionless constant whose value lies between 1/2 and π/4. For field soils a good mean value for b is 0.55. With simplification and, dividing by the area of the disc, we find the steady-state flow rate per unit area

$$q = K_0 + \frac{4bS_0^2}{\theta_s - \theta_r} \qquad (15)$$

Rearranging (15) to find the conductivity, we have

$$K_0 = q - \frac{4bS_0^2}{\theta_s - \theta_r} \qquad (16)$$

During the early stages of flow from the disc, capillarity domiantes flows irrespective of the disc. At short infiltration times the system behaves as if it were one-dimensional. In this case the cumulative infiltration is given by (Philip, 1969). where Q is the total volume of water infiltrated and t is time from the commencement of infiltration. Sorptivity, then is the Slope of the cumulative infiltration vs t1/2 plot.

To calculate the hydraulic conductivity from (4), the measurements required are the sorptivity, the steady state flow rate, the initial volumetric moisture content at the supply potential.

(iii)Guidelines for Disk Permeameter Operation

(a) **Warning**

Be sure the "O" rings are in place before assembling the disc.

(b) **Calibration**

Prior to use each reservoir must be calibrated. Remove the reservoir from the disc, turn it upside down, and secure it vertically in a stand on a balance. Add a volume of water and record the scale readings and the change in mass. Repeat several times over the length of the reservoir. Using an approximate water density of 1.00 g cm-3, calculate an average calibration of volume per scale distance for the entire length of the scale.

(c) **Initial Water Content and Bulk density**

The initial water content and the bulk density are needed to calculate to hydraulic conductivity . At least two measurements should be made for each infiltration measurement. Measurements are made on cores taken approximately 250 mm from the centre of the disc measurement surface. Use metal cylinders of diameter 50 mm and height 50 mm sharpened at one end. Drive the cylinder into the soil and carefully excavate it. Trim off the ends and place the core in an air-tight container for weighing and oven drying. Place the air-tight container in a plastic bag and seal it for transportation.

(1) Ponded Permeameter Measurements

(i) Setting the Potential

The potential for the ponded permeameter is adjusted by means of the height adjusting screws on the base of the disc. The potential at the soil surface is the distance from the bottom of the air entry tube to the soil surface .

(ii) Side tube volume

After a potential is chosen, the pond volume can be calculated by multiplying the distance from the bottom of the disc to the soil surface by the ring area. Calibrate the side tube by finding the volume of water per unit of height in the tube. Divide the pond volume by this number to obtain the height of water necessary in the side tube to fill the pond. Measure this height from the top of the disc plate and mark the side tube.

(iii) Site Preparation

The amount of site preparation depends on the surface and the potential used. These factors will determine the amount of clearance between the bottom of the permeameter and the surface. The usual supply potential for ponded infiltration is +10 mm.

1. Clear a thin band on the soil surface where the edge of the steel ring will be in contact with

   the soil. It may be necessary to remove stones or clip vegetation along the outside circumference of the ring . Remove from the centre of the ring any large stones that would interfere with the disc and clip the vegetation to a height below the level of the bottom of the disc.

2. Insert the ring about 4 mm into the soil surface by placing a cover plate over the ring until the cover plate contacts the spacer. Note that the depth of insertion must be constant as it affects the supply potential. Remove the cover plate and spacer and seal the ring on the outside with a bentonite or local clay paste.

3. Set the empty permeameter on the ring and check that the permeameter is as level as possible and that the supply potential is properly adjusted.

4. Remove the permeameter from the ring and place in a bucket of water. Fill the side tube to

   the required volume . Fill the reservoir tube with water being certain that the one-way valve has been wetted to insure an air-tight seal. Check to make certain that the water level in the supply reservoir does not fall. If it does, the stop-cock or one way valve is leaking.

(iv) Infiltration Measurements

Carefully place the permeameter on the ring. To begin the measurement, open the stopcock on the side of the tube. Start the stopwatch when the side tube empties. It is essential that the seal on the outside of the ring does not leak. Check for leaks periodically but especially at the outset.

With recording stopwatch, record times at constant predetermined scale increments on the reservoir tube, usually 5 or 10 mm. It is important to record as many accurate measurements as possible during the early stages of flow. The scale increment used depends on the soil and is best determined by experience. We find that 5 mm increments for the early time data is satisfactory for most soils except sands. For sands increments of 10 mm or more may be required. After the early stages, measurements can be recorded continuously or interrupted until flow approaches steady state before recording again. In the latter case, when approximately one-half the reservoir volume has been infiltrated into the soil, begin recording again. In the latter case, when approximately one-half the reservoir volume has been infiltrated into the soil, begin recording again. Continue recording until flow appears to be steady (i..e., the time taken for equal scale increment does not change). For the steady state flow we use a scale increment of 10 mm. At least 10 measurements should be taken to insure that an accurate value for steady state flow is obtained. In some soils several reservoir volumes are required before steady state flow is reached.

(v) Supply Surface Water Content

At the end of infiltration measurements, close the stopcock and remove the permeameter. Watch the water level in the ring closely and skim a soil sample off the surface (2-3 mm) with a spatula as soon as the free water disappears from the surface. Place the sample in an air-tight container for weighing. Seal the air-tight container in a plastic bag for transportation.

It is important to take the sample as close to the surface as possible, when the excess water has just disappeared from the surface. Sample taken too deep or too late will give incorrect, low values of soil moisture.

Unsaturated Permeameter

(i) Setting the Potential

The potential is set by altering the water level in the bubbling tower as shown in fig . The water potential at the membrane is Z2 - Z1. The value of Z2 is fixed for each disc so that the potential is varied by altering Z1, the height of the water above the bottom of the air-inlet tube.

A plastic syringe with a length of thin tubing attached is used to add or withdraw water from the bubbling tower. When checking the water level, make sure that the air-inlet tube is completely air filled by forcing air into the air-inlet tube until it is empty of water.

(ii) Testing the membrane seal

The unsaturated permeameters are not air-tight unless the disc is soaked in water for several hours prior to the measurements. Proper operation can be checked by setting the potential in the bubble tower, filling the reservoir and holding the disc level, placing absorbent material in contact with the disc. The bubbling tower should begin to bubble but no bubbles should form in the reservoir above the membrane. To test for air leakage, move the towel around the circumference of the disc.

(iii) Site Preparation

If the soil is not bare and flat (usually only sandy soils), then it will be necessary to prepare a cap of contact material . Clean an area about 100 mm larger in diameter than the disc by clipping any vegetation down as low as possible (< 3 mm) and removing any large stones from the surface. Place the 3 mm high ring on the surface and fill with a suitable contact material , such as fine sand. Tamp down the sand lightly and smooth the by drawing a steel rule across the top of the ring. Carefully remove the ring. Infiltration measurements should be made as soon as possible to prevent the contact material surface from drying. Fill the disc reservoir and make the following checks.

1. One-way valve should be wetted (stopcock does not leak)

2. Level of water in the bubbling tower should be set properly;

3. No air bubbles should be present in the disc section.

(iv) Infiltration measurement

The same scale increments are used for the unsaturated measurements as are used for the ponded measurements. When placing the disc directly on the soil surface, begin until the wetting front has moved through the cap. The time taken depends on the cap material, the thickness and the value of the water potential set by the bubbling tower. It is better to begin timing too early rather than too late.

Record times as often as possible during the early stages of infiltration. As with the ponded measurements, recording may be interrupted until the flow rate approaches steady state. When the reservoir is about half empty, begin recording again. Continue making measurements until the flow rate is constant. Ten or more measurements constant to within sampling error are required.

(v) Supply surface water content

At the completion of infiltration remove the disc and quickly scrape aside a portion of the contact material cap. Sample the top 2 – 3 mm of soil with a spatula. Place the sample in an air-tight container for weighing. The sample must be taken from lower than 5 mm below the soil surface.

(vi) Required Measurement Times

Both the duration of the sorptive phase and the time of approach to steady state depend on the soil. The duration of the sorptivity-dominated phase can range from 0.02 to 1 hour. The time required to approach steady-state flow ranges from 0.2 to 6 hrs.

(Figure of Disc permeameter set up is appended)

2.1.2.3 Guelph Permeameter Apparatus

The Guelph permeameter is essentially an `in hole' Mariotte bottle constructed of concentric transparent plastic tubes. The apparatus comprises the following sections:

Tripod Assembly
Support tubes and lower air tube fittings
Reservoir assembly

Well Head scale and upper air tube fittings
Auxialiary tools

The Guelph permeameter method (Reynold et al. 1985) measure the steady state liquid recharge Q, necessary to maintain a constant depth of liquid H in an uncased cylindrical well of radius 'a' finished above the water table. Constant head level in the well hole is established and maintained by regulating the level of the bottom of the air tube which is located in the centre of the permeameter . As the water level in the reservoir falls, a vacuum is created in the air space above water. When the permeameter is operating , an equilibrium is established.

When a constant well height of water is established in a scored hole in a soil, a bulb of saturated soil with specific dimension is rather quickly established. The bulb is very stable and its shape depends on the type of soil, the radius of the well and the head of water in the well. The shape of the bulb is numerically described by the C factor used in the calculations. Once the bulb shape is established , the outflow of water from the well reaches a steady state flow rate which can be measured. The rate of this constant outflow of water, together with the diameter of the well and height of water in the well can be used to determine the field saturated hydraulic conductivity of the soil.

The Richard analysis of steady state discharge from a cylindrical well in unsaturated soil, as measured by the Guelph permeameter technique accounts for all the forces that contribute to three dimensional flow of water into soils, the hydraulic push of water into soil, the gravitational pull of liquid out through bottom of the well and the capillary pull o water out of the well into the surrounding soil. The Richard analysis is the basis for the calculation of field saturated hydraulic conductivity. The C factor is a numerically derived shape factor which is dependent on the well radius 'a' and head 'H' of water in the well.

(i) Procedure for field use

Before making measurement with the Guelph permeameter in the field , it is necessary to perform a site and soil evaluation, prepare a well hole assemble the permeameter, fill the reservoir, and place permeameter in the well hole.

(ii) Well preparation

A borehole is drilled using soil and sizing auger. The soil auger is used to remove bulk amounts of soil and rock. The sizing auger is used as a finishing tool to produce a proper sized well hole of uniform geometry and to clean debris off the bottom of the well hole. The sizing auger is designed to produce a hole that is uniformly 6 cm in diameter with a flat bottom. Generally, the procedure is to use the soil auger to excavate the well hole last 15 cm can then be excavated using the sizing auger to produce a debris free well hole of uniform geometry.

In the moist soils or in medium to fine textured soils, the process of augering a hole may create a smear layer which can block the natural flow of water out of the well into the surrounding soil. In order to obtain reliable and representative results using the Guelph permeameter, the smear layer must be removed.

(iii) Permeameter Placement

Simply centre the Tripod over the well hole and slowly lower the permeameter so that the support tube enters into the well hole. The tripod is used to support the permeameter in well down to approximately 38 cm in depth. For use in wells deeper that 38 cm, the tripod bushing alone provides the functions of centring and stabilising the permeameter. After the permeameter is placed, it can be easily filled with water. The following standard procedure should be followed for making measurements.

(ii) Verify that both the reservoirs are connected . The reservoirs are connected when the notch on the reservoir valve is pointing up.

(iii) Established 5 cm well Head Height (H1). Slowly raise the air inlet tip to establish the 5 cm well head height. Raising the air tube too quickly can cause turbulence and erosion in the well.

(iv) Observe the rate of fall of the water level in the reservoir. If it is too slow, then turn the reservoir valve so that the notch is pointing down. Water will then be supplied, only from the small diameter inner reservoir which will result in a much greater drop in water level between readings.

(v) Measure permeameter outflow. This is indicated by the rate of fall of water in the reservoir. Readings shold be made at regular time intervals, usually 2 minute intervals are used. The difference of readings at consecutive interval divided by the time interval equals the rate of fall of water, R1 in the reservoir. Continue monitoring the rate of fall of water in the reservoir untill the rate of fall does not significantly change in three consecutive time intervals. This rate is called R1 and is defined as the "Steady state rate of fall" of water in the reservoir at height H1 which is the first well height established and is always 5 cm in the standardized procedure.

(vi) Establish 10 cm Well head height (H2). Slowly raise the air inlet tip to establish the second well head height of 10 cm. Monitor the rate of fall of water, R2, in the reservoir until a stable value of R2 is measure.

(vii) The field saturated hydraulic conductivity, Kfs can be calculated using the following equation:

$$Kfs=0.0041 .X. R2 - 0.005 .X. R1 \quad \text{-----------------------------}(17)$$

where,

X = Reservoir constant, equal to 35.39 when reservoir combination is used.

R2 = Steady, rate of fall of water in the reservoir when second head H2 equal to 10 cm of

water is established.

R1 = Steady rate of fall of water in the reservoir when the first head H1 equal to 5 cm of

water is established.

Kfs = Field saturated Hydraulic conductivity in cm/sec.

(Figure of Guelph permeameter setting is appended)

Strength and Weaknesses of the Various Instruments used for Field Determination of Hydrologic Properties

1. Disc Permeameter : It is advantageous to use the disc permeameter which disturbs the soil layer very minimum. It is possible to determine both saturated and unsaturated hydraulic conductivities by using the same instrument. In addition to, infiltration and hydraulic conductivity it is possible to calculate sorptivity and pore characteristics. The instrument is quite handy and time required is comparatively very less. Quite suitable in hard rock terrains. Estimates three dimensional flow.

2. However, there are disadvantageous in certain regions like black cotton soils with deep cracks. In some cases it makes overestimation of infiltration rates. Since the depth of penetration of ring is very less it is possible to flow water laterally which cannot be accounted in the calculation. It is very difficault to take initial readings which may mislead the sorptivity values. As the calculation depend on soil moisture, soil moisture estimation brings up errors in infiltration estimate. The value of `**b**' used in the calculation require modification for different types of soils.

3. Double ring infiltrometer is quite is useful in developing infiltration capacity curve. The lateral flow of water is restricted by using double ring, i.e, buffer ring outside. The most difficult part of this technique is that, it is difficult to transport from place to place. It requires large quantity of water and time consuming. It gives only the rate of infiltration (depth in cm)

4. Guelph permeameter estmates only hydraulic conductivity at a required depth. This is very useful in irrigation water requirement studies. One of the limitation of this instrument is that it cannot be used conveniently in clayey soils.

2.12.4 Pressure Plate Apparatus

This is a standard method for obtaining the soil moisture retention curve. Pressure plate apparatus consists of a pressure chamber in which a saturated soil sample is placed on a porous ceramic plate through which the soil solution passes but no soil particle or air can pass. The soil solution which passes through the membrane is in contact with atmospheric pressure. As soon as the air pressure inside the chambers are raised above the atmospheric it takes excess water from the soil out of the chamber through the membrane outlet. Soil water will flow out from the soil sample until the metric potential of the unsaturated flow is same as the applied air pressure.The air pressure is then released and the moisture content of the soil is gravimetrically determined.

During a run, soil moisture will flow from around from each of the soil particle and out through the ceramic plate until such time as the effective curvature of the water film through out the soil are the same as at the pores in the plates. When this occurs an equilibrium is reached and the flow of moisture ceases. When air pressure in the chamber is increased, flow of water from the samples starts again and continue until a new equilibrium is reached. A source of regulated gas pressure is required for all extraction work. Compressed air from a compressor is the most efficient source of supply.

The ceramic plates are available in different range. Each ceramic pressure plate cell consists of a porous ceramic plate, covered on one side by a thin neoprene diaphragm sealed to the edges of the ceramic plate. An internal screen between the plate and diaphragm provides a passage for flow of water. An outlet stem running through the plates connects this passage to an outflow tube fitting which to the atmosphere outside of the extractor. To use the ceramic pressure plate cell, one or more soil samples are placed on the porous ceramic surface held in place by retaining rings of appropriate height. The soil samples together with the porous ceramic plate are then saturated with water. This is usually done by allowing an excess of water to stand on the surface of the cell for several hours. When the saturation is complete, the cell can be mounted into the pressure vessel. Air pressure is used to effect extraction of moisture from the soil samples under controlled conditions. The 1 bar ceramic plates are ideal for the routine determination of the 1/10 bar and 1/3 bar range of the soil suction. The 3 bar pressure plate cells are used in the range of 0 - 3 bars. The 15 bar ceramic cells are commonly used for measurement of soil moisture suction in the range of 5 - 15 bars of soil suction.

The moisture retention curve of a soil sample can generally be determined by equilibrating a soil sample at a succession is known tension value and each time determining the amount of moisture. The graph is plotted between the tension and corresponding soil moisture value to obtain the soil moisture retention curve. Different types of soil yields different retention curves.

3.0 Watershed Characteristics and Soil hydrologic Properties

3.1 Forested Watershed (Barchi)

The escalating intrusion into forest because of increasing socio-economic pressures(Pereira, 1991), combined with dichotomy of scientific beliefs arising from the hydrological impacts of forest conversion, provides a clear need for an increased number of controlled experiments in the various sectors of forestry. The impact of forestry operations, such as logging and reforestation, on water supply has been the subject of many field investigations Relationships determined from these studies form the basis of number of sophisticated, physically based mathematical models designed to predict how forestry operations will affect streamflow over the long term. Other effects, however, such as the influence of logging on soil water accumulation and redistribution have so far received little attention from the hydrologist. Removing the forest cover can result in increased soil water content and, in poorly drained areas, near surface water tables. Both conditions have important implications for forest regeneration, particularly during melt season and after heavy rains during the growing season.

This alarming rate of forest degradation causes loss of soil nutrients, compaction of soil, removal of top soil and organic matter, subsequent soil erosion leading to exposure of parent rock, lowering of water retentive capacity of soil, change of micro climate and increase of fire hazards etc. All these factors, directly or indirectly influence the soil vegetation and water relationship of a watershed. Many studies have been attempted to assess the influence of forest on various hydrological parameters and processes viz. Rainfall, interception, infiltration, soil moisture, evapotranspiration, groundwater, water yield, flood and soil loss etc. However, the reported results to this effect have been mainly confined to small experimental watersheds or runoff plots. Also as the watershed experiments are long term and expensive, not many studies have been done in the developing countries. In this study, Barchi watershed, an undisturbed forest in a humid tropical climate which is underline by basaltic rocks has been selected for the estimation of soil hydraulic properties.

3.1.1 Study Area

The Barchi river originates from Thavaragatti in Western Ghat at an altitude of about 734 m, and 20 km north of Dandeli in Uttara Kannada district of Karnataka State.. The watershed is relatively short in width and the river flows in a southerly direction and joins the Kali river near Dandeli. Th total watershed area is around 14.5 sq. km. The watershed lies between 75 ° 35' E and 75°40'E longitude and between 18 18 and 15 24 latitude (figure) High land region, forming part of the foot hills of western Ghat consist of steep hills and valleys intercepted with thick vegetation. The slopes of the ghats are covered with dense deciduous forest. Most of the trees looses their leaves during the latter part of the summer months. Barchi watershed has distinct seasons in the year such as winter, summer and monson. The principal soil found in the watershed are silty clay and red gravelly soil. The watershed receives the rainfall during the south-west monsoon period, the average rainfall being around 1500 mm. The average annual evaporation in the watershed is around 1300 mm.

Spatial variability of the soil water content at a given depth in the field is caused by spatial heterogeneity of physical characteristics of soil layers, irregularities at the surface, artificial drainage structure and by heterogeneous root distribution. This spatial variability is difficult to include in the models.

One of the predominant factors which can affect the movement of soil moisture in the unsaturated zone is the type of land use cover such as forest, grass, agriculture barren land etc. Different land use may have different effects on movement of the water through unsaturated zone. Forest soils are noted for the proliferation of macropores, especially in the surface layers, because of the high density of roots and soil fauna activity. Such macropores allow the vertical by-passing of the unsaturated matrix and allow preferential flow of water to reach the saturation zone more quickly than the soil matrix.

This watershed (Barchi) of Karnataka (India) can be categorized as microwatershed.

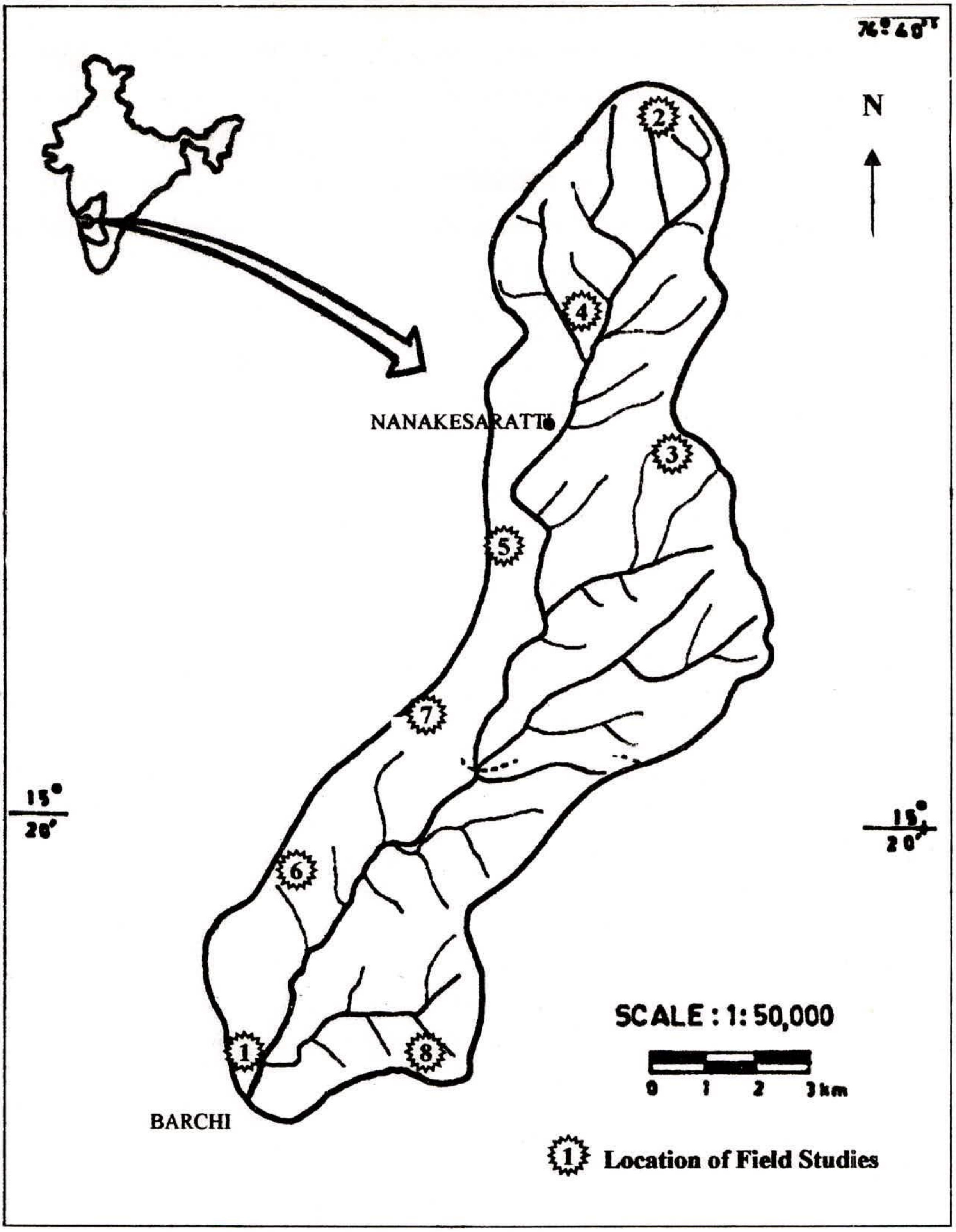


Figure 1. Barchi Watershed

3.1.2. Spatial Variation of soil hydrologic properties in Barchi watershed

Infiltration and Saturated Hydraulic Conductivity: Saturated hydraulic conductivity was measured at 8 locations in the study area by using disc permeameter and Guelph permeameter(locations are shown in fig.1). The infiltration rate observed for the study area varied between 2 mm.hr and 6 mm/hr The average saturated hydraulic conductivity values for the upper layer (0-45 cm) and lower layer (below 45 cm depth) were found to 0.34 cm/hr and 1.61E-4 cm/hr respectively.

Table 1 : Soil Hydrologic Properties of Barchi watershed

Station	Ks Cm/hr	θs	αv	η	Proportion of Variance (%)	Pressure in Bars							
						0.33	1.0	3	5	7	10	12	15
1	0.58	0.37	0.0073	1.434	80.78	0.24	0.22	0.19	0.16	0.13	0.11	0.10	0.08
2	0.57	0.37	0.0023	1.509	74.08	0.30	0.28	0.27	0.23	0.20	0.18	0.14	0.14
3	0.60	0.38	0.0021	1.465	79.07	0.33	0.25	0.25	0.22	0.20	0.16	0.12	0.09
4	0.18	0.53	0.0067	1.523	92.00	0.43	0.39	0.36	0.35	0.33	0.32	0.31	0.30
5	0.20	0.55	0.0129	1.373	80.66	0.41	0.38	0.36	0.35	0.34	0.32	0.30	0.28
6	0.18	0.53	0.0235	1.300	64.09	0.40	0.38	0.37	0.37	0.35	0.33	0.30	0.28
7	0.24	0.52	0.002	1.580	84.07	0.44	0.43	0.37	0.34	0.32	0.29	0.26	0.25
8	0.16	0.54	0.0019	1.552	91.51	0.51	0.44	0.39	0.38	0.38	0.36	0.33	0.30

The textural analysis of the soil samples showed that clays are the dominating constituents in all the soil samples (except at site 3) compared to sand silt content. Clay percentage varies between 28% and 53% (site 4). Silt percentage varied between 20% (site 4) and 33% (site 3). Percentage of sand varied between 20% (site 8) and 39% (site 3).Field capacity of the samples range from 29% to 44% and the wilting point varies between 16% and 30%. All soils showed a high antecedent moisture content (ranged between 49% and 54%). Deep percolation in black cotton soils is less due to very low infiltration as reported by the authors. Though the soil moisture content was appreciable this could be only due to the presence of high litter and organic matter content in the top layer. Soil moisture retention characteristics of the study area are presented in figures 2 to 9.

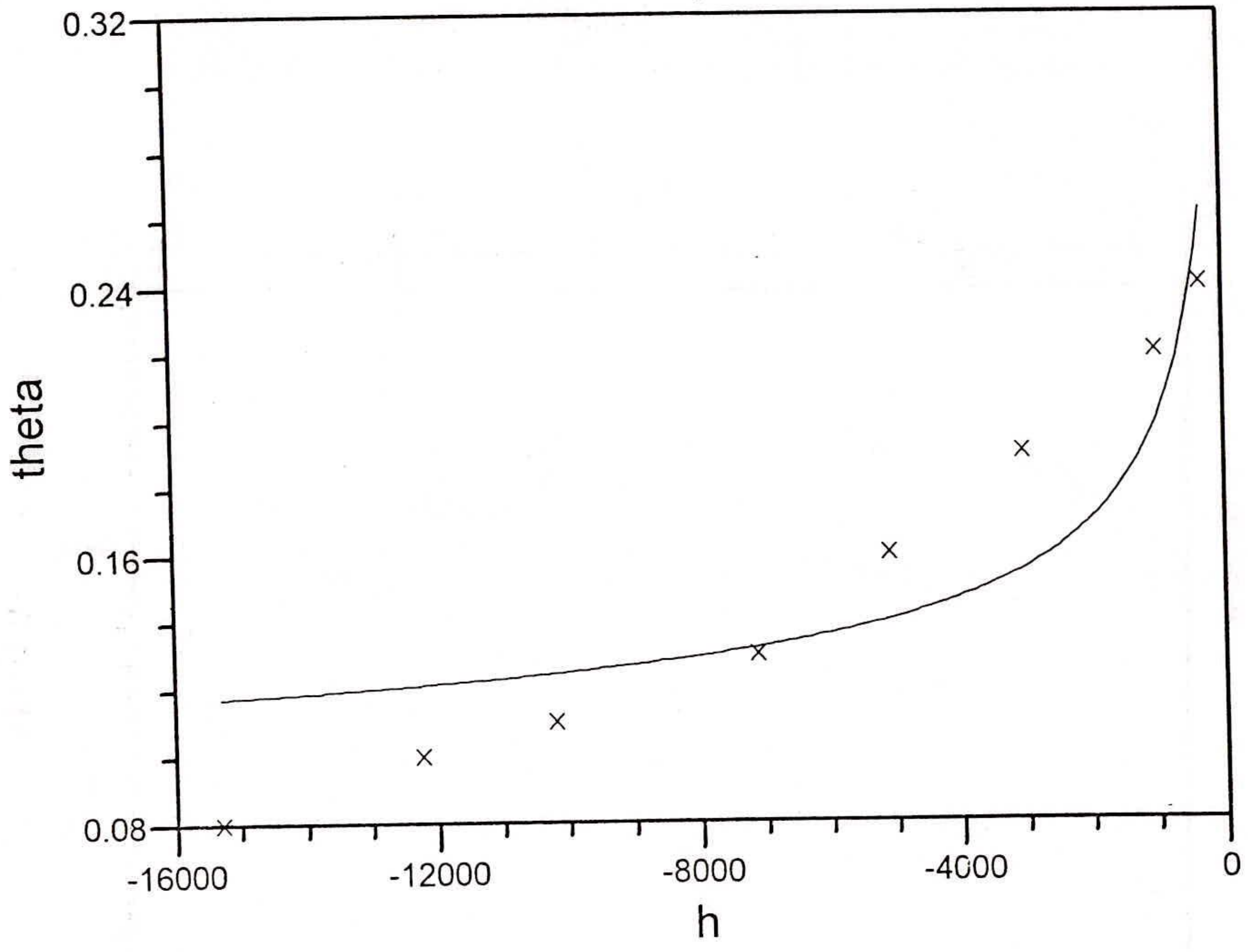


Figure. 2. Soil Moisture Retention Curve for Forested Watershed.
(Site 1.)

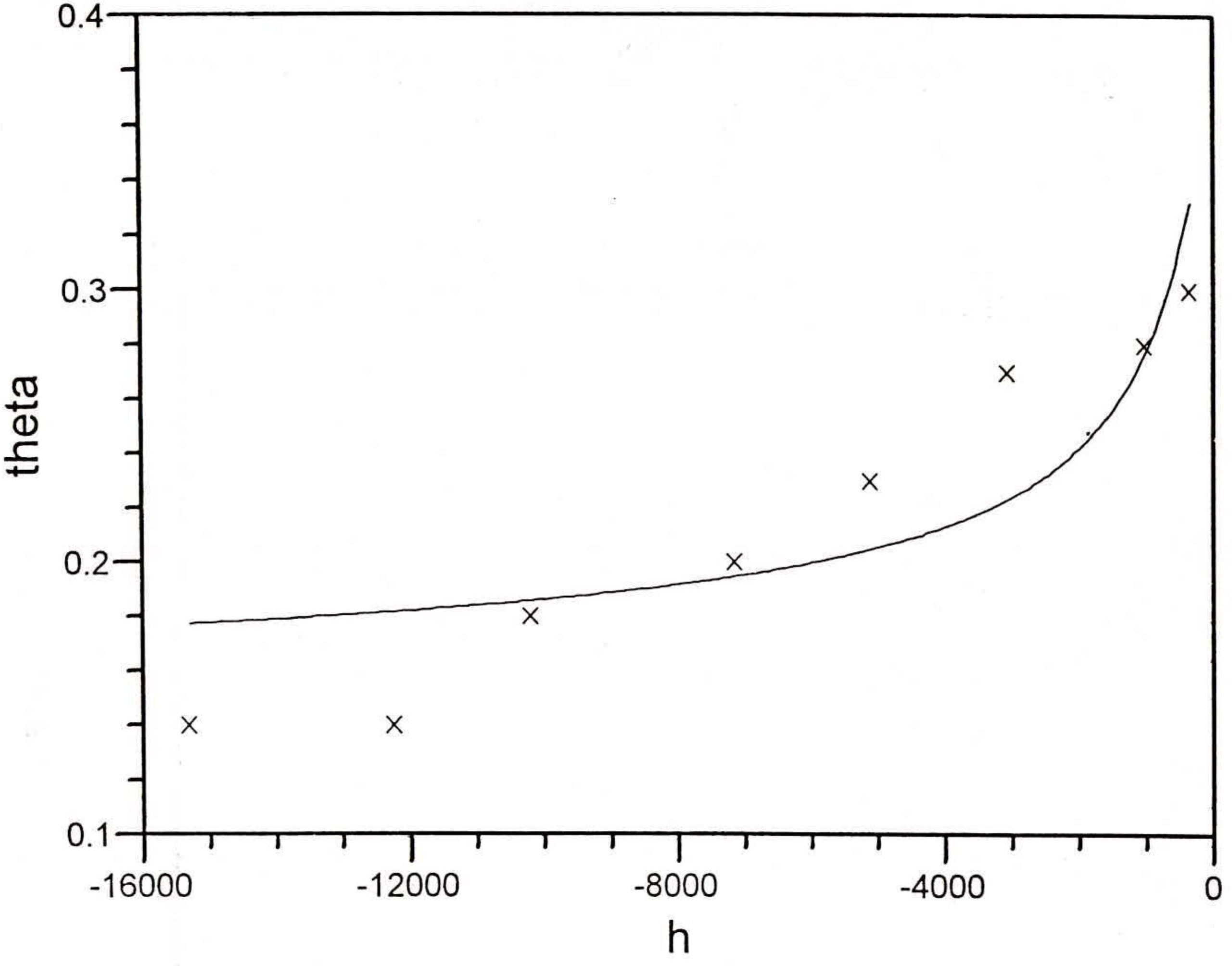


Figure. 3. Soil Moisture Retention Curve for Forested Watershed.
(Site 2.)

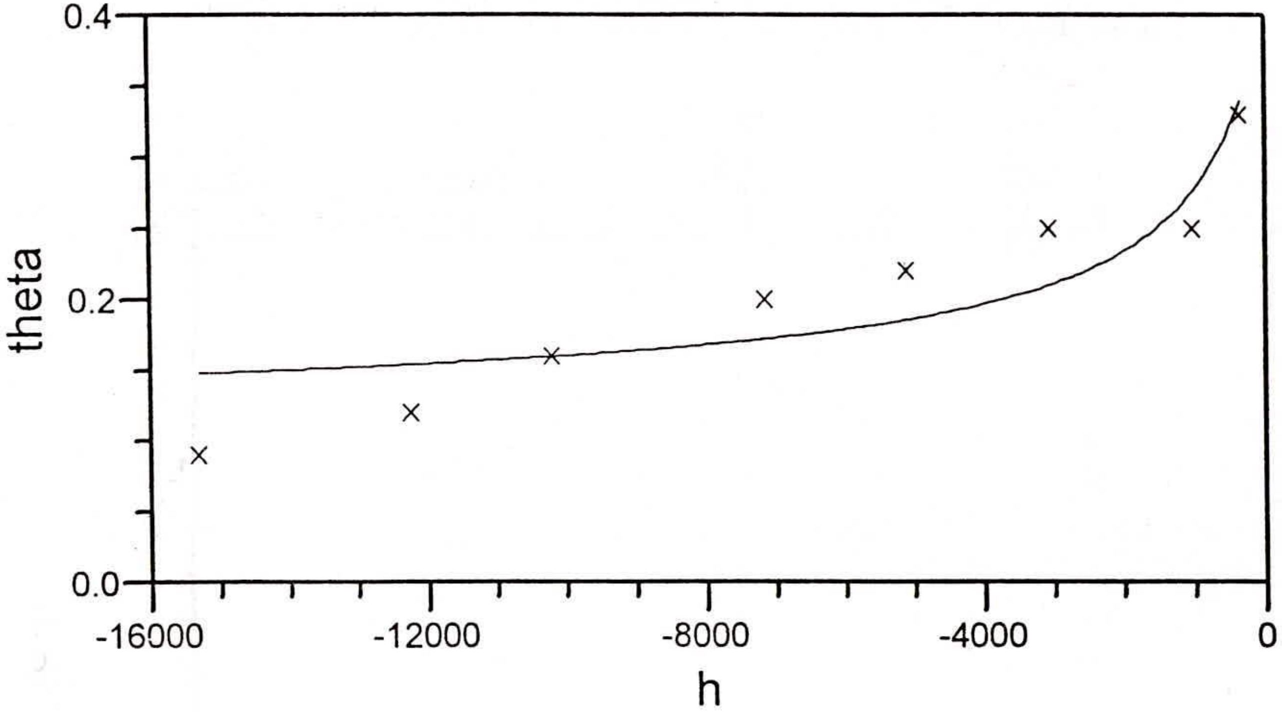


Figure. 4. Soil Moisture Retention Curve for Forested Watershed.
(Site 3.)

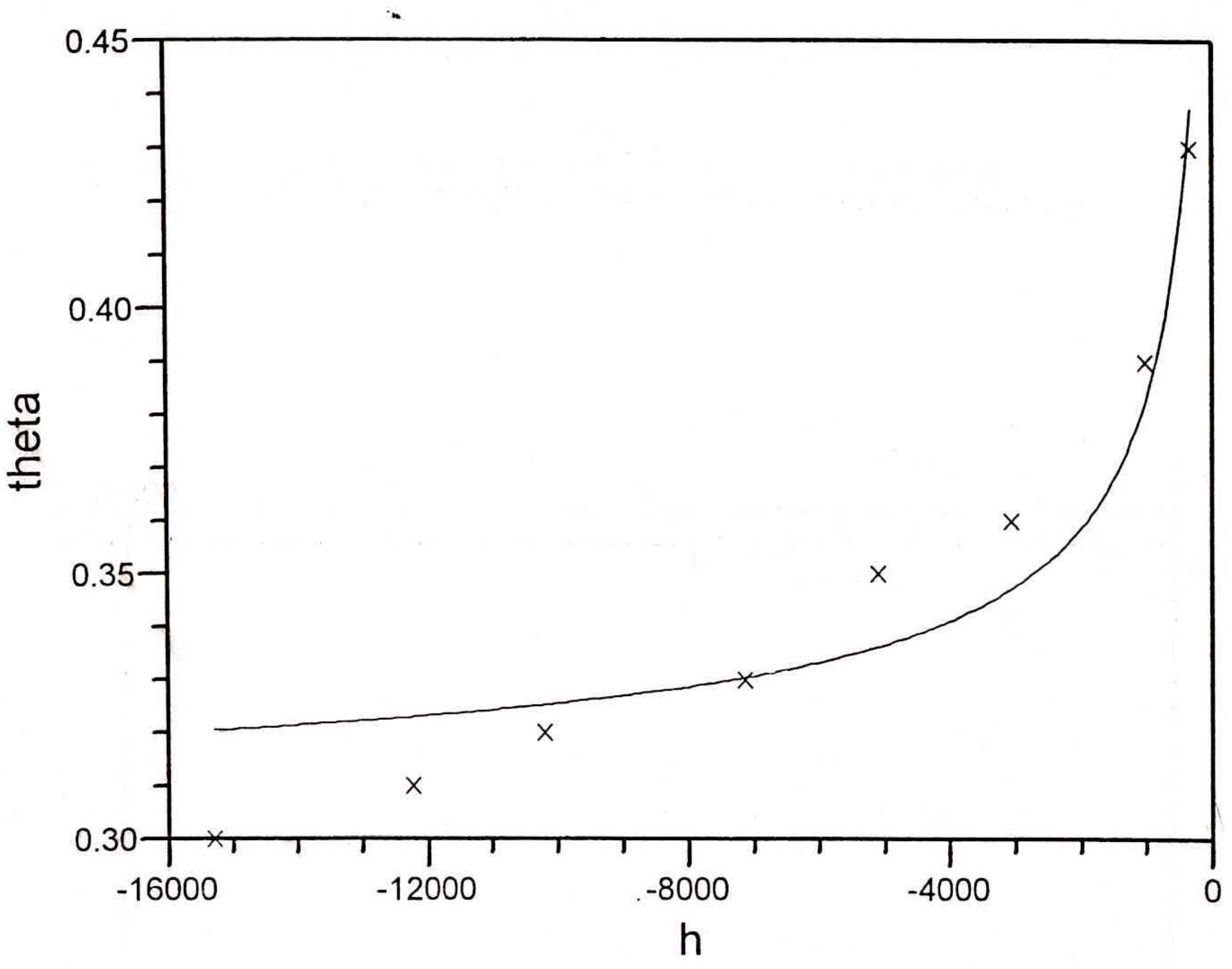


Figure. 5. Soil Moisture Retention Curve for Forested Watershed.
(Site 4.)

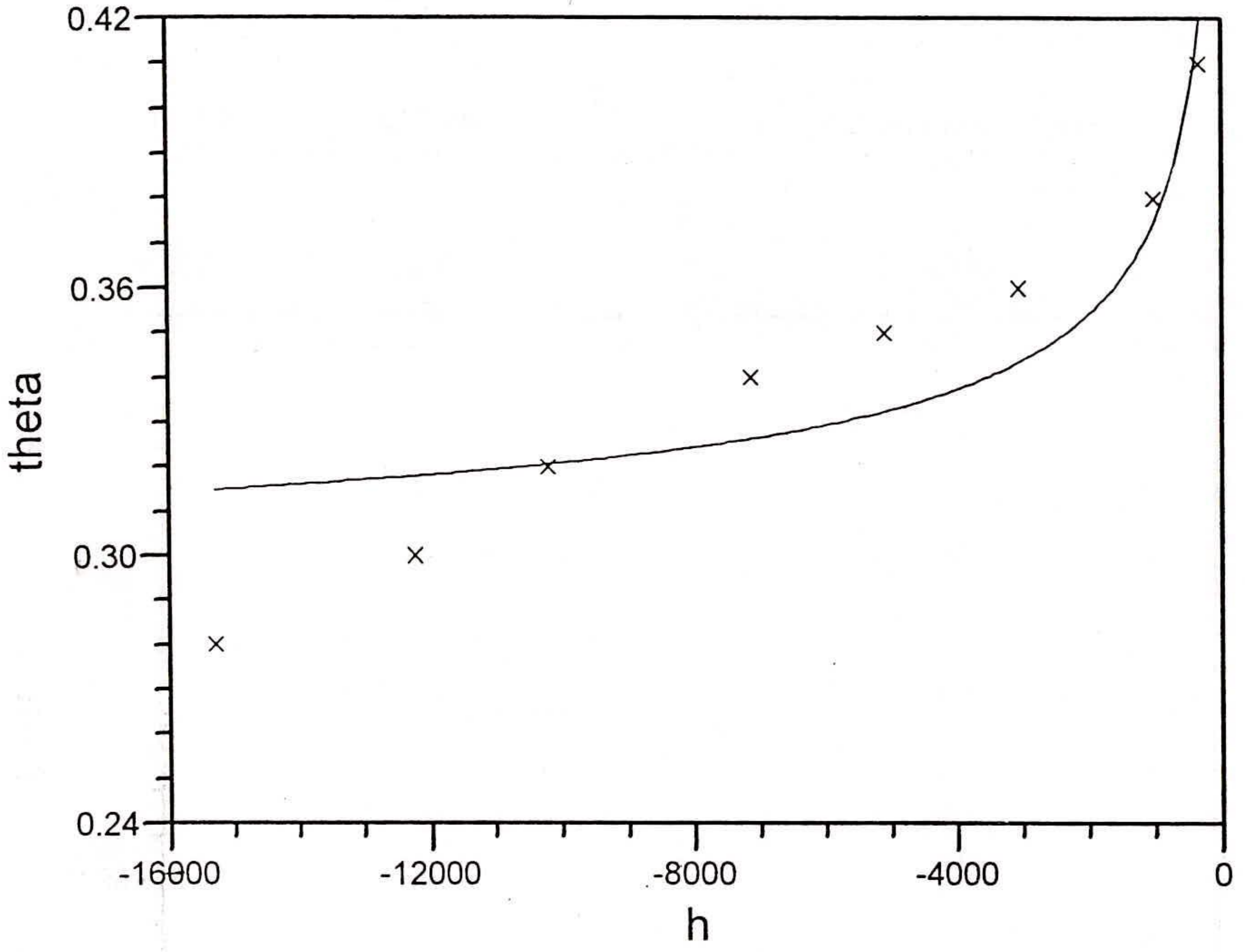


Figure. 6. Soil Moisture Retention Curve for Forested Watershed.
(Site 5.)

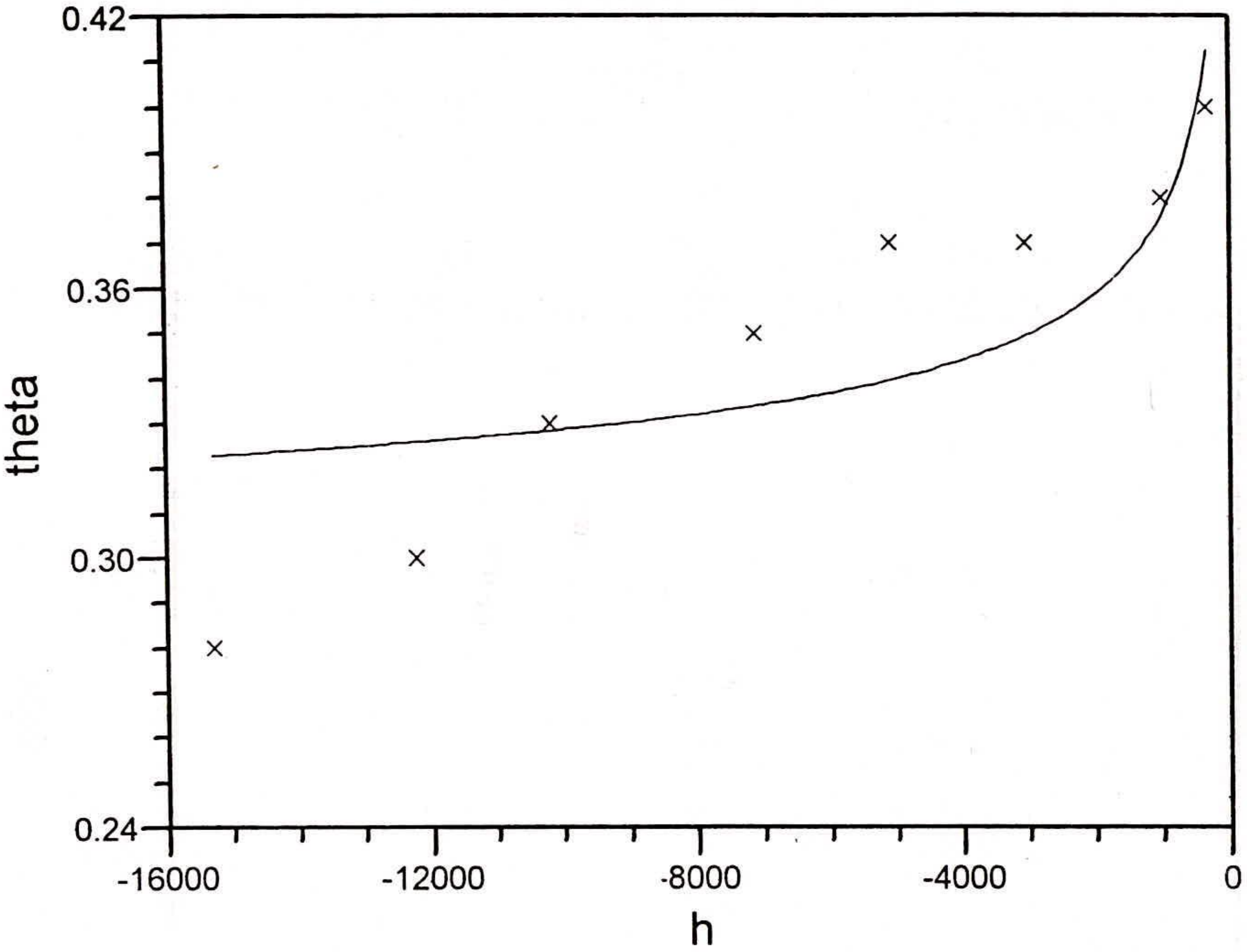


Figure. 7. Soil Moisture Retention Curve for Forested Watershed.
(Site 6.)

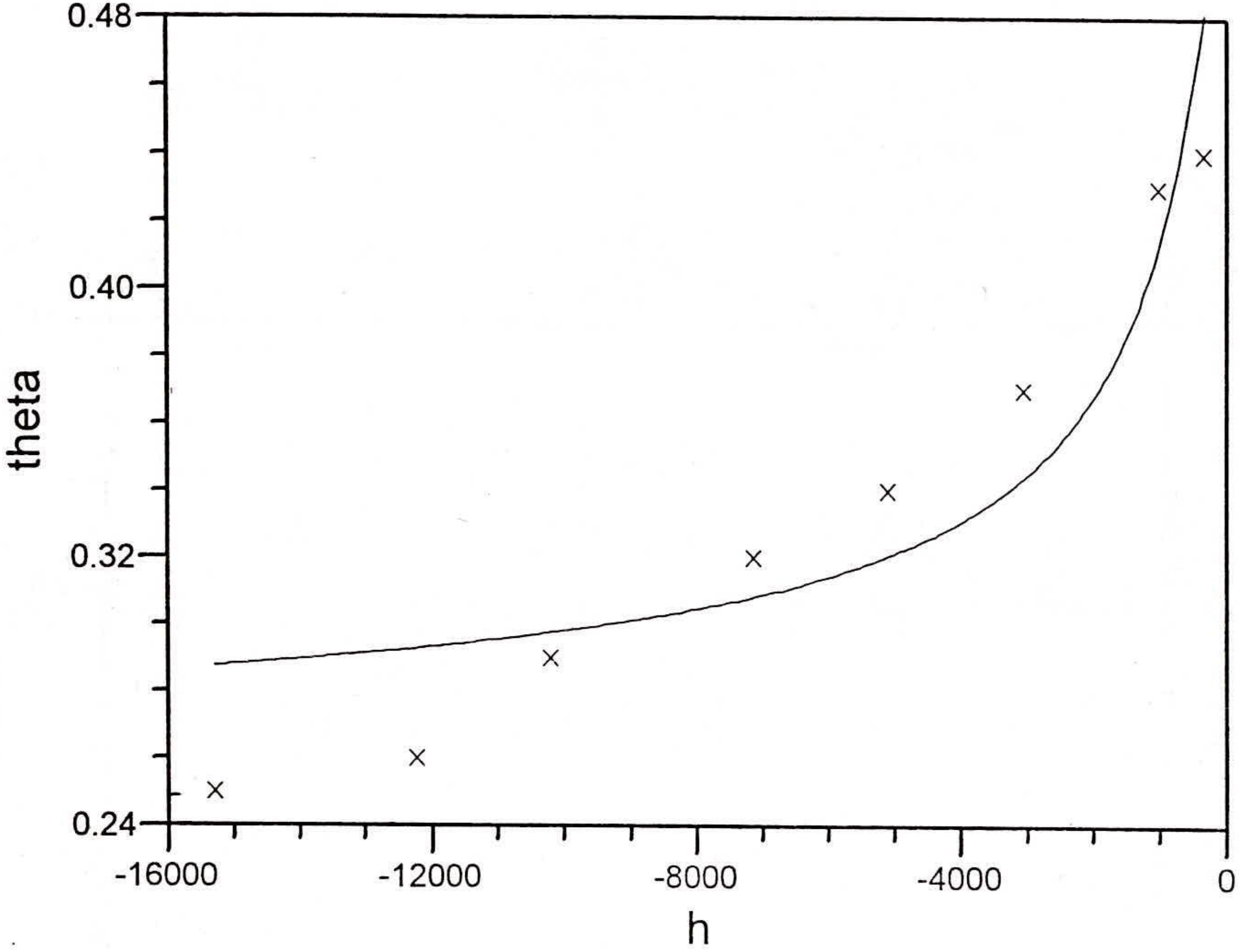


Figure. 8. Soil Moisture Retention Curve for Forested Watershed.
(Site 7.)

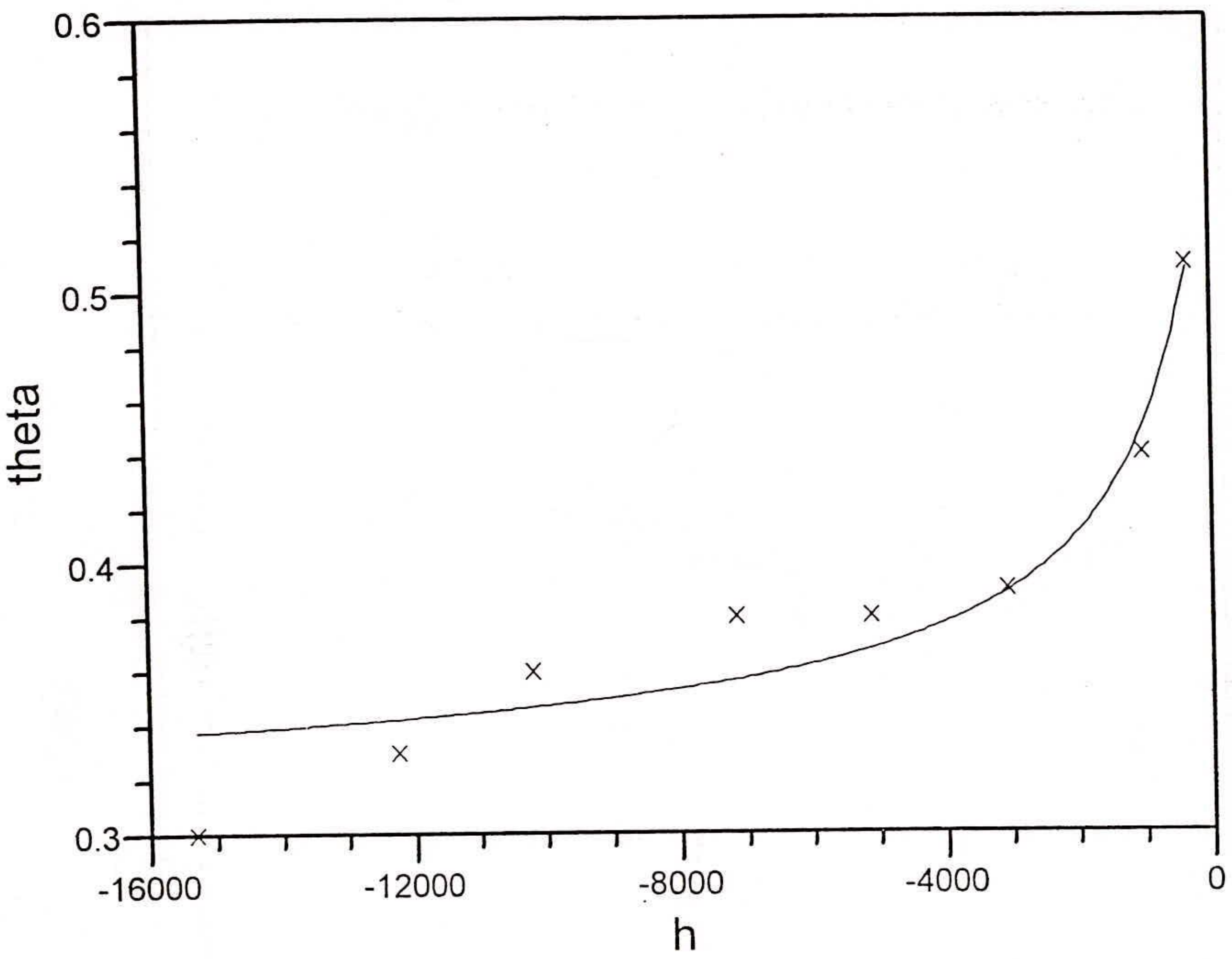


Figure. 9. Soil Moisture Retention Curve for Forested Watershed.
(Site 8.)

3.2 URBAN WATERSHED (BELGAUM CITY)

The rapid growth of population in the urban areas continues, and the various resources required by the populations put ever-greater demands upon the environment. It seems clear that the growth must have its limits. Yet it is difficult to see at the moment, at least any concerted effort to stop the deterioration of the landscape that is already obvious. The problem also is by no means limited to those urbanizing areas of the developing countries, with the concept of bankruptcy now being extended, in theory at least for the moment, to several cities in well developed countries The problems of maintaining, let alone improving, the infrastructures of these cities for the management of their water resources is of ever increasing concern. In developing countries water problems can be affected by two some times very contradictory policy categories. The first deals with the under development of the resources, the second those caused by activities involved in economic development. The co-existence of this water issues are some times difficult to resolve. The politicians are, therefore often caught in difficult situation of trying to increase the industrial development of the country in order to improve economic standing, but the industry they encourage are often very same ones that are relatively unconstrained in polluting of the waters and impairing the health of their people.

The hydrology of the urban areas dealing with relatively small catchments or watershed compared with the rural areas require data with very fine time and space resolutions such data are usually not available from the national meteorological services for example rainfall data, soil, hydrological data etc. which are very important for the estimation of runoff and water budget which must have time resolutions of the order of grid size. Such data are usually not available with special measurements. Therefore, a typical watershed which is a part of the Belgaum urban area has been selected for the study and its spatial variation in hydraulic properties were determined. This particular watershed is further going to be a destroyed due to the developmental activities by converting into an autonagar.

3.2.1 Study area

The Belgaum city is one of the major cities of the state and is located at Longitude 74 ^{0} 30 ^{1} and latitude 15 ^{0} 57 ^{1}(fig 10), covering an area of 31.8 km^2. The city is distributed in 3 river catchments namely Bellary Nala (53.35 %). Markandeya river catchment (31.65 %) and Mangetri Nala catchment (14.98 %). The population of the city is about 4 lakhs including cantonment population. The city gets its water supply from Rakaskop barrage across Markandeya river located about 25 km. West of Belgaum city. The area falls under semi-arid climate with an average annual normal rainfall of 1324 mm. Nearly 95 % of the annual rainfall is received during the period June to October through South-West monsoon. The present study area is located about 6 km. from the city on the side of National High way - 4, as shown in figure . It covers an area of 6 km^2.

Geomorphologically, in the upstream of the watershed there are few small hillocks. The peak of the hill of Ramtirth is 850 - 900 ft above m.s.l. Few nalas are flowing down the hill. The hill is with steep gradient and flat at the top. The flat top of the hill receives rainfall and infiltrates downward. It is noticed that there are some springs at the foot hill. This indicate that deep percolation is less because of the underlying geological structure. There is a natural tank at the temple and is used for domestic purposes by the people in the surrounding area. It is said that the water level in the tank is constant throughout the year. Geologically this region is covered by sandstones and conglomerates.

At the foot hills of Ramtirth there is a low-lying area where active agriculture is going on. However, the observation at few cuttings show that the top few meters are mainly composed of clay layers with good quantity of water. Two observation wells have been selected from this area, in which one well is found within the Nala with shallow depth and another one at higher elevation. However, the water is only used for domestic purposes except for drinking.

Kangarali and Goundvad area: This is typical basaltic zone occupied by partially and fully weathered basalt. However, the fractured and joints are quite minimum and discontinuous

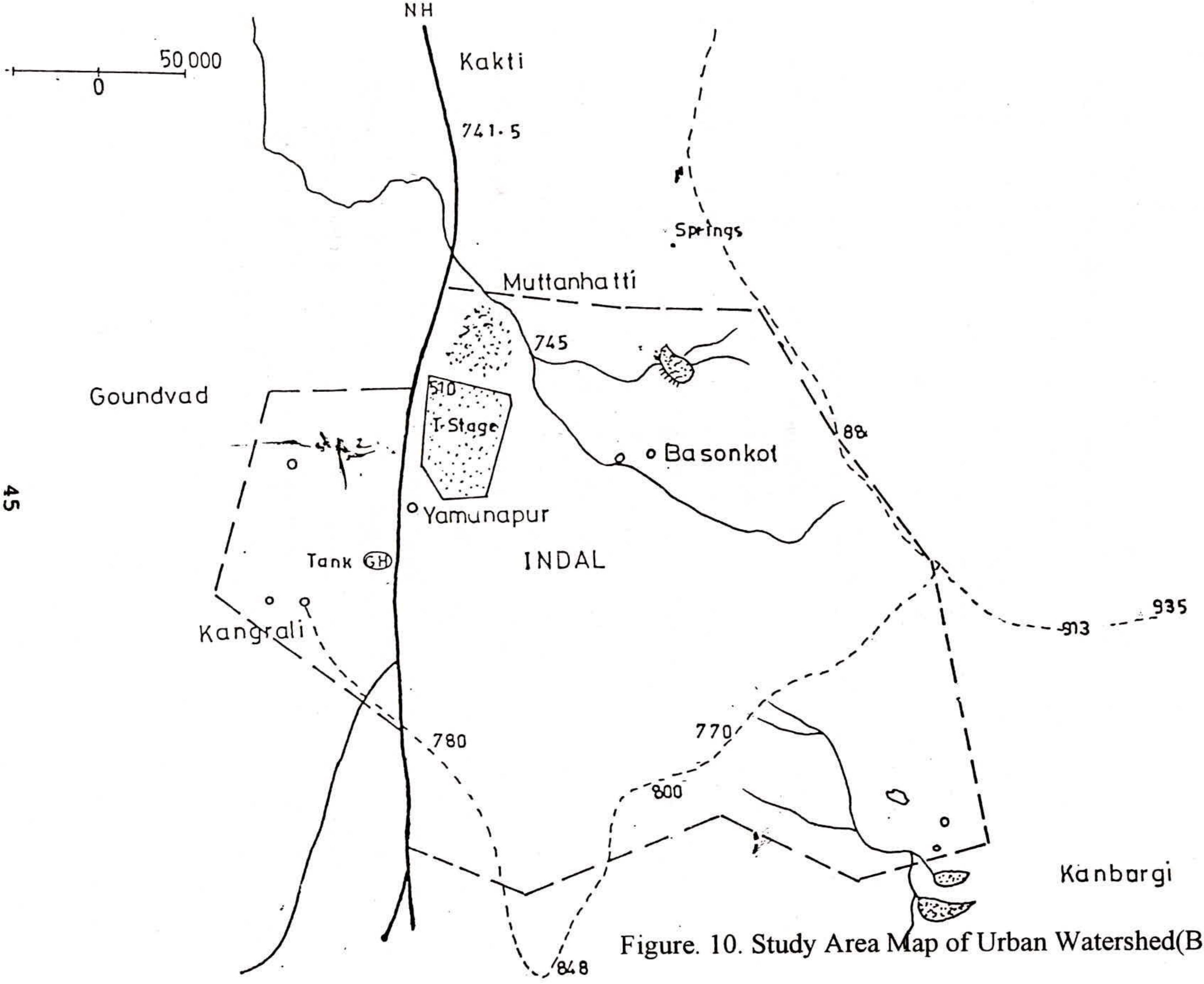


Figure. 10. Study Area Map of Urban Watershed(Belgaum City).

from point to point. Kangrali area is covered by medium black soils and Goundwad area is covered by red sandy soils.

Kanabergi area: This zone is fully covered by typical weathered laterite. There are few tanks which are used for irrigation by local people shows that the tank has an influence on water levels in the adjoining wells, which indicates the nature and extent of the aquifer in that area.

In the valley region (Yamunapur, etc.), the thick black cotton soils and sandy lateritic soils occupy the surface layer. Fresh basalt are inter-bedded with various types of layers at different depths . The Kaladgi formations which are composed of sandstones quartzite's and conglomerates are exposed in the eastern side of the valley while in the west, the basalt occupy the major portion. The top layers of basalt constitute laterites of varying degree of weathering over which study area is located.

3.2.2 Spatial Variation of Hydrologic Soil Properties in Urban Watershed

To understand the process of infiltration in the study area 7 sites have been selected based on various geomorpholoical, soil type and land use pattern.

The experiments were conducted using Disc Permeameter. Representative infiltration rates observed in typical zones which is demarcated as black soil region - 11.45 mm/hr; red soil zone - 214.87 mm/hr; low-lying agricultural area -185.84 mm / hr; Disturbed area - 16.31 mm/hr; Weathered basaltic zone - 73.67 mm/hr; lateritic capping zone (Kanbargi) - 5.156 mm /hr ; and close to National Highway area - 61. 44 mm /hr. Saturated Hydraulic conductivity is shown in table 3. The saturated hydraulic conductivity varied between 1.4 mm/hr and 54.73 mm/hr. The maximum hydraulic conductivity is obtained for typical red soil in Kangrali and Goundwad areas. Minimum rate hydraulic conductivity is observed on a disturbed land in Kanbargi where theanthropogenic activities are quite heavy. Low rates of hydraulic conductivity is also observed for soils dominated clay samples. Textural analysis of soil samples presented in table 2. Soil retention characteristics of the soil of the study area are presented in figures 11 to 17and Table.3.

Table 2. Soil Texture for the Study Area

Sl. No.	Sand %	Silt %	Clay %
1	9.64	44.01	46.35
2	7.50	18.02	74.48
3	28.78	64.38	6.48
4	0.82	40.76	58.42
5	6.13	80.57	13.30

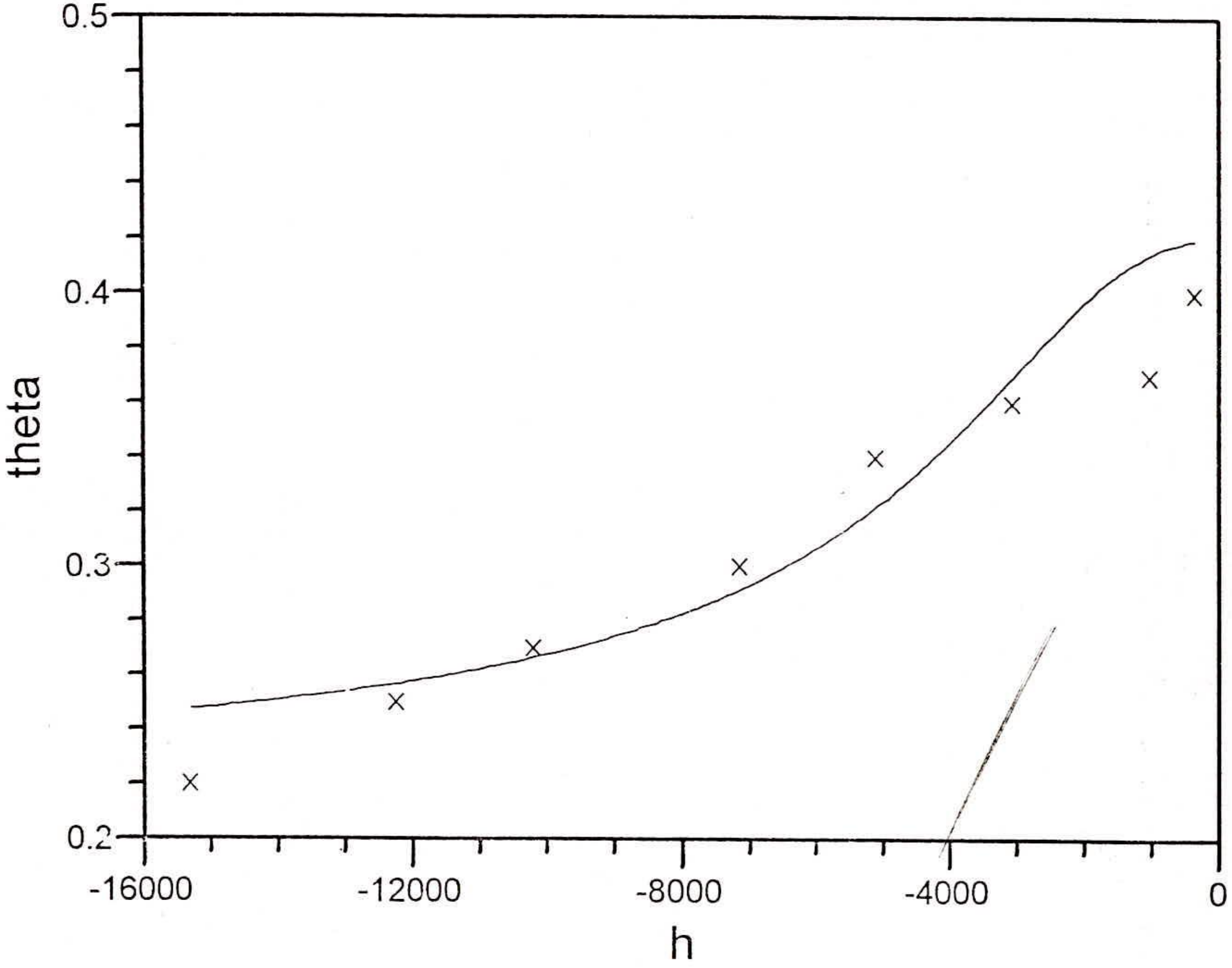


Figure. 11. Soil Moisture Retention Curve for Urban Watershed.
(Site 1.)

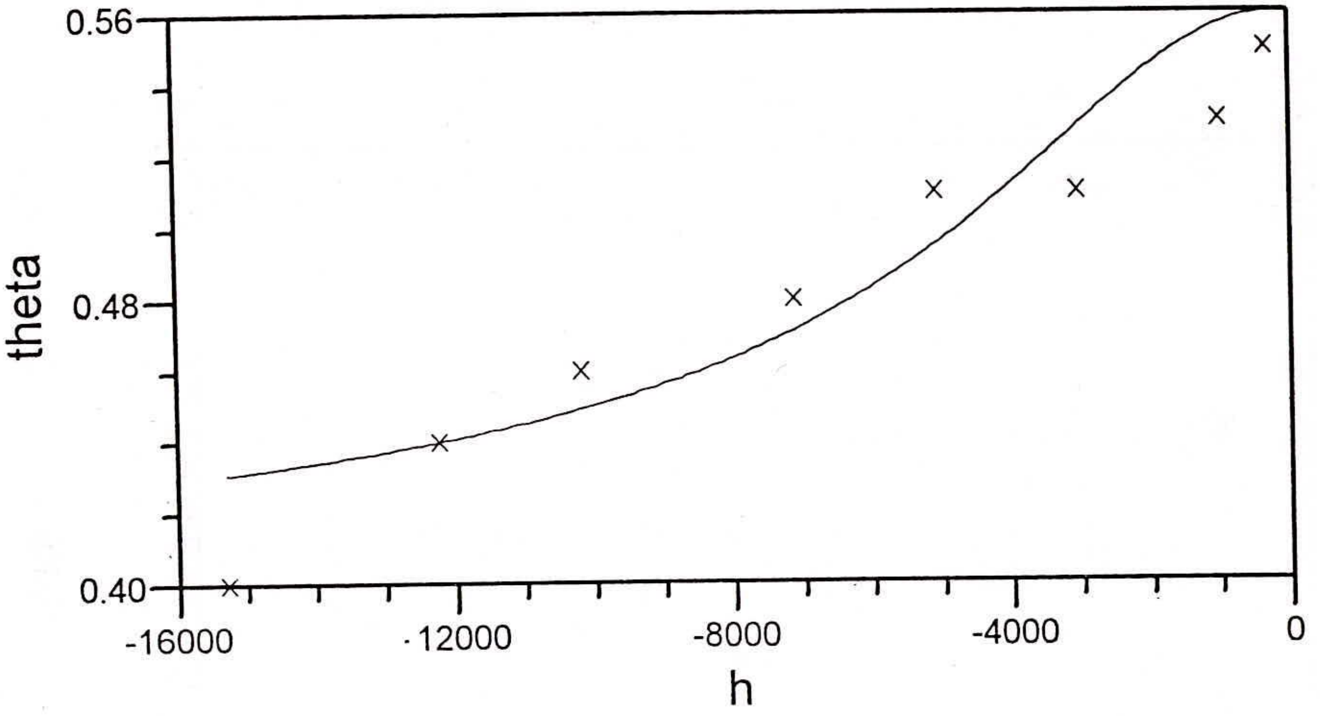


Figure. 12. Soil Moisture Retention Curve for Urban Watershed.
(Site 2.)

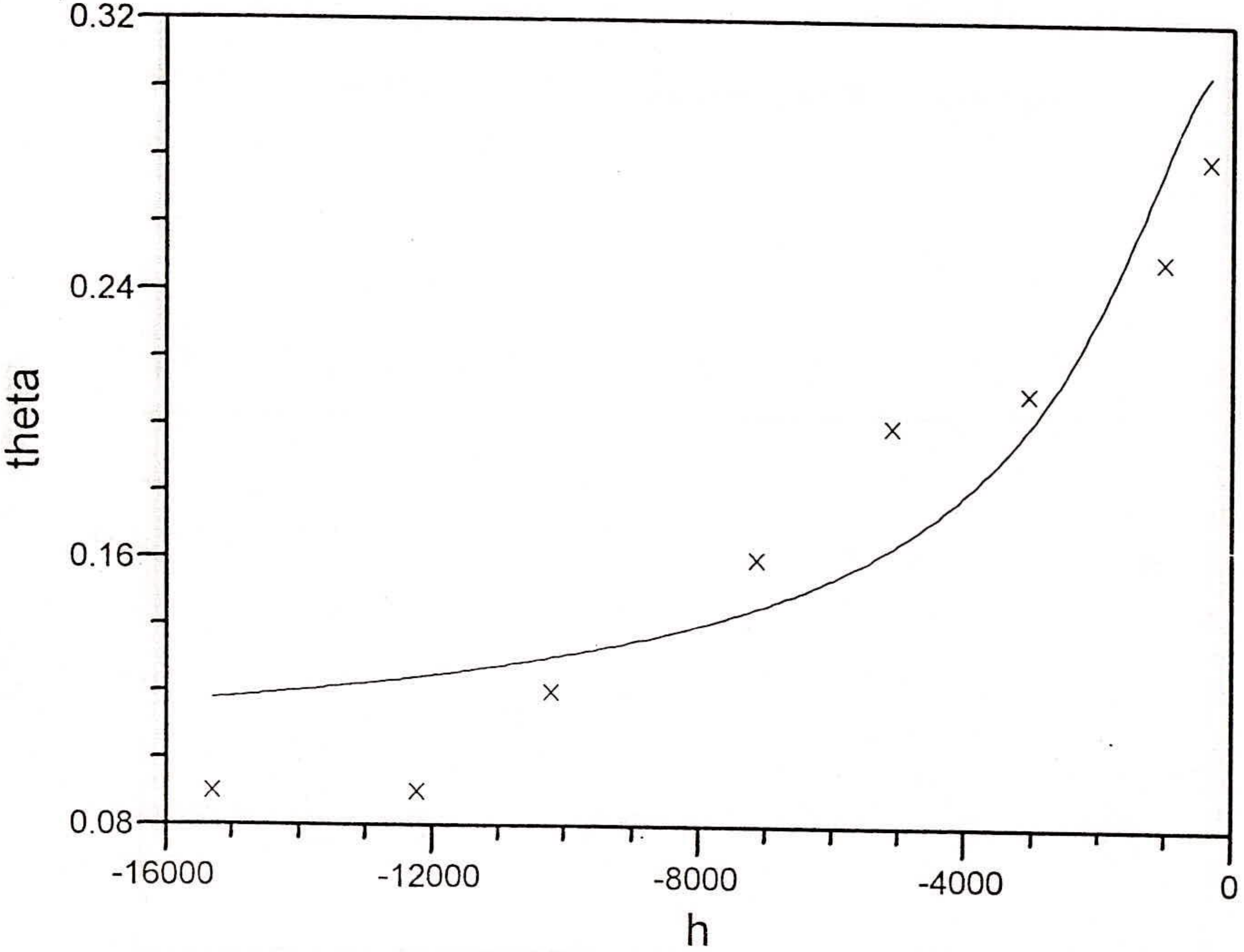


Figure. 13. Soil Moisture Retention Curve for Urban Watershed.
(Site 3.)

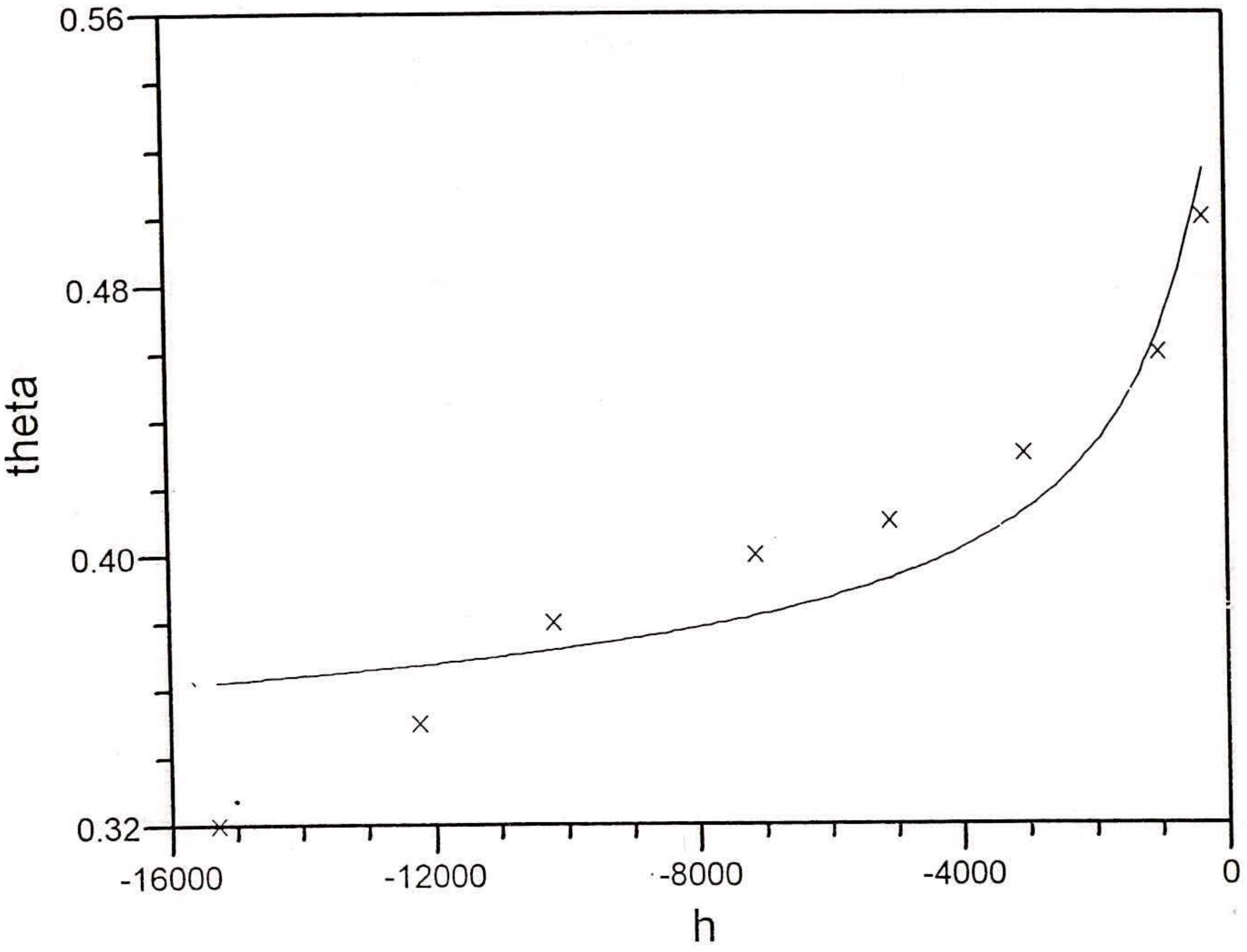


Figure. 14. Soil Moisture Retention Curve for Urban Watershed.
(Site 4.)

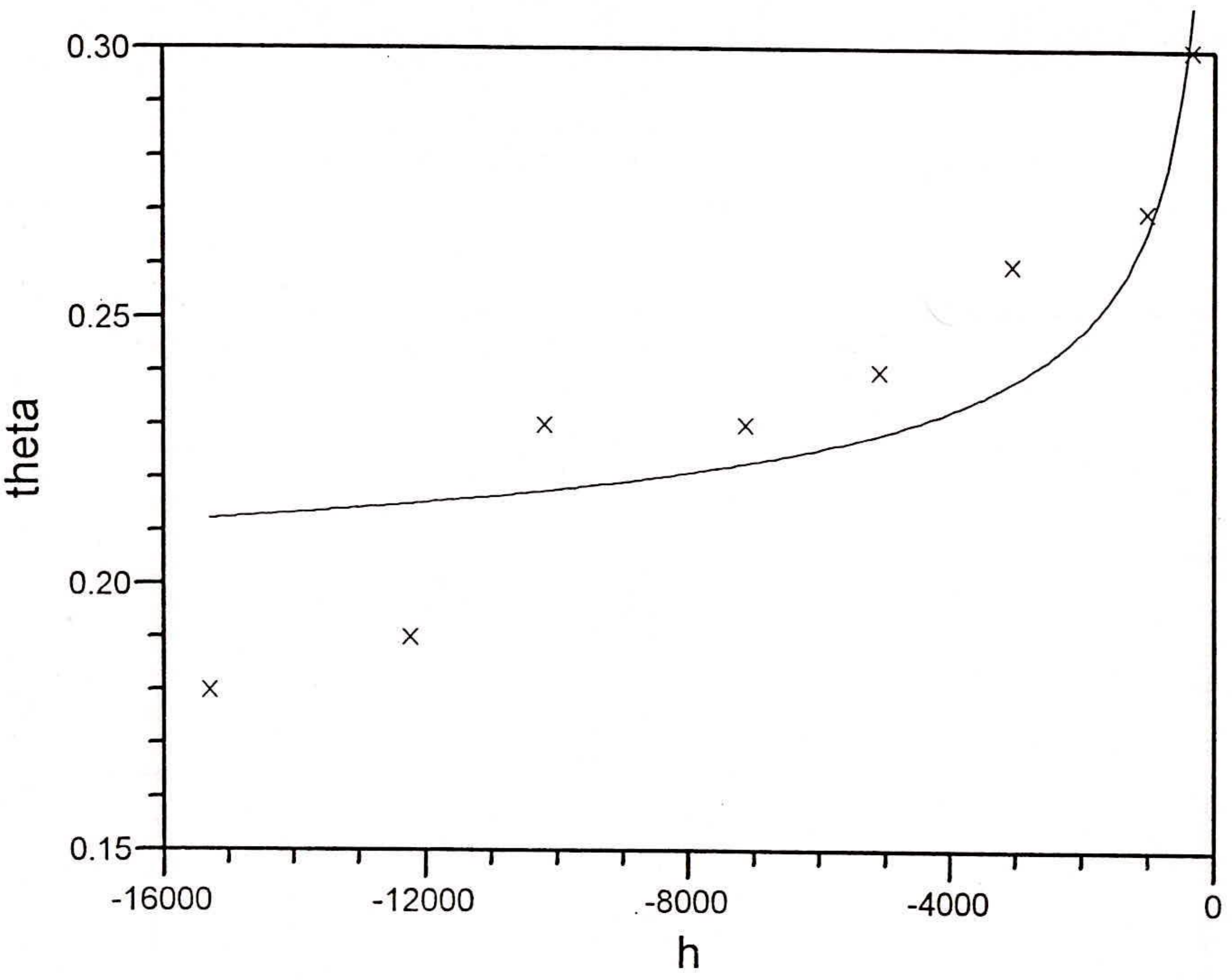


Figure. 15. Soil Moisture Retention Curve for Urban Watershed.
(Site 5.)

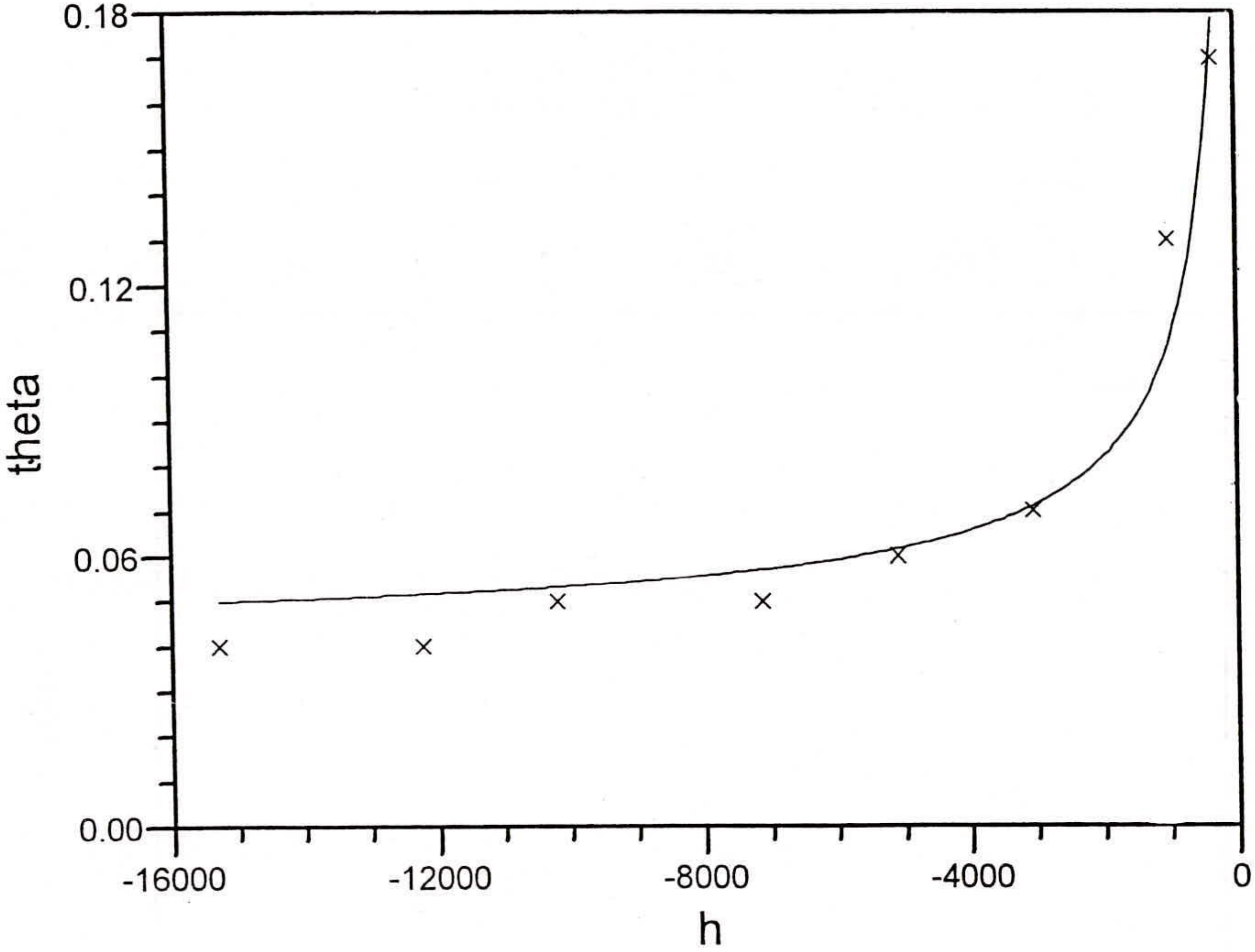


Figure. 16. Soil Moisture Retention Curve for Urban Watershed.
(Site 6.)

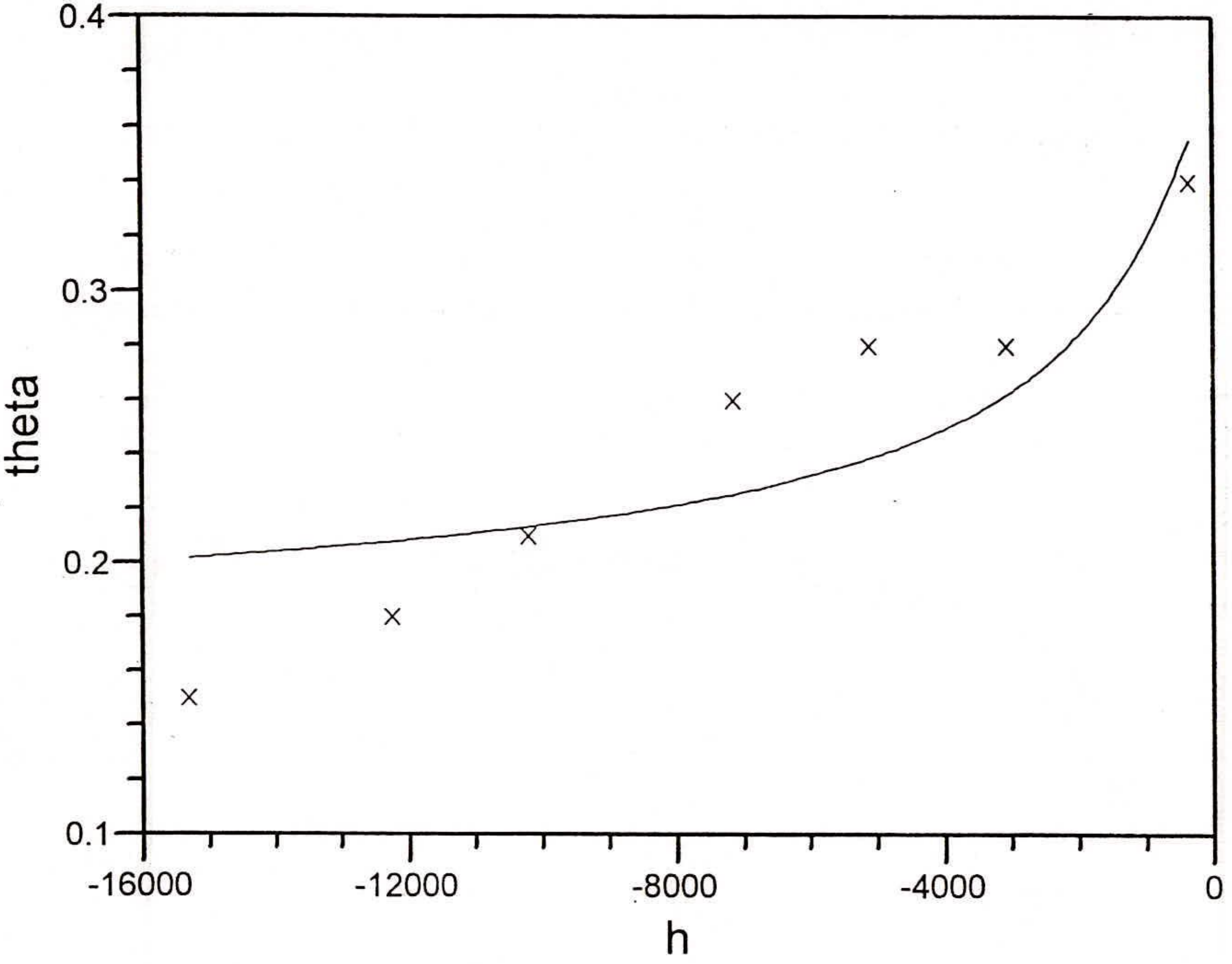


Figure. 17. Soil Moisture Retention Curve for Urban Watershed.
(Site 7.)

Table 3: Soil Hydrologic properties of Urban watershed

Station	Ks Cm/hr	θs	αv	η	Proportion of Variance (%)	Pressure in Bars							
						0.33	1.0	3	5	7	10	12	15
1	0.14	0.42	0.003	2.377	87.07	0.40	0.37	0.36	0.34	0.30	0.27	0.25	0.22
2	0.51	0.56	0.002	2.249	85.68	0.55	0.53	0.51	0.51	0.48	0.46	0.44	0.40
3	3.55	0.31	0.006	1.930	85.93	0.28	0.25	0.21	0.20	0.16	0.12	0.09	0.09
4	0.80	0.54	0.0017	1.502	85.82	0.50	0.46	0.43	0.41	0.40	0.38	0.35	0.32
5	5.47	0.47	0.027	1.364	76.83	0.30	0.27	0.26	0.24	0.23	0.23	0.19	0.18
6	5.37	0.33	0.0075	1.713	94.43	0.17	0.13	0.07	0.06	0.05	0.05	0.04	0.04
7	1.88	0.37	0.0011	1.509	72.57	0.34	0.29	0.28	0.28	0.26	0.21	0.18	0.15

3.3 Agriculture Watershed

In India, about 75 % of the total cropped area is unirrigated and it accounts for about 42 % of food grain production. Nearly 50 % of geographical area of our country receives a rainfall ranging from 40 - 120 cm/year. More than 78 % of cotton, 82 % of oilseeds, 96 % of sorghum, 98 % of millets, as much as 62 % of rice and 38 % of wheat of the country are grown under rainfed conditions. Improvement in the productivity of these crops holds the key to the success of our agriculture.

The rainfall in the arid and semi-arid areas exhibits wide variations in time and space. The undependable and erratic rainfall introduces an element of risk, uncertainty and instability in crop production. There are several features that distinguish the rainfed agriculture in the tropics, e.g. (i) the rainy season is short (2-4 months) and is followed by dry season, the monsoon rains are inadequate to meet demands, erratic and uncertain, the lower the mean annual rainfall the greater is the variation and less the dependability; (ii) in the semi-arid tropics, the rains are of high intensity, together with the lack of organic matter like black soils of India, this tells upon the moisture intake and results in excess runoff; (ii) in the tropics, the rainfall effectiveness is lessened by the prevailing high temperature, and, therefore, greater evaporation. Coupled with shallow and light soils (due to erosion) this makes cultivation a challenge.

The low and erratic rainfall normally occurs with high intensity and of short duration's resulting in high runoff events and poor soil-moisture storage. The people of the area are poor and keep relatively large cattle population. The dependence of the people and cattle on these lands causes large-scale denudation resulting in most of the rain-water ending in runoff leading to problems of down-stream flood hazards.

3.3.1 Hard Rock Terrain

3.3.1.1 STUDY AREA (Ozhar, GV -7, Niphad tehsil, Nasik district)

Ozhar, Niphad tehsil, Nasik district (fig 18) is known for its water management strategies. In Ozhar, conjunctive use of surface and groundwater through active participation of farmers through Samaj Parivartan Kendra is in practice. The study area includes tail end part of right bank canal of Waghad project. The wells in the area are not much productive because hard, massive rock appears very close to surface. The part of the watershed has been sub-divided into 6 micro-watersheds. The runoff estimation and assessment of groundwater of the area have revealed that there is a scope for construction of bunds to prevent runoff through nalas and that new wells could be constructed for utilisation of groundwater.

The quantity of canal water made available to co-operative society through Samaj Parivartan Kendra is 5024 m. The utilisation of this water has resulted into irrigation of 370 ha. area in Rabi season, out of total area 1151 ha. owned by the society.

There are 339 irrigation wells existing in the project area. The depth varies from 8 to 10 m. The quantity of water available from wells varies from 180 to 210 Kl in winter and 70 to 90 Kl in summer (1 Kl = 1000 litres).

The availability of surface water was calculated on the basis of Stranger's table. The groundwater recharge was calculated for the total area of microwatersheds ignoring entire area of watershed. The calculations have revealed that the water available annually is 1823.75 TM.

The annual recharge to groundwater works out to 472.63 ham while the quantity of water pumped is 272.95 Ham. The balance of groundwater available is 199.68 ham. Considering the annual availability of 1.5 Ham of water per well, the feasible number of wells work out to 150.

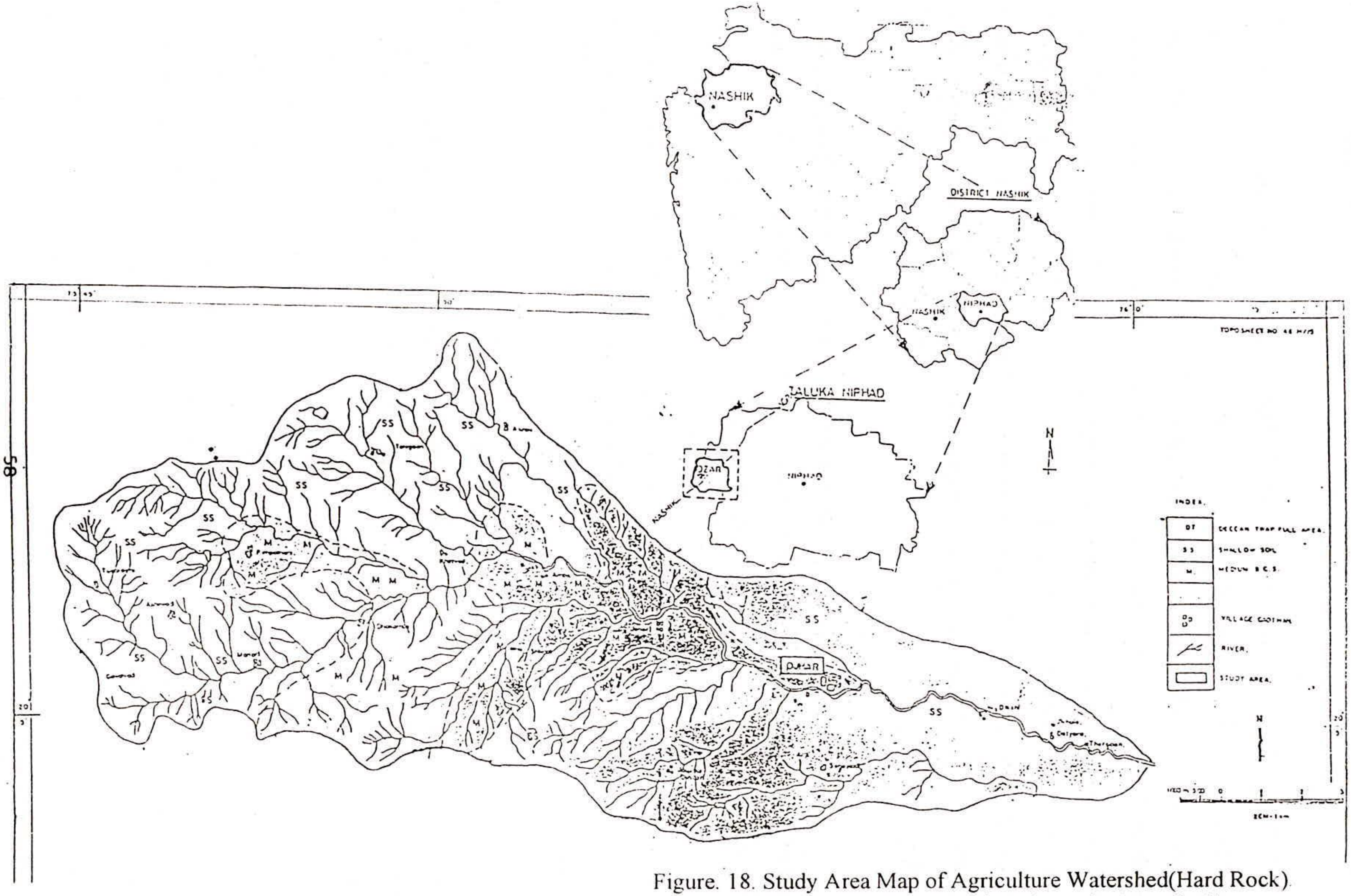


Figure. 18. Study Area Map of Agriculture Watershed(Hard Rock).
(Locations of study sites shown in Appedix 1)

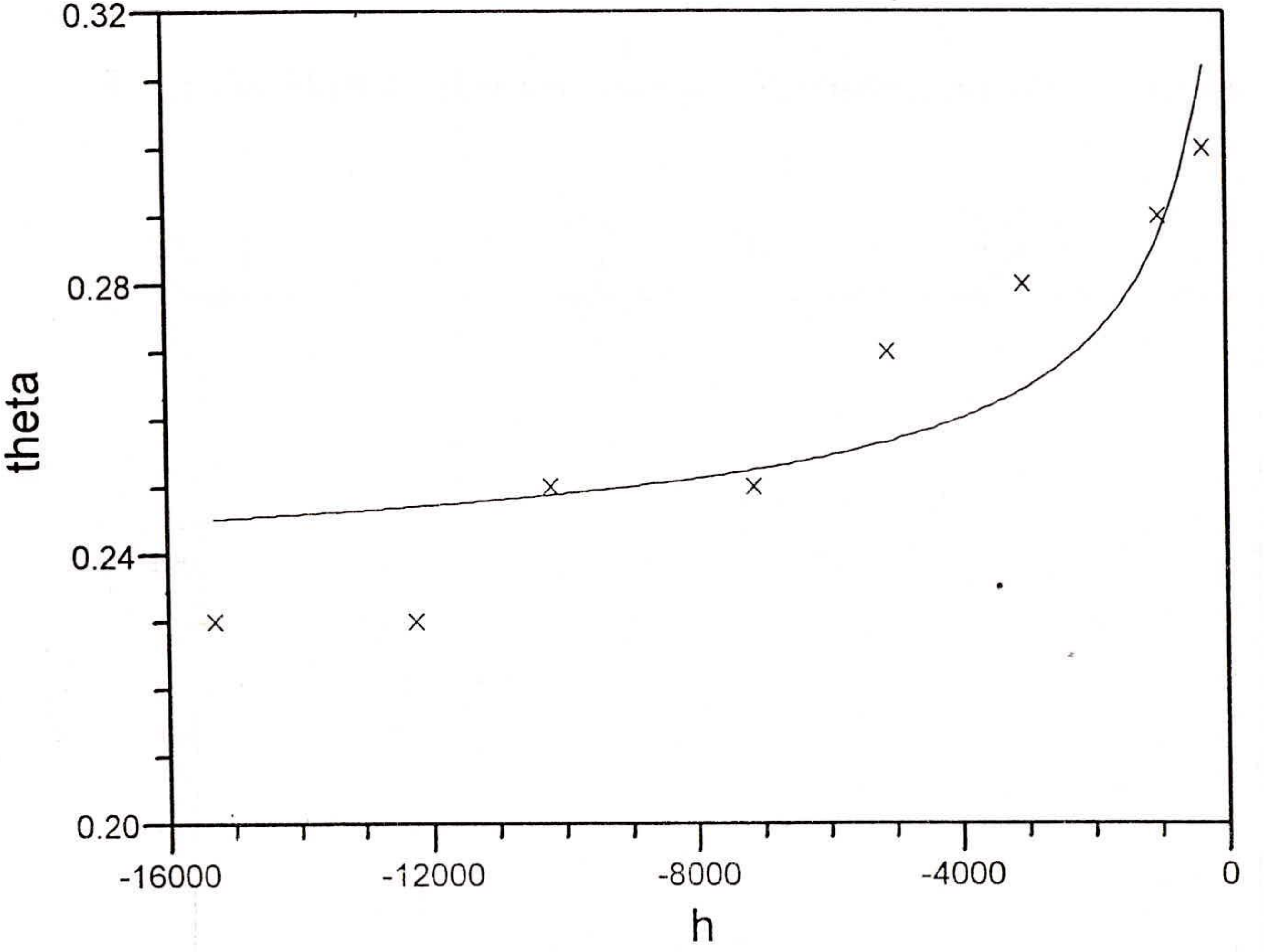


Figure. 22. Soil Moisture Retention Curve for Agriculture Watershed (Hard Rock). (Site 4.)

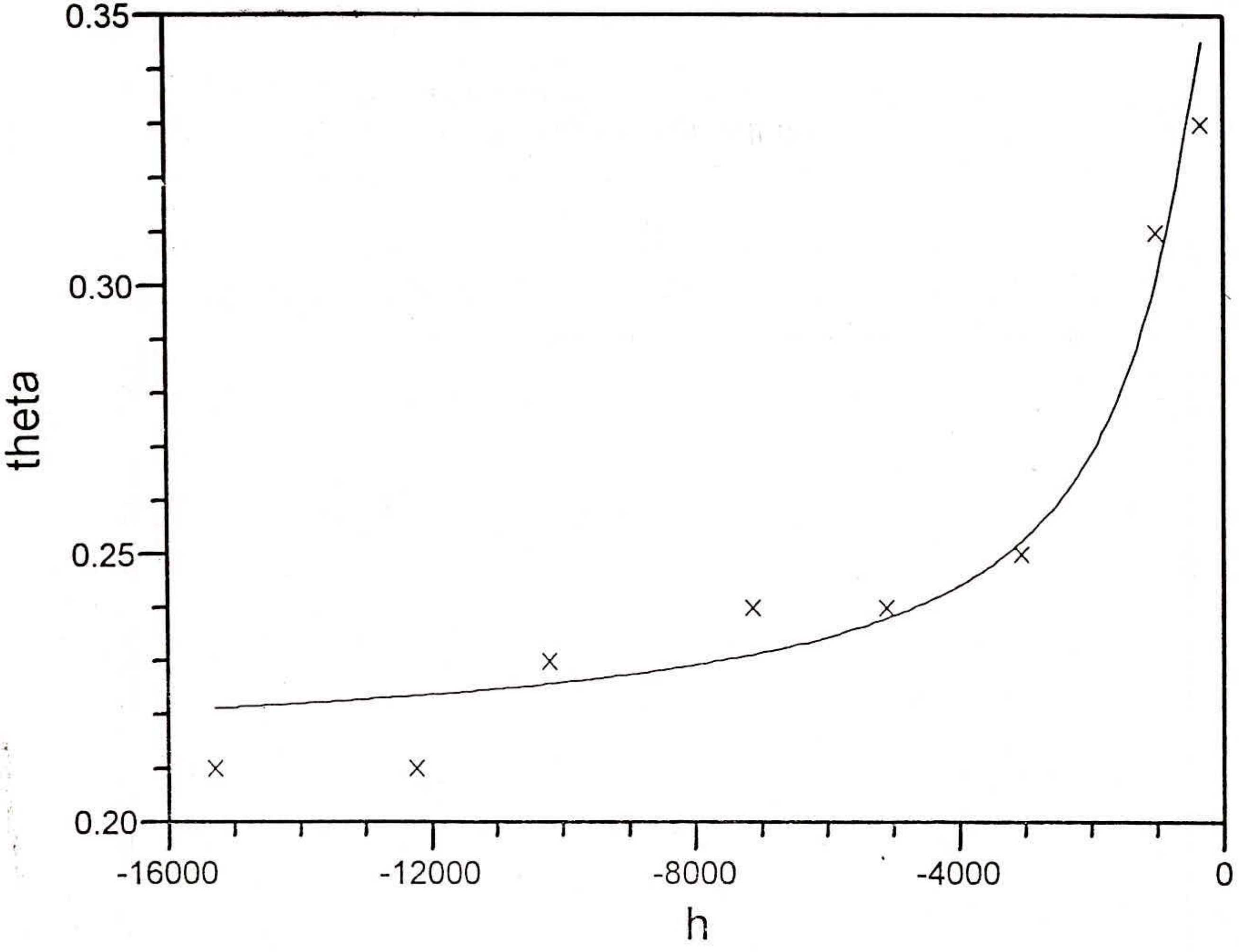


Figure. 21. Soil Moisture Retention Curve for Agriculture Watershed (Hard Rock).
(Site 3.)

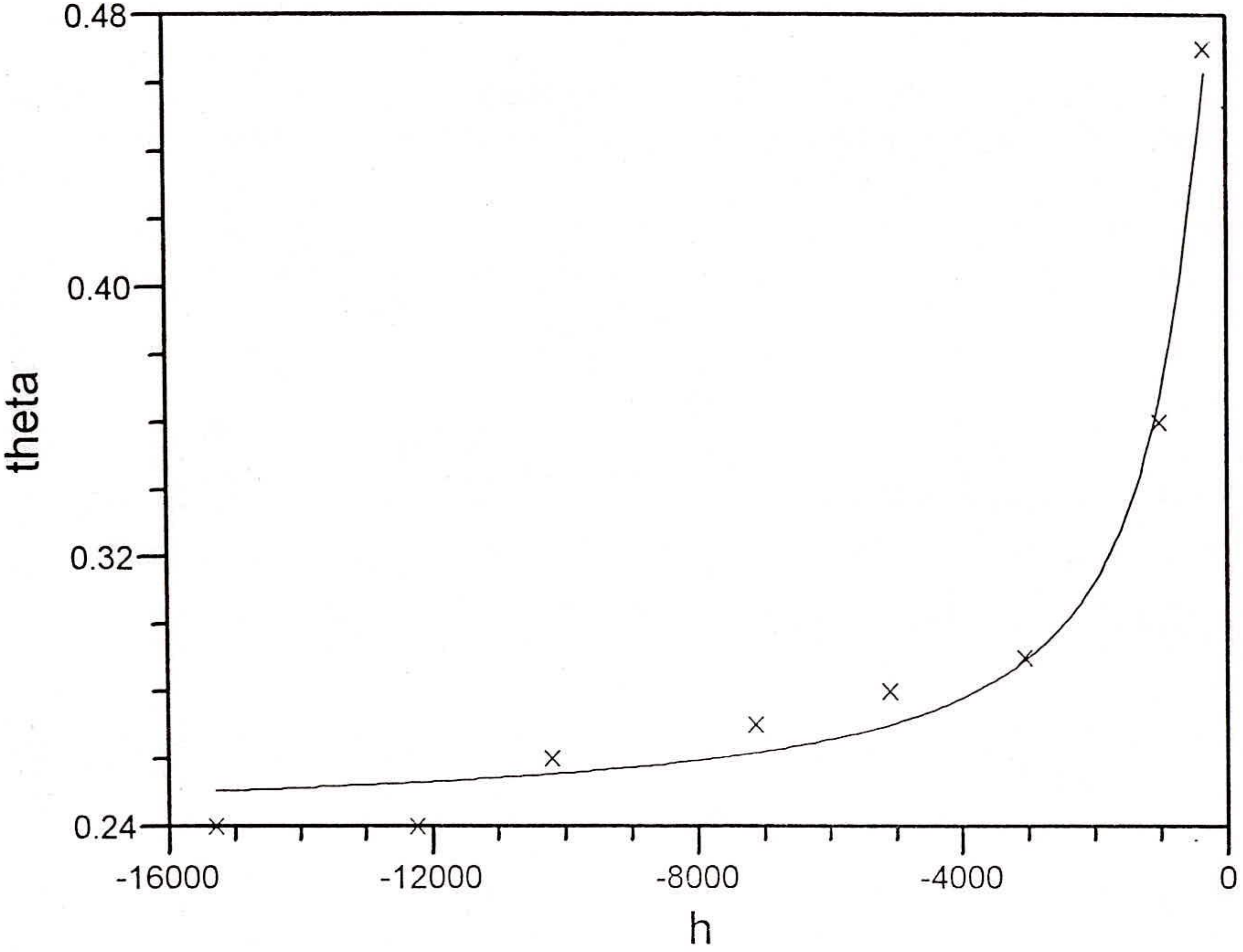


Figure. 20. Soil Moisture Retention Curve for Agriculture Watershed (Hard Rock).
(Site 2.)

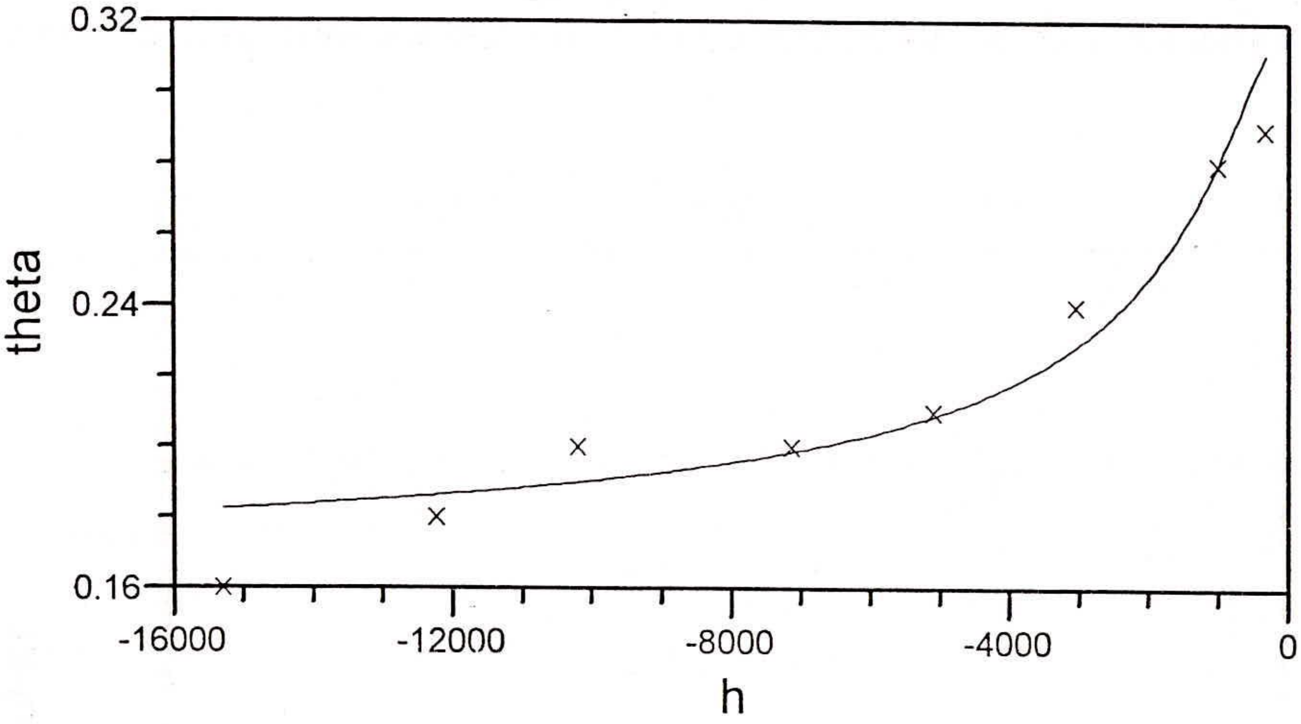


Figure. 19. Soil Moisture Retention Curve for Agriculture Watershed (Hard Rock). (Site 1.)

3.3.2 Alluvial Terrain (Bamnod (TE 11), Yawal taluk, Jalgaon district)

Bamnod is one of the critical area due to its low groundwater yield. It is situated in the extreme south-east corner of the watershed TE-11. Over capitalization of groundwater withdrawal structures in the area coupled with an increase in pumpage from open wells and tube wells that tap alluvial aquifers has caused serious year to year decline in groundwater levels. Therefore, artificial recharge measures are necessarily required for maintaining the water levels. Bamnod area lies between latitude 21^0 8' and $21^0$10' and east longitude 75°48' and 75°50' (fig 23). Total command area of the study area is 910 ha. This watershed forms a part of the Tapi river basin and is located on the northern bank of the river Tapi. In the north, it is bounded by Satpura hill range while the Tapi river forms the southern boundary. Morphologically, the area of the village has been classified as alluvial plain having gentle gradient towards south and exhibits flat topography.

Hydrogeomorphologically the Bamnod area has been designated as `Storage Zone' The alluvial formation in the Tapi valley are deposited in faulted basin and have attained a considerable thickness. The alluvium mainly consists of clay, silt, sand, gravel and pebbles. The thickens of the sedimentary formation which occur as lenses varies from 1 to 10 m. Generally, they occur within a depth of 90 meters and sometimes even down to a depth of 480 meters below surface as evident from the lithologs of tubewell drilled by GSDA in 1976 at Vadhode in Yawal taluka. Based on the exploration carried out by CGWB and GSDA, the alluvium is broadly divided into younger alluvium occurring upto 80 meters below ground level. The younger alluvium is coarser in nature than older alluvium which comprises of thick and sticky clays with beds of gravels at lower horizons. The granular zone is heterogeneous consisting of fine to coarse grained sand, gravels and kankars.

The principal water bearing formation in Bamnod is alluvium where granular zones are encountered at various depths. The clay horizons occurring as alternate layers from aquiclude with significant effect on the occurrence and movement of groundwater. Groundwater in the area generally occurs under unconfined conditions at shallow depth and under semiconfined to confined conditions at deeper levels. In alluvium multi-aquifer

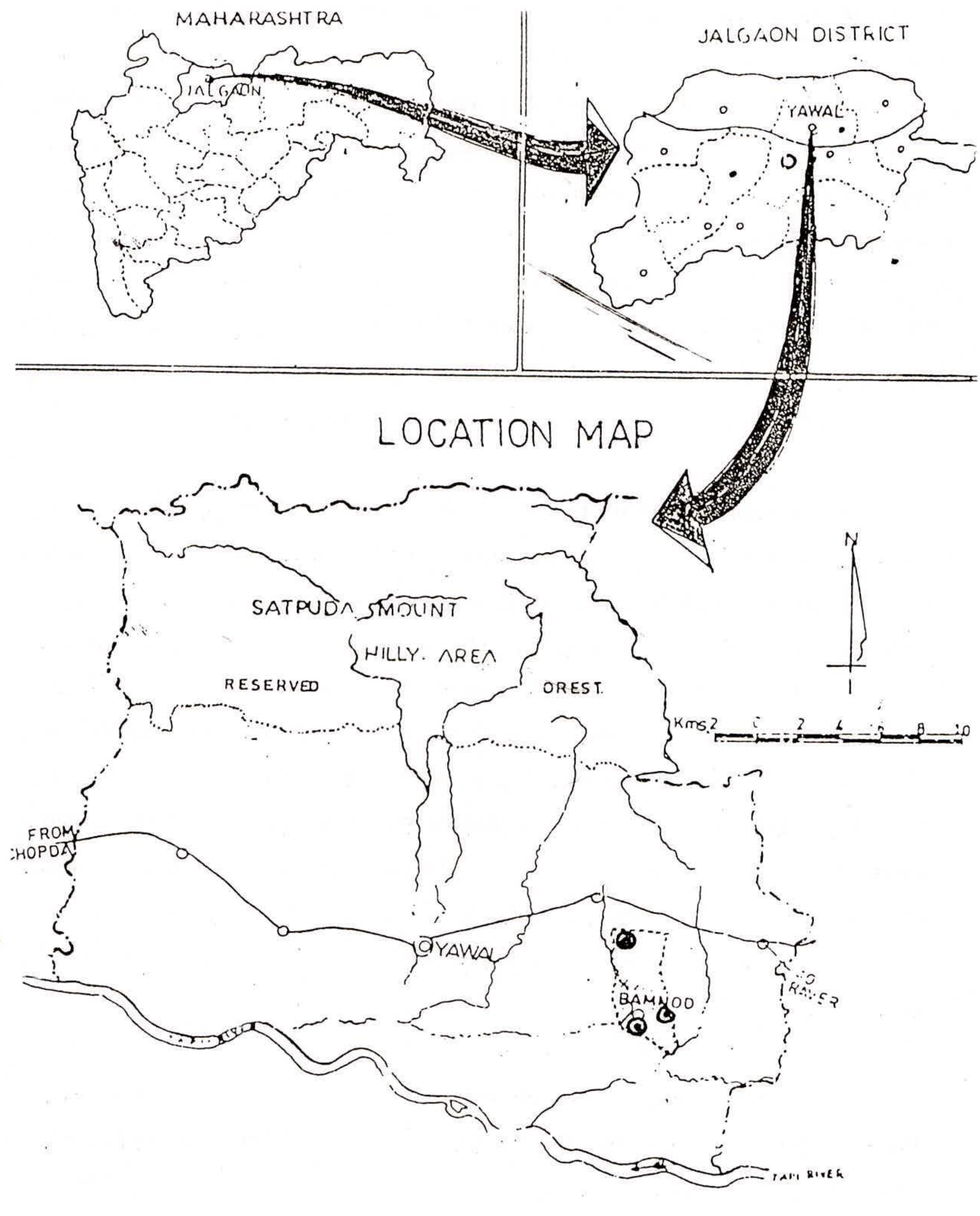


Figure. 23. Study Area Map of Agriculture Watershed(Alluvial).

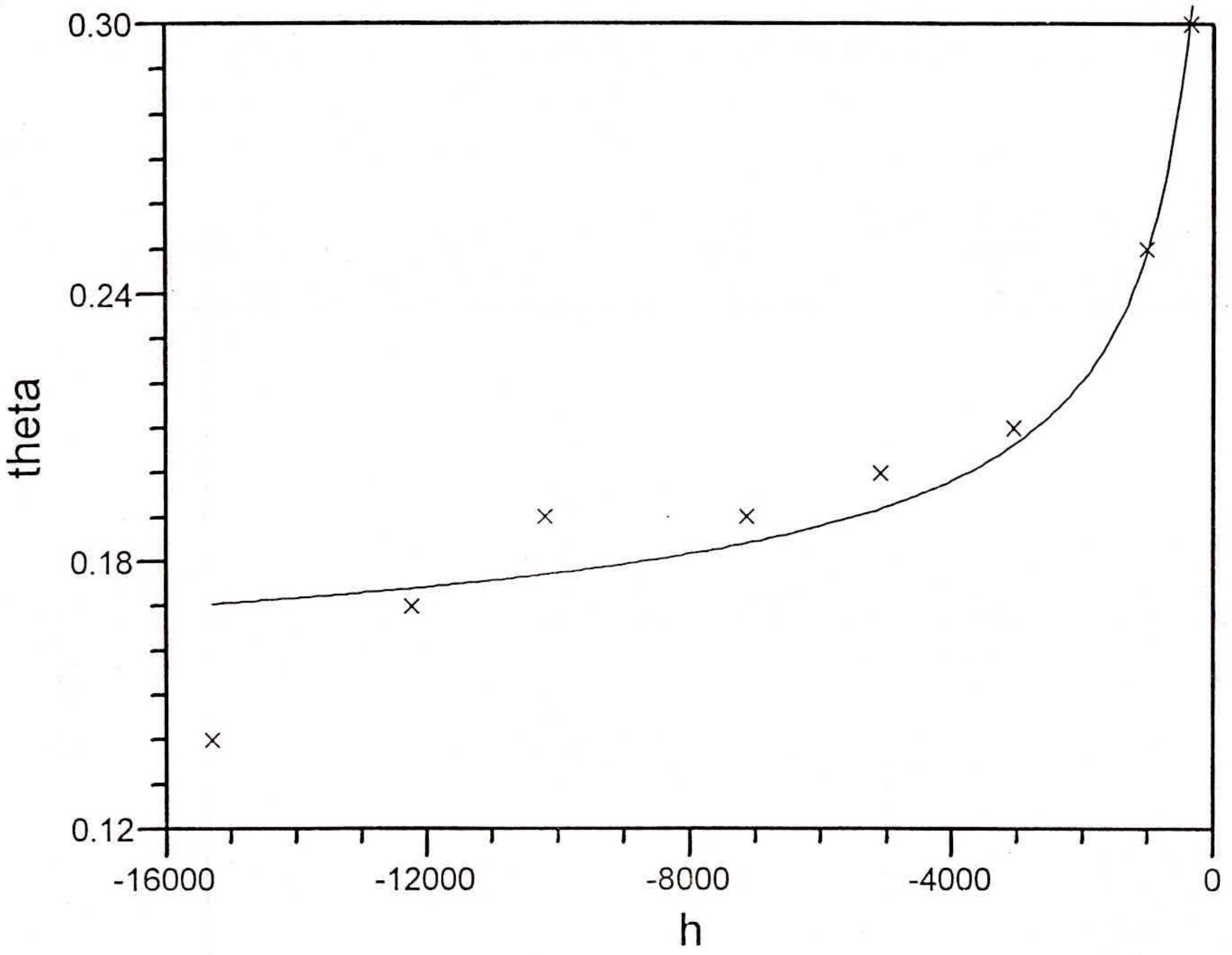


Figure. 24. Soil Moisture Retention Curve for Agriculture Watershed(Alluvial).
(Site 1.)

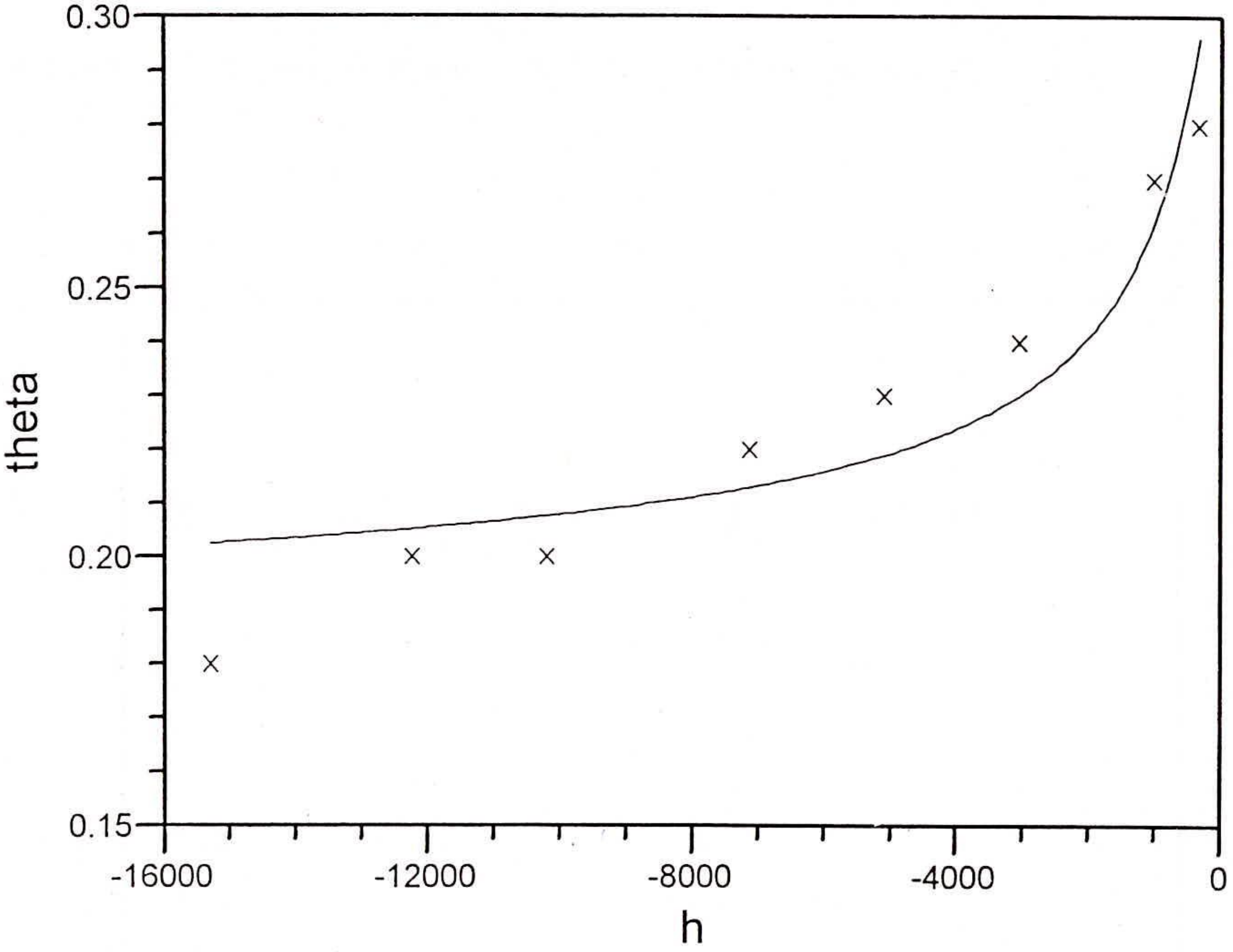


Figure. 25. Soil Moisture Retention Curve for Agriculture Watershed(Alluvial).
(Site 2.)

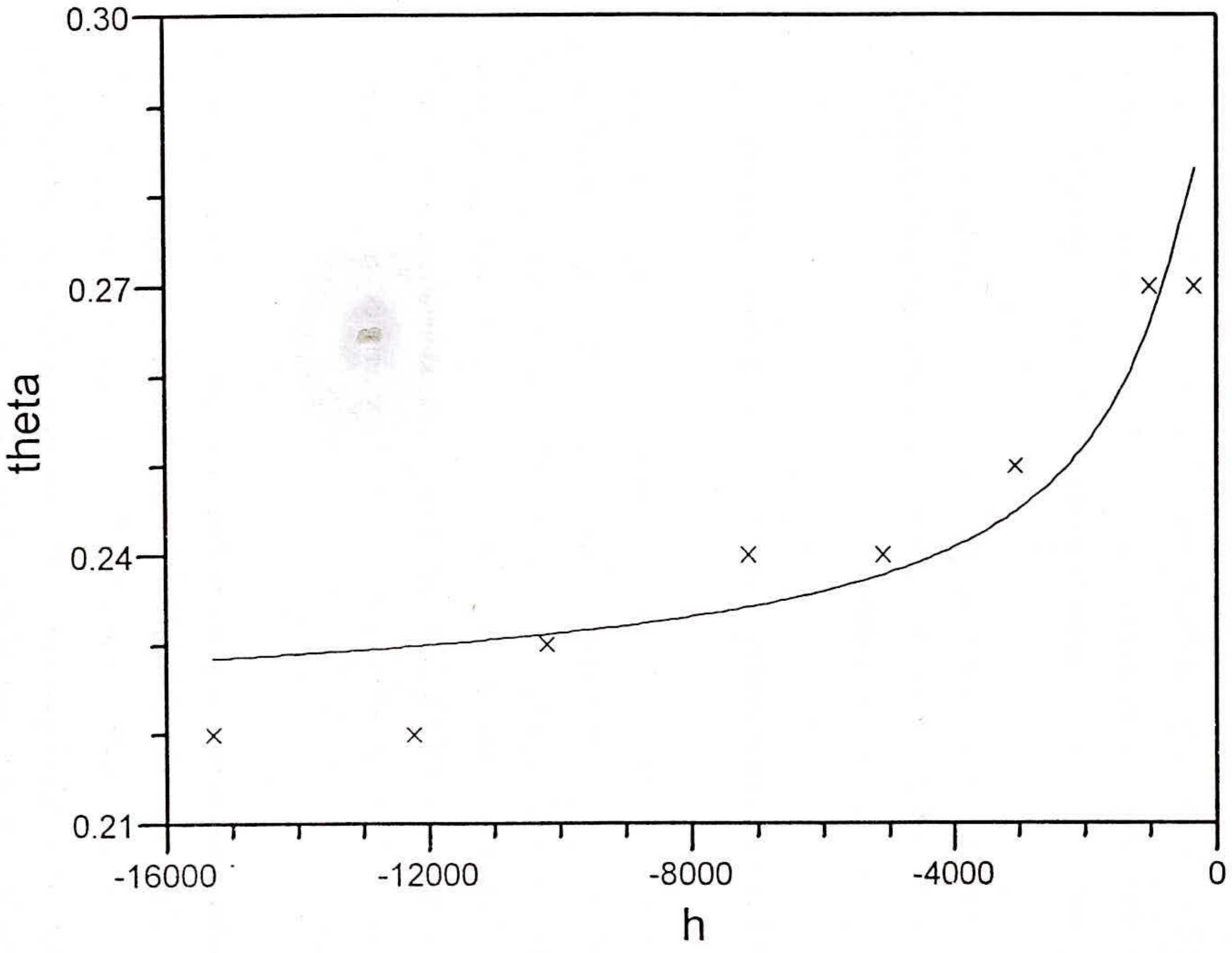


Figure. 26. Soil Moisture Retention Curve for Agriculture Watershed(Alluvial).
(Site 3.)

systems are present where each aquifer is separated by confining clayey formation. The thickness of granular zone varies from 4 to 15 meters.

The readings of water levels in observations well fixed at Village Bamnod in 1981 shows declining trend. The water level measured in 1981 was 36 meters(Pre-monsoon) whereas in 1996 it was lowered down to 47.3 meters. From figure 4, it is evident that within a span of 15 years, the water level declined by 13.3 m. This situation reflects that is heavy withdrawal and annual replenishment does not match with the withdrawals.

Aquifer performance test conducted in a village area reveals that the specific capacity of wells ranges from 4.58 to 38.07 lpm/m. The transmissibility of the aquifer is 259.7 to 950 sq.m/day. The storage coefficient ranges from 0.03 to 0.07.

3.3.3 Spatial Variation soil hydrologic parameters in Agriculture watersheds

In the hard rock region, the soils are characterized by black soils having high content of sand particles. The experiments conducted at four different locations showed that the percentage of sand varies between 77% and 90%. The percentage of clay is very less. Infiltration rate varies between 0.6 cm/hr to 3.6 cm/hr. The saturated moisture content varies between 32% and 50%. The bulk density of the sample varies between 1.75 g/cc and 1.86 g/cc. hydraulic properties and retention characteristics are given in table 4 and figures 19 to 22.

In an alluvial watershed, soil types are sandy and light to dark brown in colour. The infiltration rates observed in the study area varies between 1.2 cm/hr and 6 cm/hr. texturally, the soil is dominated by sands (70% to 95%) followed by silt and clay. The bulk density varies between 1.67 g/cc to 1.74 g/cc. The saturated moisture content shows variation between 34% and 37%. Soil moisture characteristics are presented in figures 24 to 26.

Agricultural practices influence the hydrological cycle in a number of ways. The agricultural practice can modify the texture and structure of the soil and the hydrologic properties such as infiltration, interception, soil moisture, sediment yield and runoff pattern. Besides, agriculture can directly affect nitrogen, phosphorous, potassium and calcium concentration and to a lesser extent sodium, chlorine, magnesium and sulfur concentration in water. The use of fertilizers, pesticides, herbicides have a considerable influence on the quality of water leaching the soil and either entering a water course or percolating into deeper strata. The per unit consumption of fertilizers in the country is increasing from almost nil in 1950-51 to about 48.44 kg/ha in 1986-87.

Table 4. Soil Hydrologic Parameters of Agriculture Watershed in Hard Rock Region (Ozar,Nasik District).

Station	Ks Cm/hr	θs	αv	η	Proportion of Variance(%)	Pressure in Bars							
						0.33	1.0	3	5	7	10	12	15
1	1.51	0.32	0.0009	1.731	91.8	0.29	0.28	0.24	0.21	0.20	0.20	0.18	0.16
2	1.8	0.5	0.0018	1.977	98.68	0.47	0.36	0.29	0.28	0.27	0.26	0.24	0.24
3	0.51	0.36	0.0014	1.844	94.75	0.33	0.31	0.25	0.24	0.24	0.23	0.21	0.21
4	0.29	0.33	0.0025	1.516	77.59	0.30	0.29	0.28	0.27	0.25	0.25	0.23	0.23

Table 5. Soil hydrologic parameters of Agriculture watershed in Alluvial(Bamnod,Jalgaon District).

Station	Ks Cm/hr	θs	αv	η	Proportion of Variance (%)	Pressure in Bars								
							0.33	1.0	3	5	7	10	12	15
1	1.3	0.36	0.0038	1.486	92.68	0.30	0.25	0.21	0.20	0.19	0.19	0.17	0.14	
2	4.60	0.32	0.0024	1.505	86.08	0.28	0.27	0.24	0.23	0.22	0.20	0.20	0.18	
3	0.90	0.29	0.0014	1.690	84.41	0.27	0.27	0.25	0.24	0.24	0.23	0.22	0.22	

3.4. Representative Basin

Several analytical framework, for, or approach to organization of hydrological studies have been suggest in recent years and the term representative basin experimental basin and other associated nomenclature such as benchmark basin, vigil basin, barometer basin and paired catchments and multiple catchments etc.

According to the Australian Water Resource Council (1969) a representative basin which contains within its boundaries a complex of landforms, geology, landuse and vegetation which can be recognized in many other catchments of a similar size throughout a particular region. Recently Toebes and Ouryvaeu (1970) have defined the representative basins as follows.

Representative basins are basins which are selected as representative of a hydrological region, i.e., region within which hydrological similarity is presumed. They are used for intensive investigations of specific problems of the hydrological cycle (or part thereof) under relatively stable, natural conditions. Thus a sparse network of representative basins may reflect general hydrological features of a given region and their variations over large natural zones.

Why Basin as a unit for representative Basin studies

The hydrological parameters (or responses / outputs) are the functions of energy inputs provided by climate above the surface and the endogenic processes below the earth surface. To understand the hydrological cycle in general and hydrological system, in particular, in different hydrological regions, the relationships among the energy inputs; and hydrological outputs is required. A drainage basin is excellent example of open system where in the input - output relationships can be obtained; most precisely. It is widely recognised as a fundamental unit in the hydrological milleu because;

- A drainage basin may be defined as a the area which contributes water to a particular stream or set of streams (Leopold, et.al., 1964).

- It is a limited, convenient usually clearly defined and unambiguous topographic unit available in a nested hierarchy of sizes on the basis of stream ordering (Horton, 1932, 1945; Chorley, 1969).
- It is possible to quantify the amount of energy inputs and basin responses within certain natural boundaries and therefore, it is easier to develop the relationship between input and output parameters and to define the amount of water capacity, balance and storage within the basin.
- Basin provide opportunity to estimate the amount of erosion because measurements of the sediment concentration can be combined with measurements of river flow and by knowing the area of the drainage basin and by assuring a diversity of material, rate of land erosion over the whole catchment may be deduced (Gregory and Walling , 1979).
- It is easy to estimate the volume of material which has accumulated in the reservoir and if the date of construction of the reservoir is known, this can also provide the basis for estimating of land erosion rate.
- The study of deposits within the basin can provide considerable informations about the hydrological processes and about the chronology of the events which occurred in the past.

Selection of Representative Basin

The selection of representative basins depends upon the purpose of the study. However, Toebes and Ouryvaev (1970) have emphasised on the following points while selecting representative basins

- Representativeness
- Basin divide
- Consistency of conditions
- Deep percolation and channel infiltration
- Quality of flow measuring stations
- Access
- Size of representative basin

A brief account of these points based on Toebes and Ouryvaev(1970) is given below.

The type and range of climate, vegetational, geomorphological, pedological and geological characteristics of the selected representative basin should be compared with those of the hydrological region.

The water divide of the selected representative basin should be as distinct as possible for the extent determination of a basin boundary and area. If a basin is suitable in all aspects but the basin divide is not clear, an artificial divide can be constructed by means of small dams or walls.

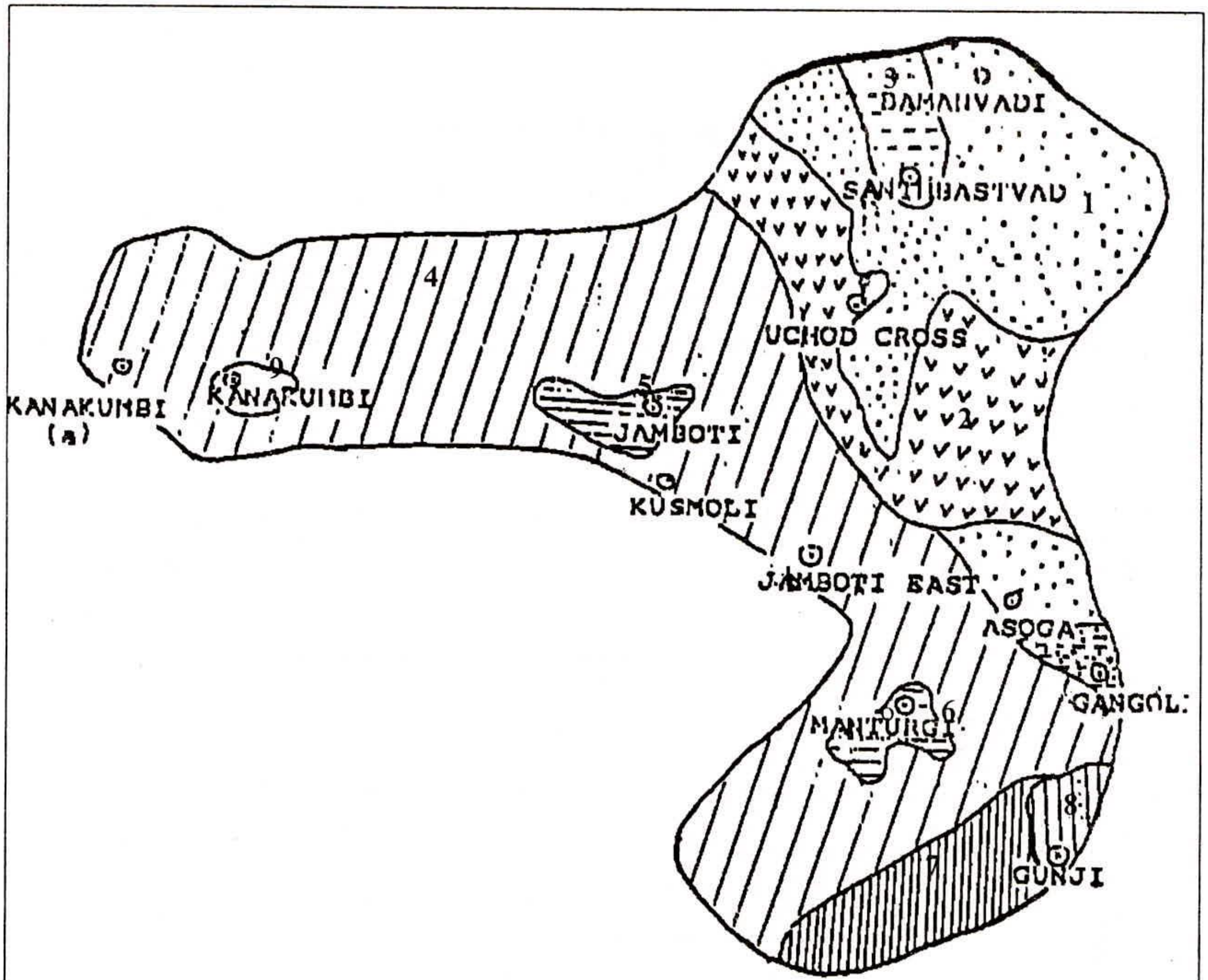
The cultural changes in land use, land management, stream utilization etc. should be minimal during the period of study and where they are inevitable, should be carefully recorded. The loss of subsurface flow by deep percolation, or the gain of this flow from neighboring basin must be as small as possible.

It is essential that stage discharge relation is relatively constants. For this purpose, the site for a gauging station should have a natural control should be constructed. Access of gauging station should be available for every stream flow conditions. Access in the representative basin should be such that precipitation and other climatic observations can be carried out.

The size of the representative basin depends on the purpose for which the basin is being established. In general the representative basin should be so small that its sensitivity to high to high intensity rainfalls of short duration is not suppressed by channel characteristics.

3.4.1 STUDY AREA

The Malaprabha representative basin lies in the extreme western part of the Krishna basin. It extends in between 74 20 and 74 30 E longitudes, and 15 20 and 15 40 N latitudes and encompasses an area of 540 Sq. km of the Belgaum district in the Karnataka state (fig 27). Two major roads run through the Malaprabha representative basin are Belgaum-Goa (N 4A) and Belgaum - Mapusa state high way. This representative basin is the major sour e of water yield for the Naviluteerth Dam constructed at 35-45 km downstream of its mouth. This dam impounds about 1377 mcm water and provides water for irrigation approximately for 2.17 lakh ha land.



1. Agriculture Land having medium black soil underlain by tertiary Basalt
2. Shrub having medium black soil underlain by tertiary Basalt
3. Barren land having medium black soil underlain by tertiary Basalt
4. Forest region having red loamy soil underlain by tertiary Basalt
5. Agriculture land having red loamy soil underlain by tertiary Basalt
6. Forest land having medium black soil underlain by tertiary Basalt
7. Forest land having Red loamy soil underlain by Pre-cambrian Sedimentary rocks
8. Agriculture land having Red loamy soil underlain by Pre-cambrian Sedimentary rocks
9. Barren land having Red loamy soil underlain by Basalt

Figure 27 Land Use Map of Malaprabha Representative Basin

Basin characteristics

A brief description of the Malaprabha representative basin characteristics, i.e., geology, soils , land use pattern and geomorphological parameters are given below.

Geology

Geologically the Malaprabha representative basin comprises of two main geological formations (1) Tertiary basalts, (ii) Sedimentary Formations of Pre-Cambrian age.

Table 6 : Distribution of area under different rock formations in the Malaprabha representative basin

Rock Formation	Area in sq. km	Area in %
1. Tertiary Basalts	518.4	96 %
2. Sedimentary Rocks	21.6	4 %
Total	**540.00**	**100 %**

Soils

Pedagogically speaking, the basin rocks are covered by thin (0.5 m) to thick (10 m) layer of soils which are divisible into two major groups. These are red loamy soils and medium black soils.

Table 7: Distribution of area under different soil groups in the Malaprabha Representative Basin

Soil Groups	Area in sq. km	Area in %
1. Red loamy soil	432.0	80.0
2. Medium Black soil	108.0	20.0
Total	**540.00**	**100.00**

Landuse Pattern

Land use pattern of the Malaprabha representative basin is very complex comprising of forest, agriculture, shrubs and barren land. Area under different category of land is presented. A brief description of the different land use based on IRS-1A-LISS-II imageries and subsequent field check is presented below.

Table 8: Distribution of area under different land use type in the Malaprabha Representative Basin

Sl. No.	Land Use Type	Area in sq. km	Area in %
1.	**Forests**	**338.58**	**62.65**
2.	**Shrubs**	**104.22**	**19.35**
3.	**Agriculture**	**90.99**	**16.85**
4.	**Barren**	**6.21**	**1.15**
	Total	**540.0**	**100.00**

Geomorphology

The relief of the Malaprabha representative basin varies between 668 and 1038 m from the mean seal level. The contour map depicts the morphological characteristics. The pattern closely spaced contours on the water divides indicates that the cress and mid-crest have convex-concave slope, and the widely spaced contours in the valley bottom indicate gentle and flat valley bottoms. Thus, the basin is divisible to three distinct morphological zones.

These are
* Convex hill summit (more than 900m)

* Concave and gentle mid-crest and (800 - 900 m)

* Flat valley bottom (less than 800 m)

This change in morphological character from hill crest to valley bottom of the basin is largely responsible in the change in behaviour of water flow between hillslope and foot slope. Further detailed geomorphological studies are required to understand the change in behavior of the hydrological processes form hill slope to foot slope.

The 800 m contour line divides the area into the hillslope. Above this contour line there is convex-concave hillslope which has completely erosional environment. This is the zone of maximum overland flow and the minimum infiltration. The area below the 800 m contour line encompassing an area of 86.5 % of the total basin, the gentle and flat slope has depositional environment. This is the maximum recharge zone of the basin as is made up of colluvial materials.

The entire basin is divisible into as many as six altitudinal zones ranging from less than 700 m to more than 100 m . The spatial distribution of these altitudinal zones is depicted in figure 11. Contains that a large part, i.e., 86.5 of the basin area falls under less than 800 m relief group and a small part falls under more than 1000 m. Area under other altitudinal ozones, i.e., between 800 m and 900 m and 900 m to 1000 m stands at 12 % and 1.5 % respectively.

Drainage Density

The drainage density based on topographic map varies between less than 0.5 km/sq. km on flat low lying depositional areas and more than 2.5 km/sq.km on convex hill crests in southern part of the basin, composed of relatively less resistant rocks of Pre-Cambrian age. The drainage network and the spatial distribution of different drainage density regions of the Malaprabha representative basin.

Stream ordering

As per Horton (1932) stream hierarchy modified by Strahler (1952) , there are as many as 784 first order, 198 second order, 50 third order, 8 fourth order and 2 fifth order streams are there in the Malaprabha representative basin.

Stream Length

The total length of the drainage network of Malaprabaha stands at 1186.03 km. The distribution of this total length under different stream order segment is presented in the table which reveals that a large part of stream length (82.7 %) is covered by the first and second order streams and a small part (4.3 %) by the large streams, i.e., fifth (.4.01 %) and sixth order stream (0.2 %). The remaining part is covered by medium size streams i.e., third (8.2 %) and fourth (4.9 %) order streams.

Table 9 :Drainage morphometry of the Malaprabha representative basin

Stream order	No. streams	Bifurcation ratio	T.S.L	M.S.L	S.L.R
1	784	3.96	651.16	0.83	-
2	198	3.96	329.3	1.66	2.0
3	50	6.25	97.46	1.95	1.17
4	8	4.0	58.14	7.27	3.73
5	2	2.0	47.62	23.81	3.27
6	1	-	2.35	2.35	0.10

* T.S.L - Total stream length in km

** M.S.L - Mean stream length in km

*** S.L.R - Stream length ratio

3.4.2. Spatial Variation of Soil hydrologic Properties in Malaprabha representative basin

The surface soil hydrologic properties are discussed below. For proper characterization of the surface soil properties 4 sites have been selected and hydrological analyses were carried out. The first site represent an agriculture land and is close to the Malaprabha river. Various types of agriculture crops are grown in this land. The soil is dominated by sand 56% followed by silt- 29% and clay-15%. Average bulk density of the soil sample is 1.48 g/cc. Observed saturated moisture content varies between 38% and 44%. The field capacity of the soil is 0.22 and the wilting point is 0.11. The infiltration rate for agriculture land with medium black soil underlain by basalt's varied between 1 -2 cm/hr and agriculture land with red loamy soil underlain by basalt varied between 2-3 cm/hr. Other hydrologic properties and retention parameters are shown in table 10 and fig.28 to 37.

Khanapur-Gunji Belt : Site numbers 1 to 7 are lying on the Khanapur- Gunji stretch (fig) Khanapur is about 30 km and Gunji is about 45 km from Belgaum at an altitude of about 686 MSL. In this stretch variation of soil moisture characteristics were observed based on different land use covers.

The sample collected from a depth of 1/2 ft - 1ft depth shows that the sand percentage decreases considerably (5%), silt (40%) and clay (55%) showed very high content. In this case, field capacity and wilting point are quite high (0.48 and 0.32). The average bulk density is 1.19. Observed saturated moisture content 0.55. The rate of infiltration also considerably.

The experiments conducted on different forestlands along the same stretch of land show that though the percentage of sand (site no 6) is higher on degraded land (site no 7), there is a considerable decrease in the rate of infiltration and hydraulic conductivity in the degraded land. When the forest cover is afforested with bamboo plantation, there is an improvement in the infiltration and hydraulic conductivity values. This clearly demonstrate that, the forest degradation will result in reduced percolation/infiltration and increase in soil erosion.

A stretch along the Belgaum - Jamboti belt, the study indicated that the soil characteristic improve with depth. It is noted that there is considerable decrease in hydraulic properties just below the surface layer(at a depth of about 1/2 ft to 1 ft) and it improved at a depth of 1'- 2'. This increase in hydraulic properties indicate that, in a forested watersheds, the root depth and density plays a significant role in improving the soil properties. (site 7 to site 10).

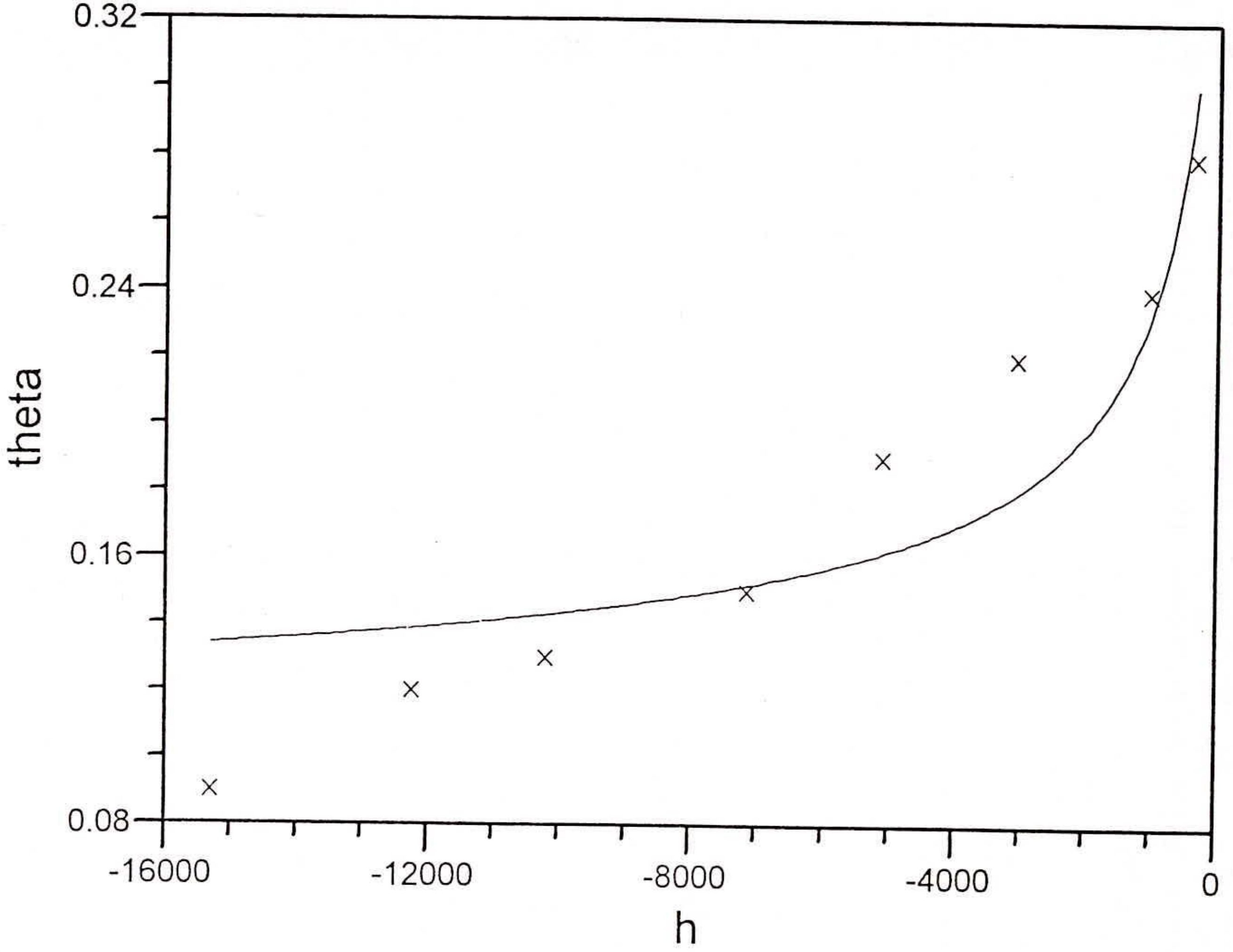


Figure. 28. Soil Moisture Retention Curve for Malaprabha Representative Basin.
(Site 1.)

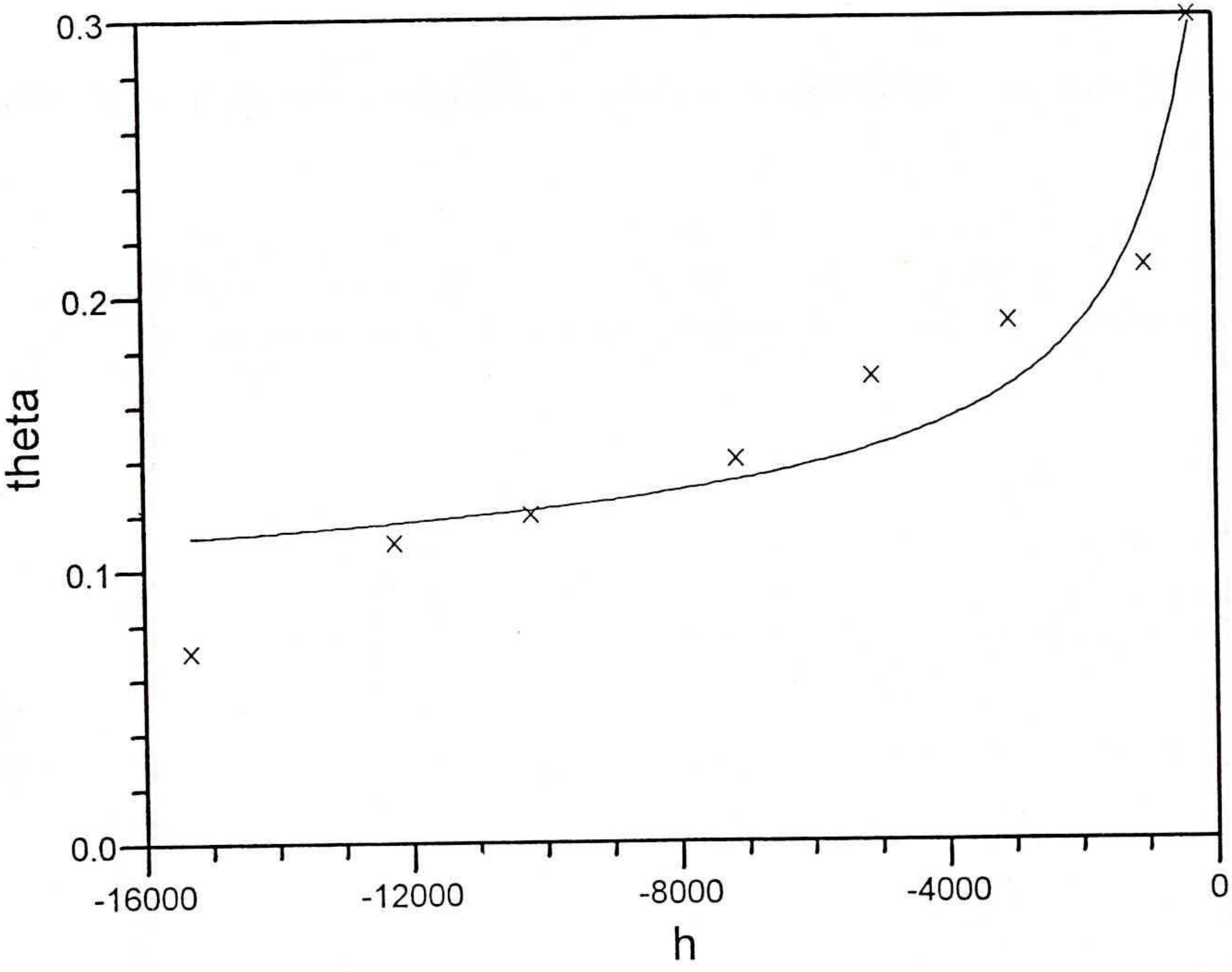


Figure. 29. Soil Moisture Retention Curve for Malaprabha Representative Basin.
(Site 2.)

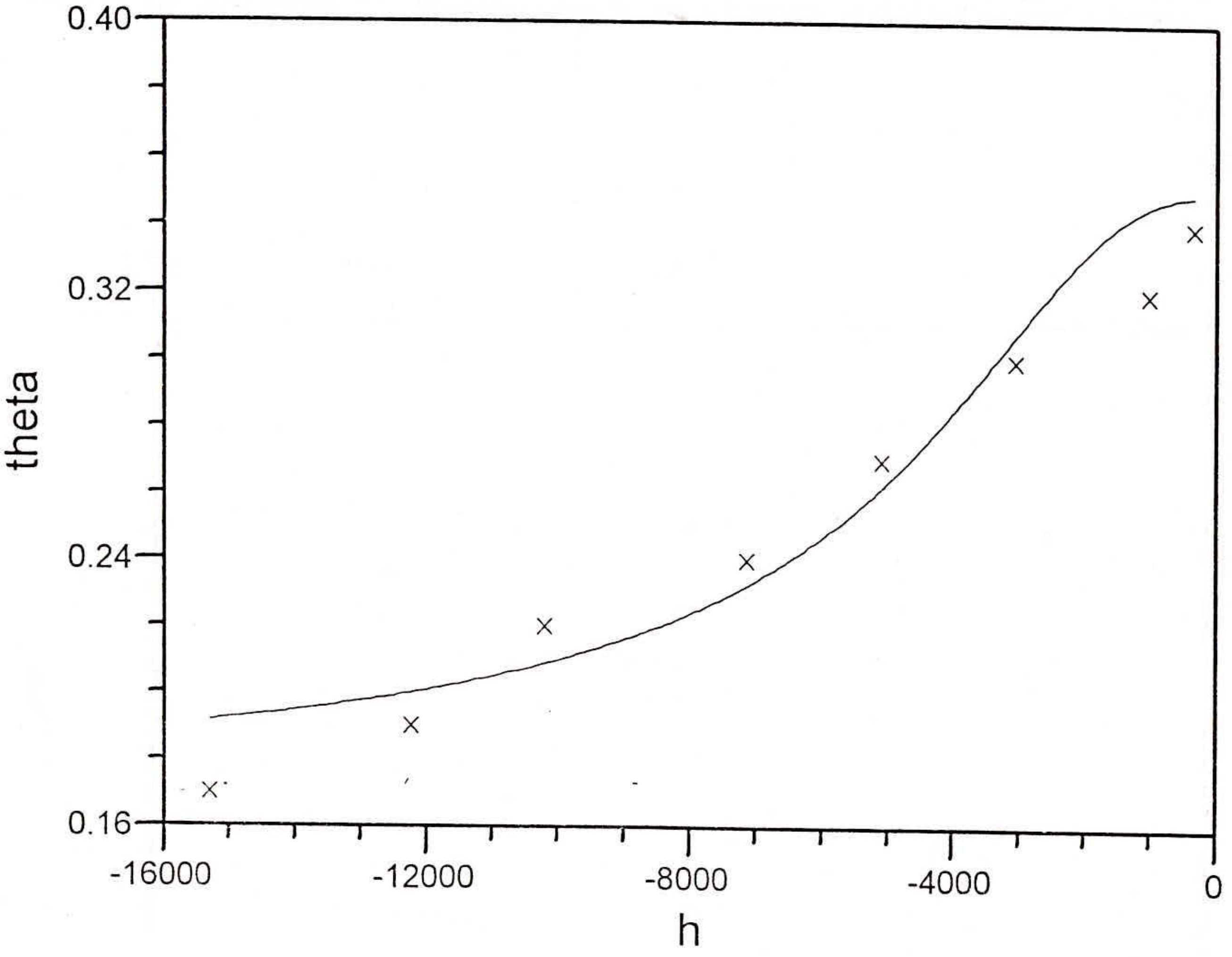


Figure. 30. Soil Moisture Retention Curve for Malaprabha Representative Basin.
(Site 3.)

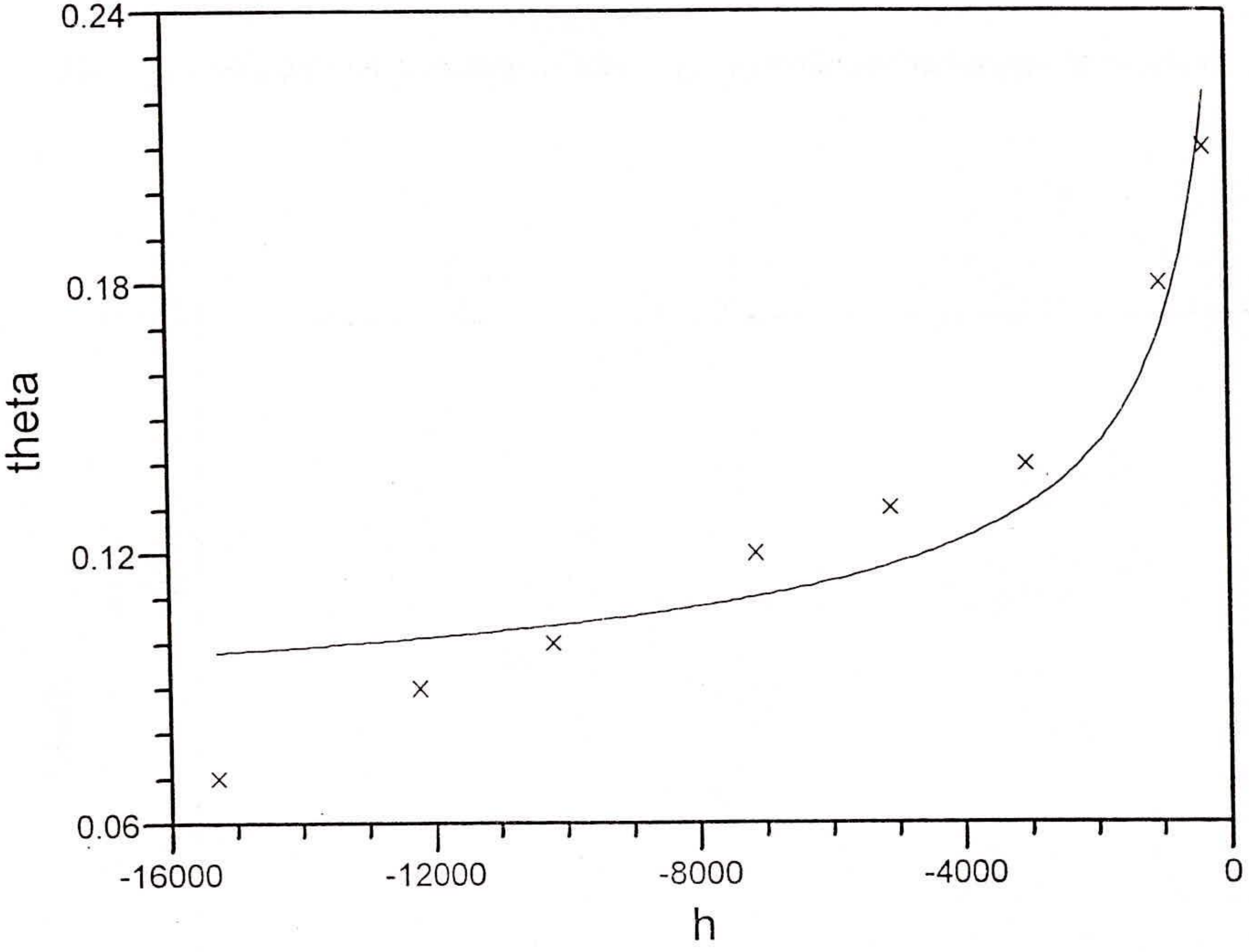


Figure. 31. Soil Moisture Retention Curve for Malaprabha Representative Basin.
(Site 4.)

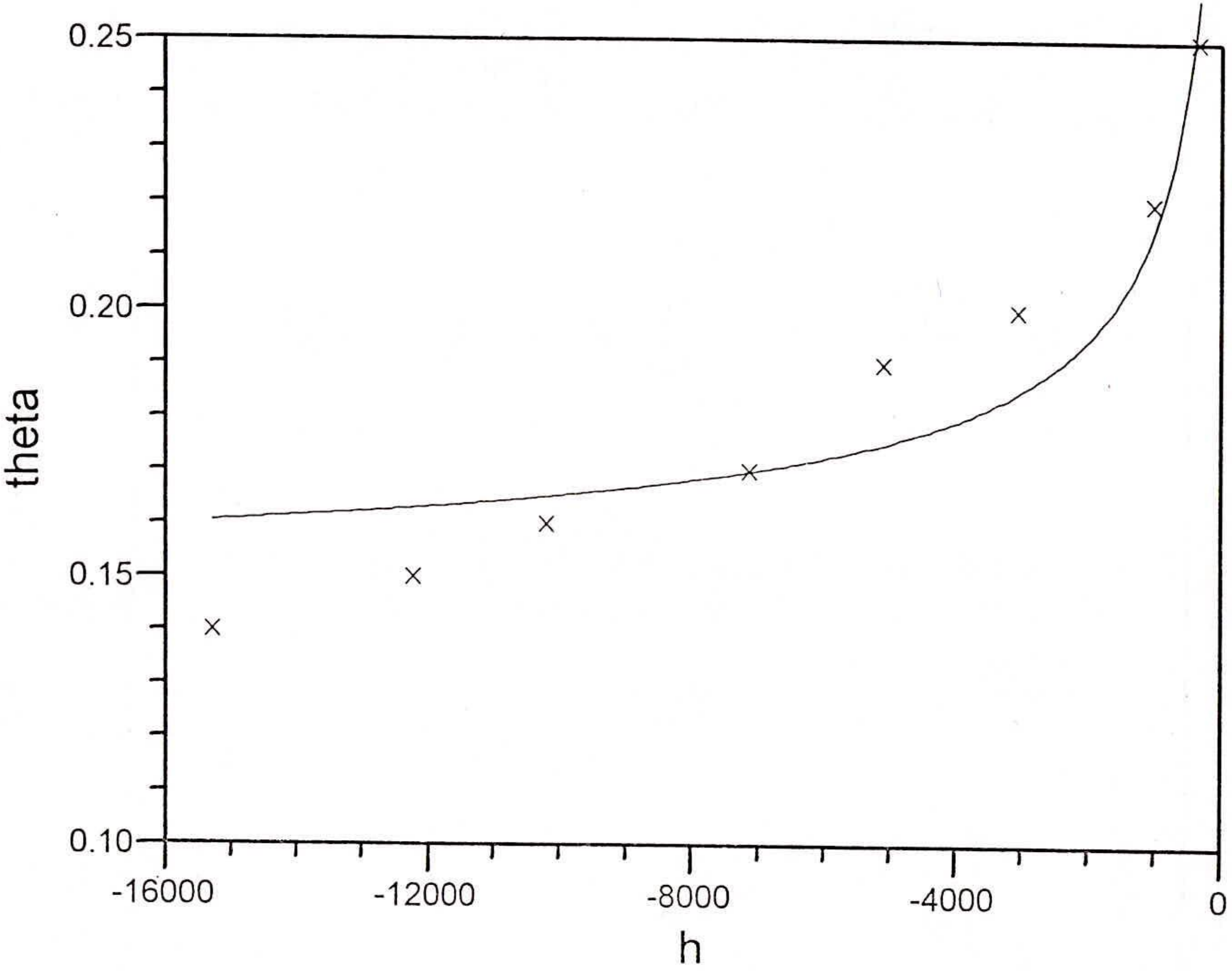


Figure. 32. Soil Moisture Retention Curve for Malaprabha Representative Basin.
(Site 5.)

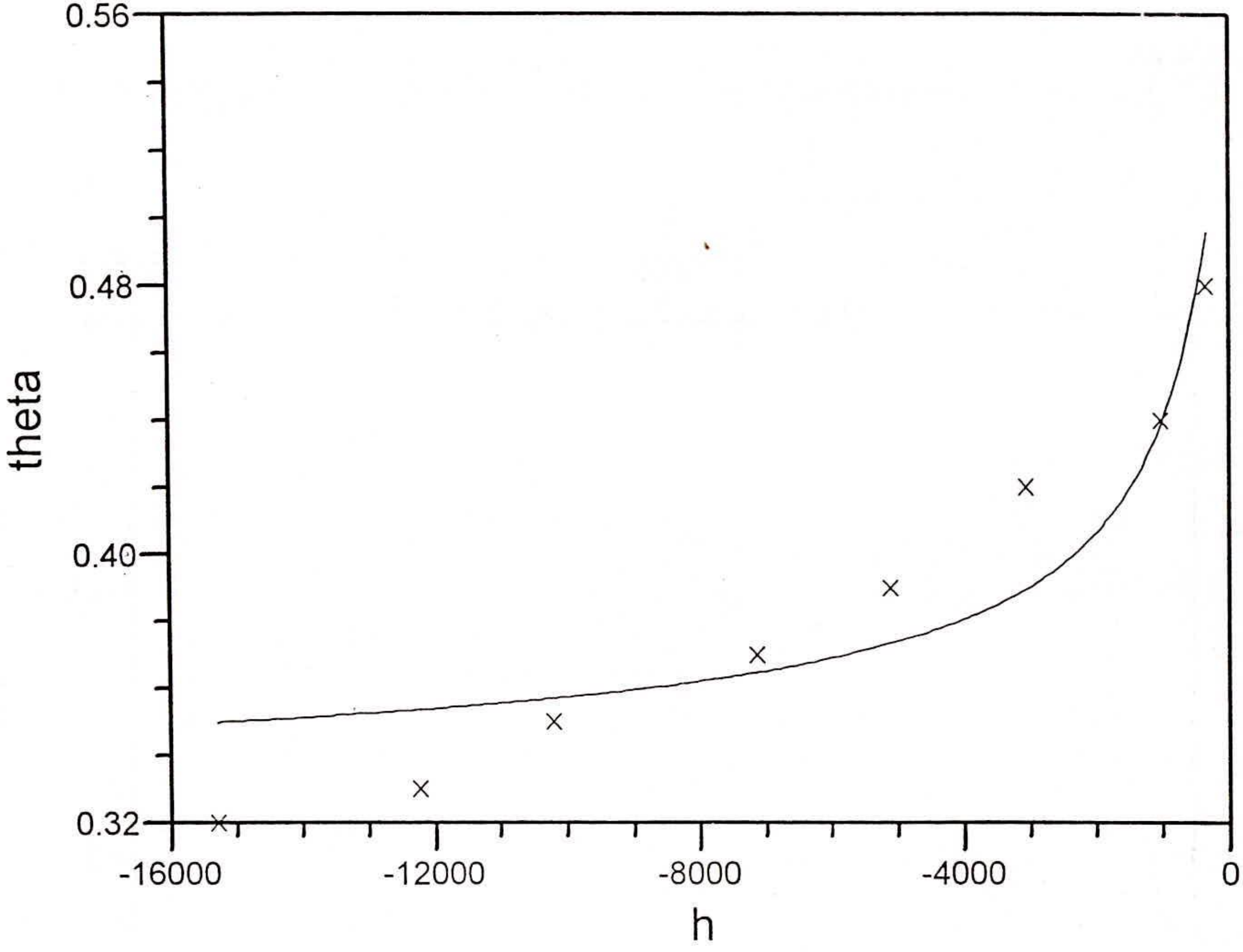


Figure. 33. Soil Moisture Retention Curve for Malaprabha Representative Basin.
(Site 6.)

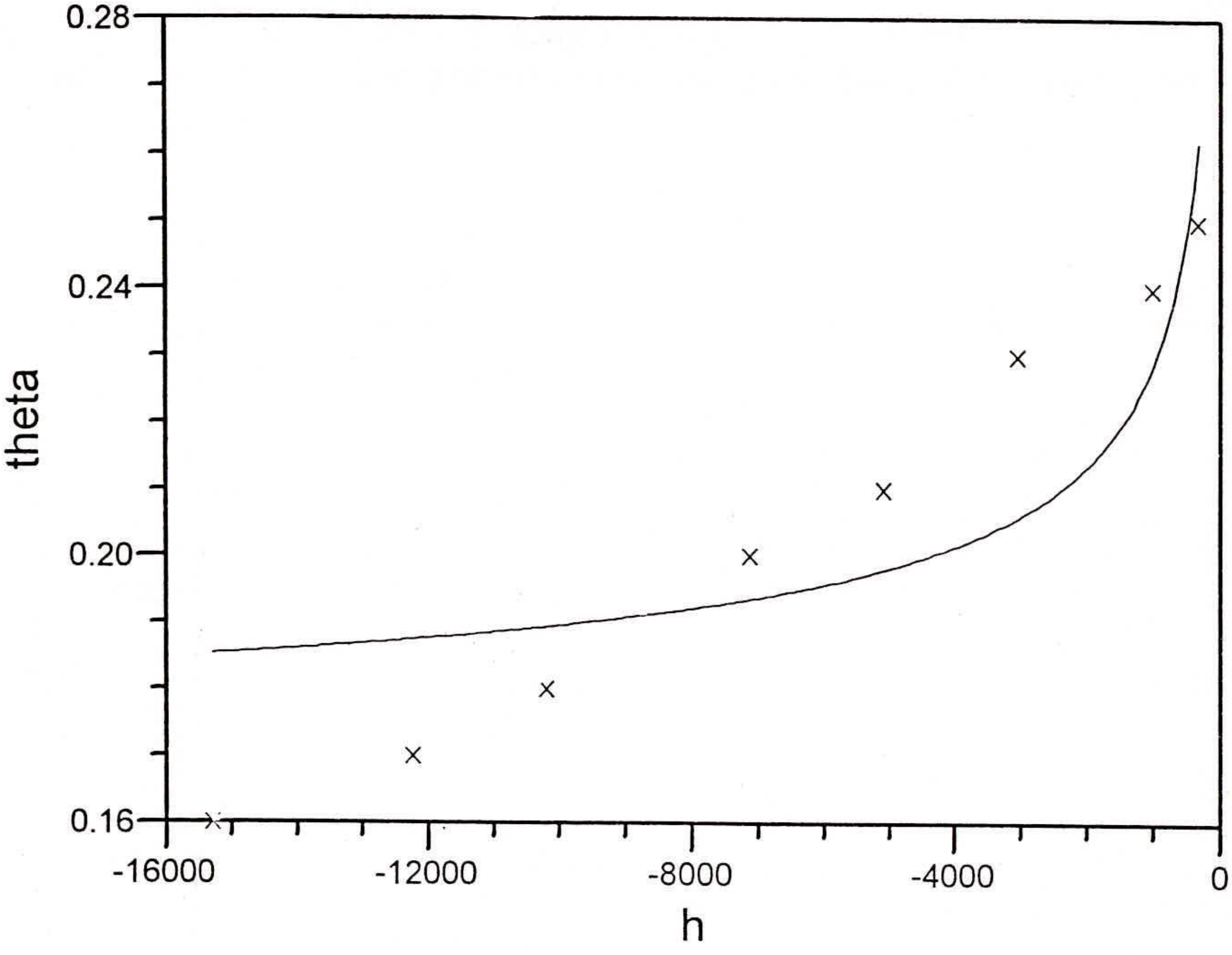


Figure. 34. Soil Moisture Retention Curve for Malaprabha Representative Basin.
(Site 7.)

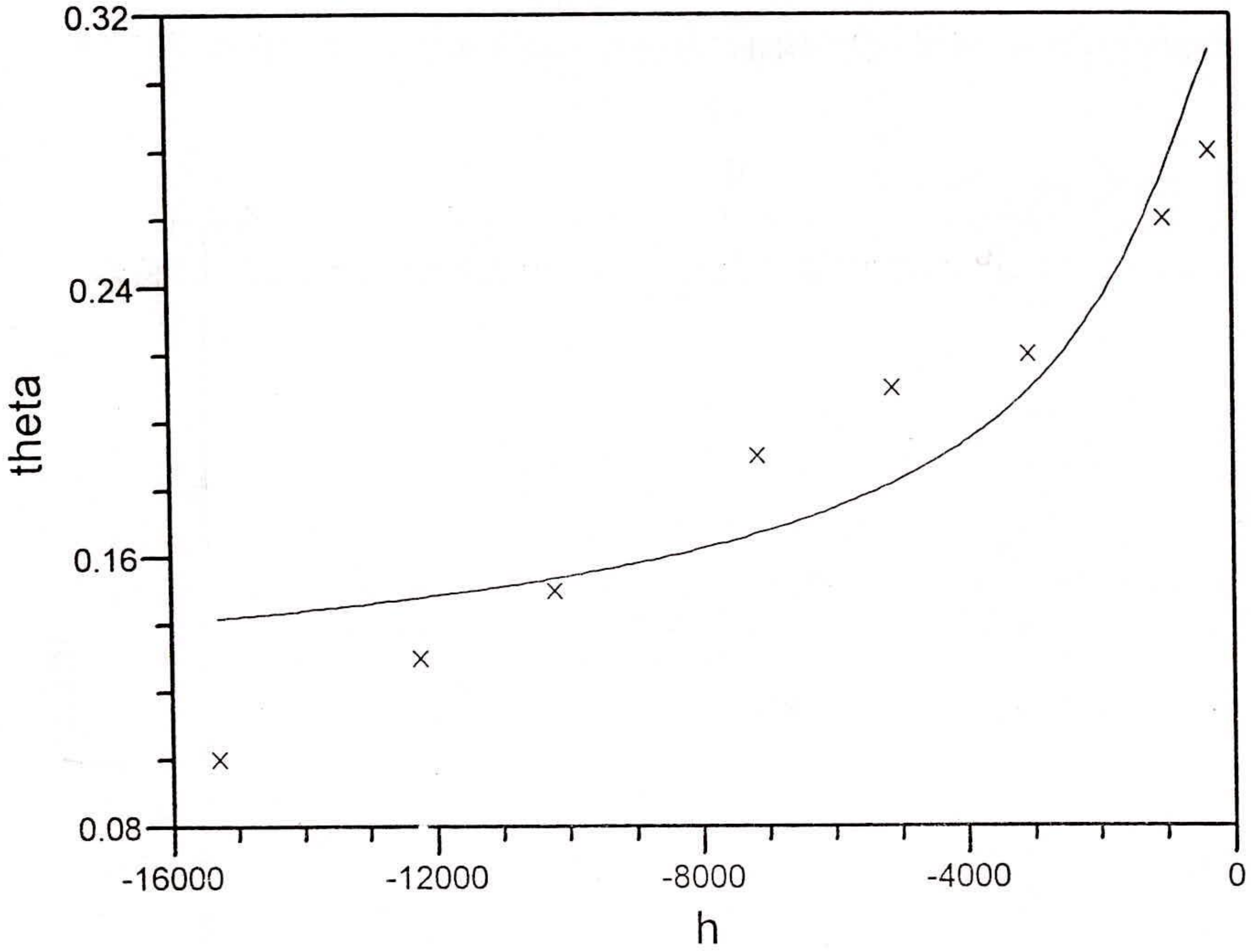


Figure. 35. Soil Moisture Retention Curve for Malaprabha Representative Basin.
(Site 8)

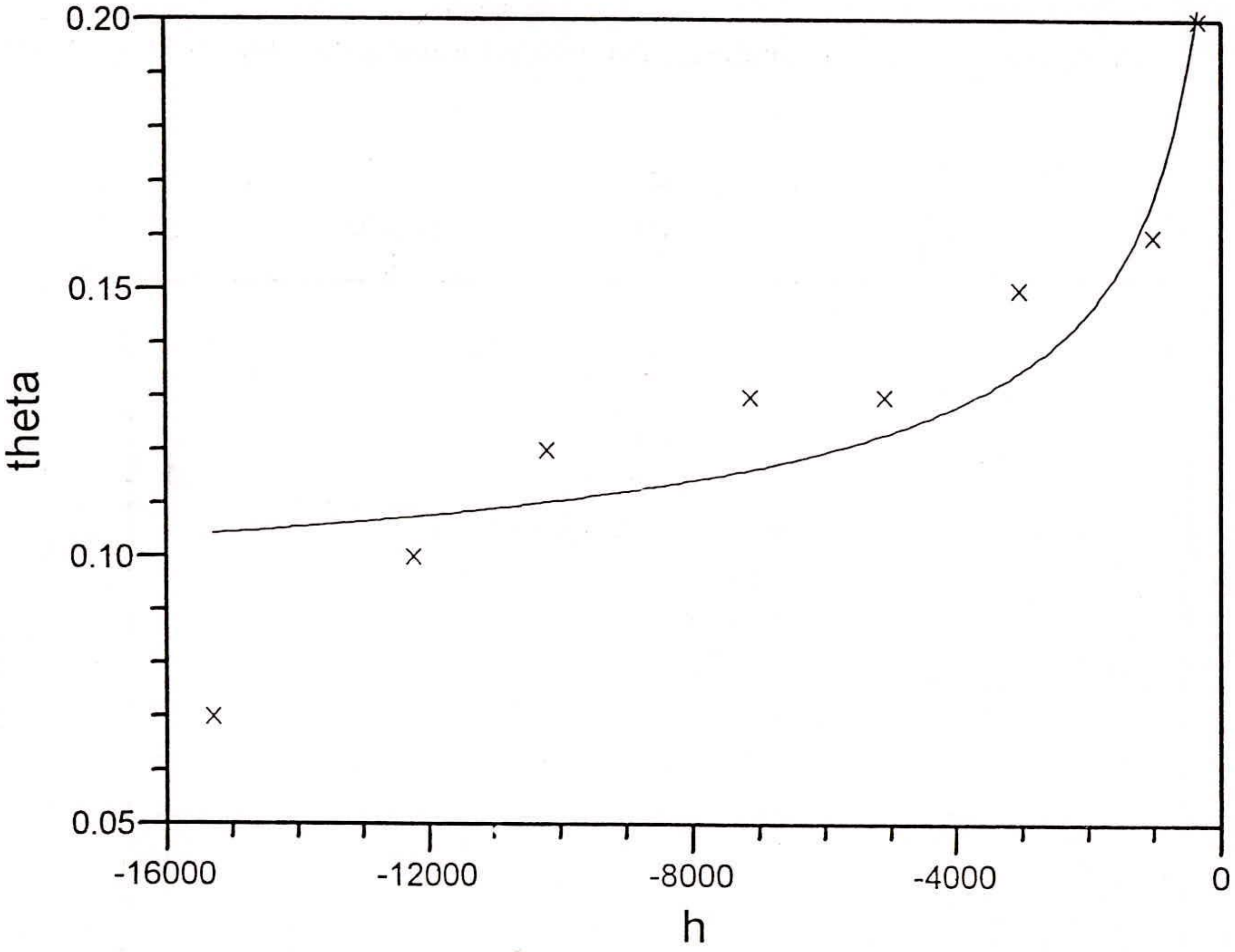


Figure. 36. Soil Moisture Retention Curve for Malaprabha Representative Basin.
(Site 9.)

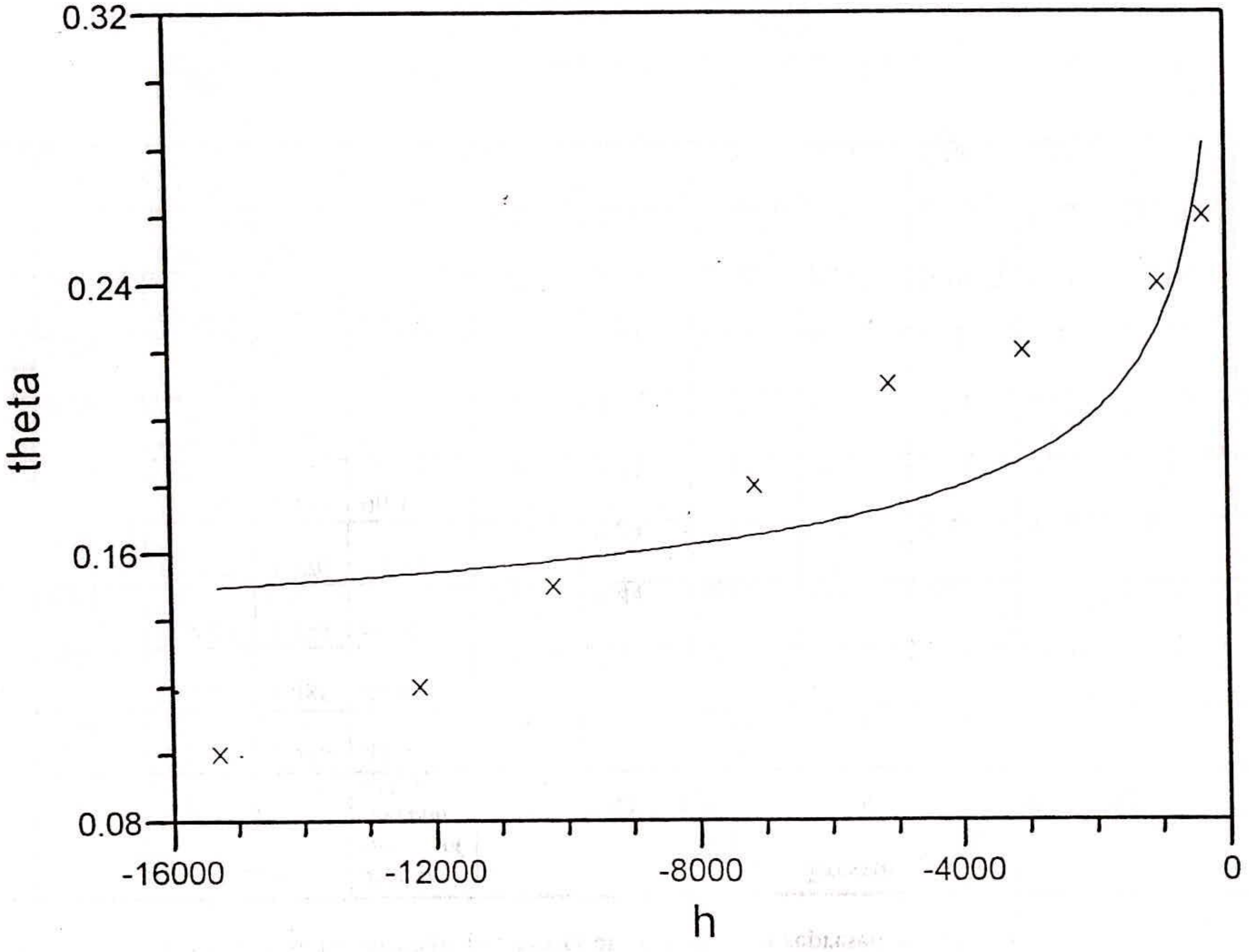


Figure. 37. Soil Moisture Retention Curve for Malaprabha Representative Basin.
(Site 10.)

Table 10 : Soil hydrologic properties of Malaprabha representative basin

Station	Ks Cm/hr	θs	αv	η	Proportion of Variance(%)	Pressure in Bars							
						0.33	1.0	3	5	7	10	12	15
1	2.40	0.38	0.0045	1.446	82.3	0.28	0.24	0.22	0.19	0.15	0.13	0.12	0.09
2	0.60	0.28	0.0042	1.485	90.06	0.21	0.18	0.14	0.13	0.12	0.10	0.09	0.07
3	1.20	0.54	0.0028	1.534	86.38	0.48	0.44	0.42	0.39	0.37	0.35	0.33	0.32
4	0.60	0.38	0.0227	1.370	73.33	0.25	0.24	0.23	0.21	0.20	0.18	0.17	0.16
5	5.40	0.34	0.0022	1.528	90.12	0.30	0.21	0.19	0.17	0.14	0.12	0.11	0.07
6	3.60	0.35	0.0003	2.521	93.79	0.34	0.32	0.30	0.27	0.24	0.22	0.19	0.17
7	0.60	0.28	0.0042	1.485	88.11	0.25	0.24	0.23	0.21	0.20	0.18	0.17	0.16
8	6.00	0.32	0.0009	1.641	83.42	0.28	0.26	0.22	0.21	0.19	0.15	0.13	0.10
9	1.20	0.24	0.0036	1.400	82.69	0.20	0.16	0.15	0.13	0.13	0.12	0.10	0.07
10	4.20	0.39	0.0099	1.350	70.07	0.26	0.24	0.22	0.21	0.18	0.15	0.12	0.10

4.0 Conclusions

On natural watersheds, even in the unusual situation of completely uniform rainfall, there are spatial varations in the supply rate to the surface of the soil. These variations are not only due to properties of the soil matrix but also due to various other factors such as fuficial characteristics(vegetal cover, topography and drainage density), soil characteristics, land use and geology rainfall intensity and antecident moisture conditons. By the process of interception, vegetation removes part of the rainfall and channels other parts to particular localities by the processes of stem flow and leaf drip. Vegetation also reduces the impact energy of droplets, so reducing surface slaking and crusting. Removal of water by tranpiration results in a more uniform reduction of soil moisture with depth, enhancing infiltration, whilst the accumulation of organic matter provides a suitable substrata for soil microorganisms as well as conferring a degree of structural stability to the soil mantle and impeding overland flow. Similar observaiton were cited by Fleming et al. (1975). Spatial variation in geology, weathering and erosional processs contribute to the creation of small depressions and of variaotns in surface slopw and reoughness and sol matrix properties. At the microhydrological level, the supply of water for infiltration can be enhanced by local run on or lateral redistribution of surface water, or process of particular significance in arid regions like Ozhar, Nasik district and Bamnod in Jalgaon district. Fleming (1976) and the bove reasons for arid region.

Form the present, it is also observed that there is a sifnificant variation in hydraulic properties within a watershed or a catchemnt. It is highly difficult task to arrive at a cnclusion or classify watershed especially in hard rock region based on hydrological soil properties. However, the experiments carried out on a catchment scale (i.e. in Malaprabha Representative Basin). In this case, the highest rate of infiltration and hydraulic conductivity were observed in the forested region under lain by red soils. Another reason for higher permeability is due to soil type. Red loamy soils are better conductor of water than medium black soils. Further in forested areas the root depth and density plays a significant role in improving the soil properties. Hydraulic properties of degraded land even with higher percentage of sand, the infiltration rate showed a considerable decrease which could be due to severe erosion taking place in the area. In the region where afforestation was done an increase in infiltration in hydraulic conducivity was observed. This demonstrate the importance of afforestation on degradeded lands.

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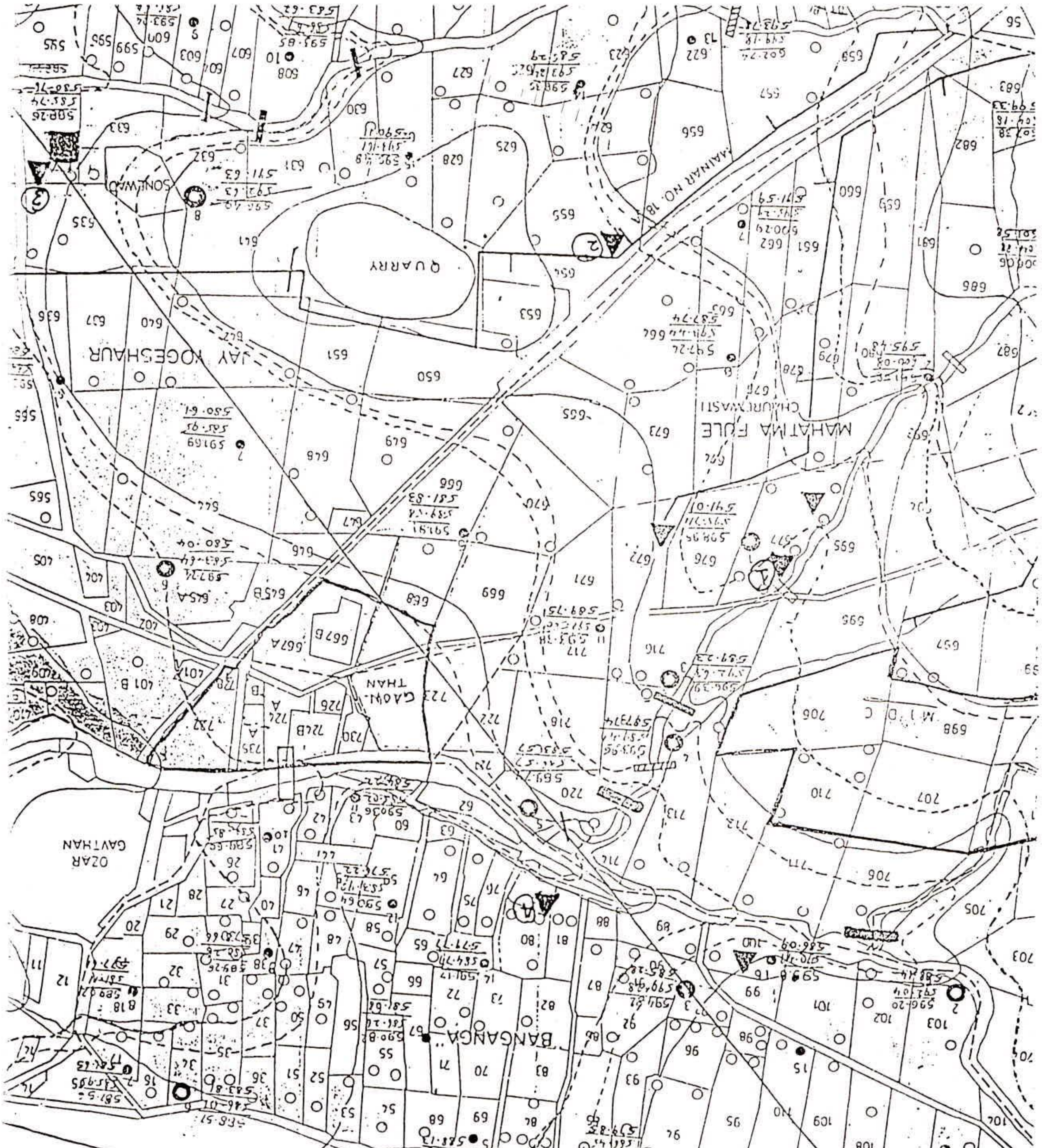
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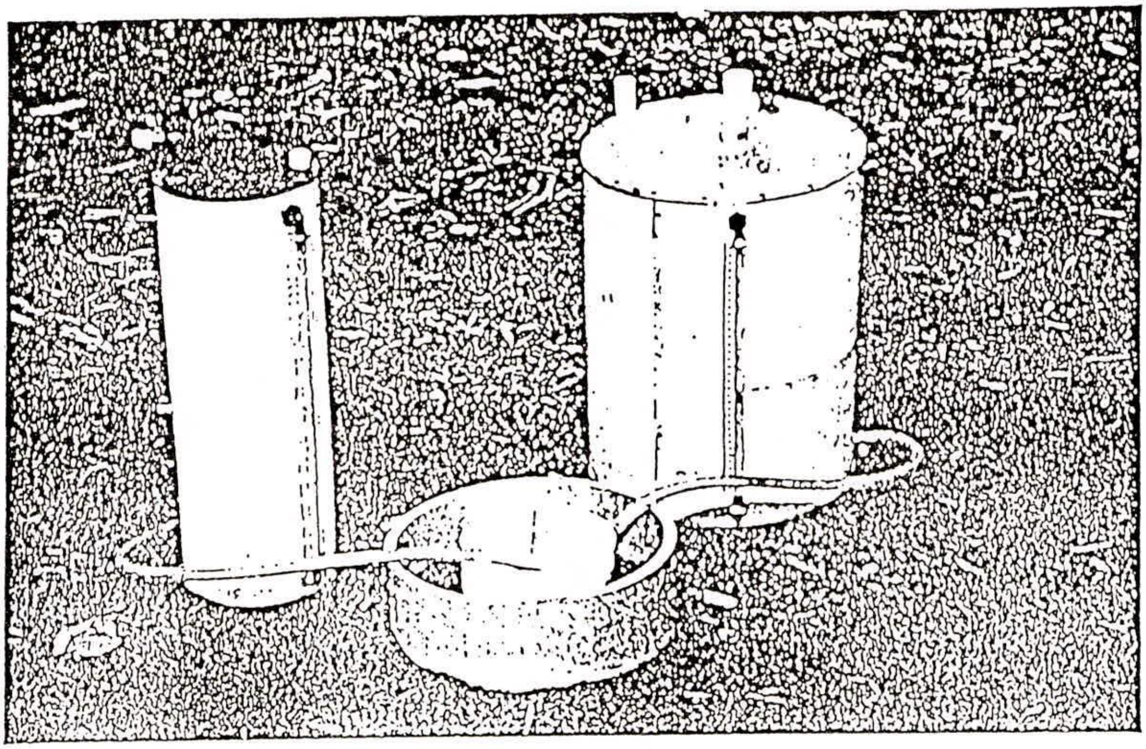


Figure 2a. Ring infiltrometer with a Mariotte hydraulic head device.

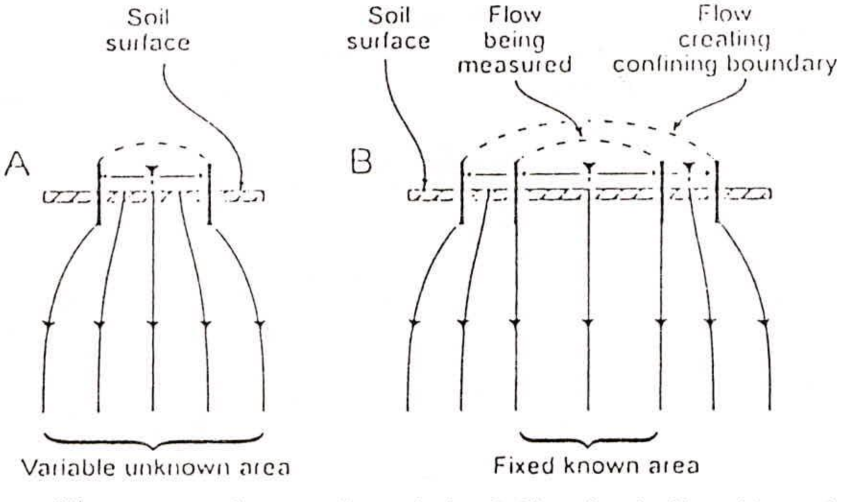


Figure Divergence of streamlines during infiltration buffered by using a double ring infiltrometer.

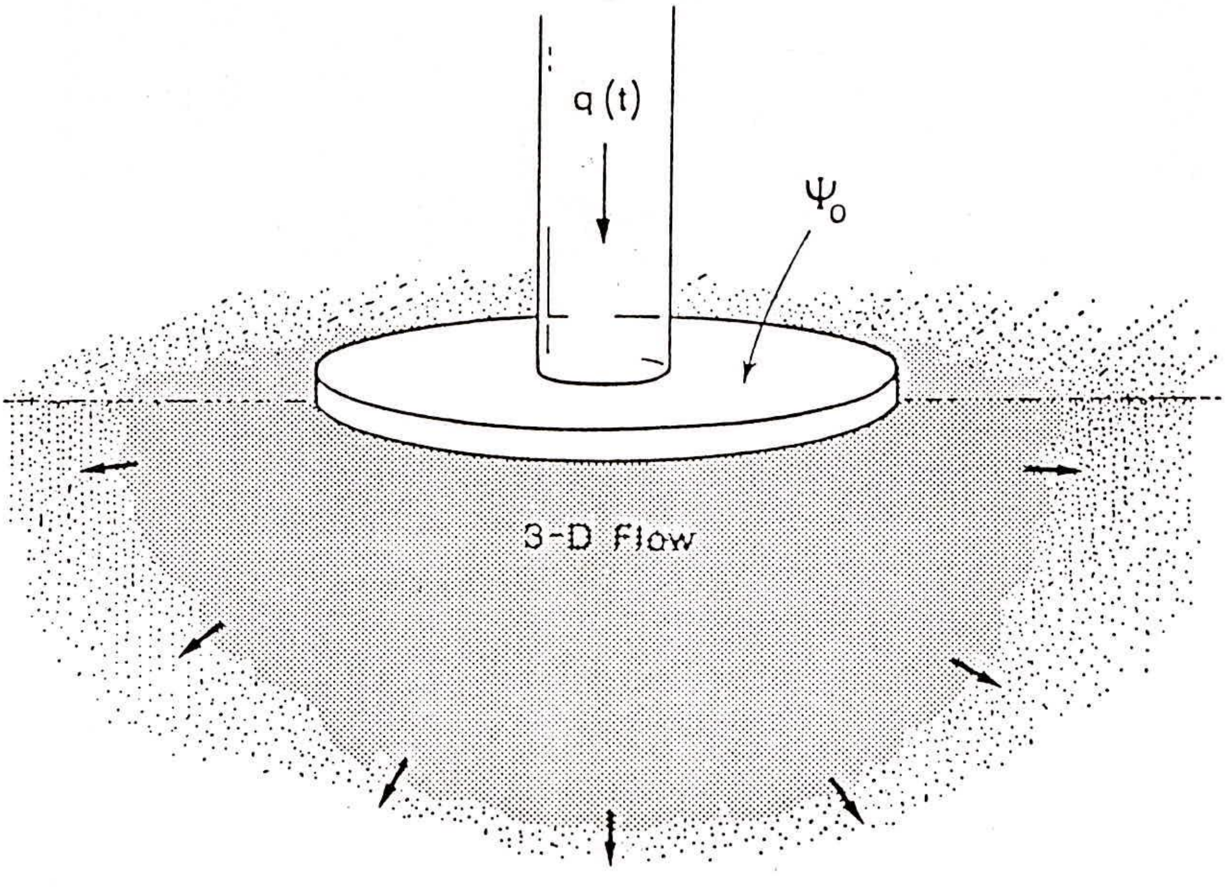


Fig. Three-dimensional flow from a shallow circular pond or surface disc.

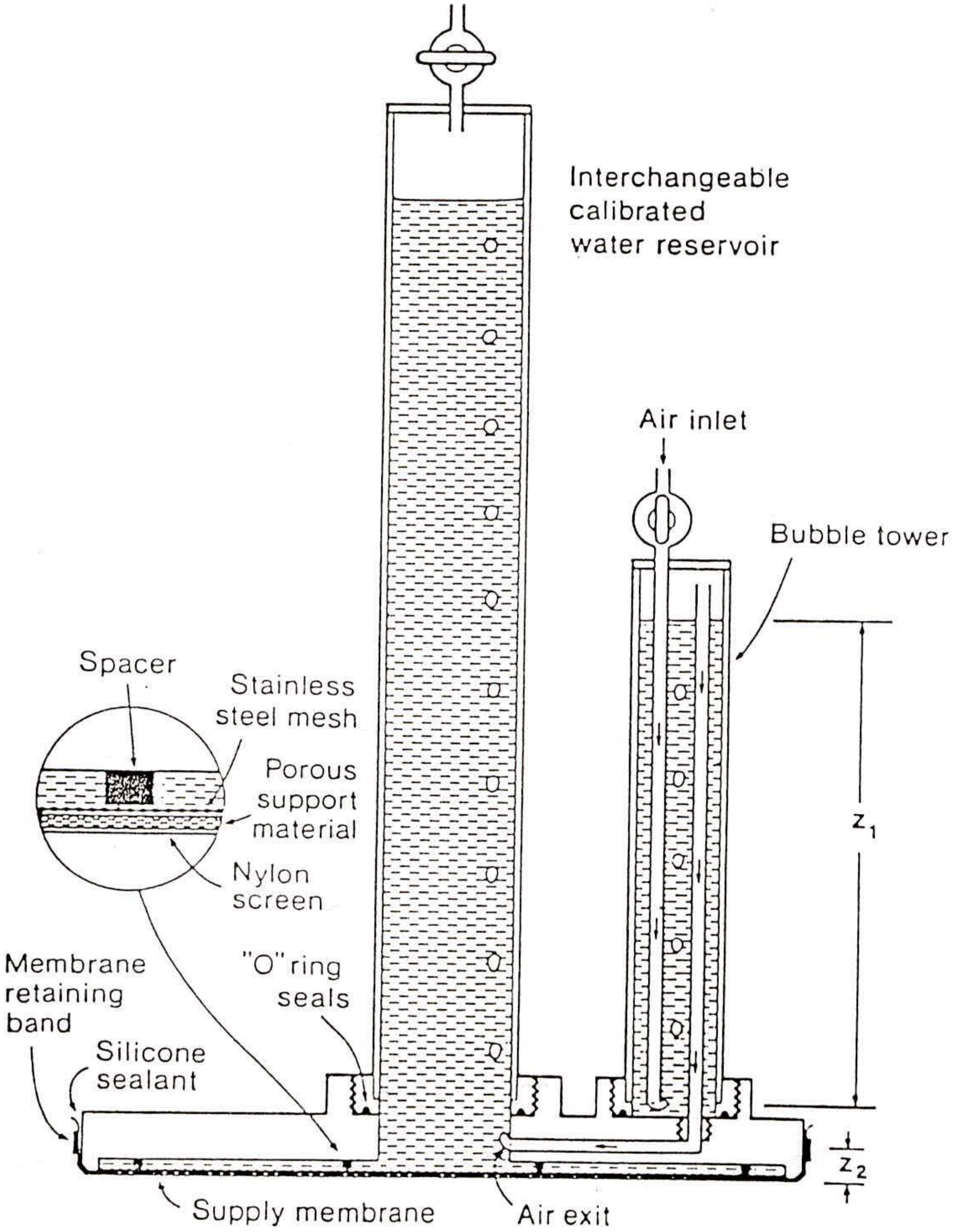


Fig. The disc permeameter for unsaturated measurements.

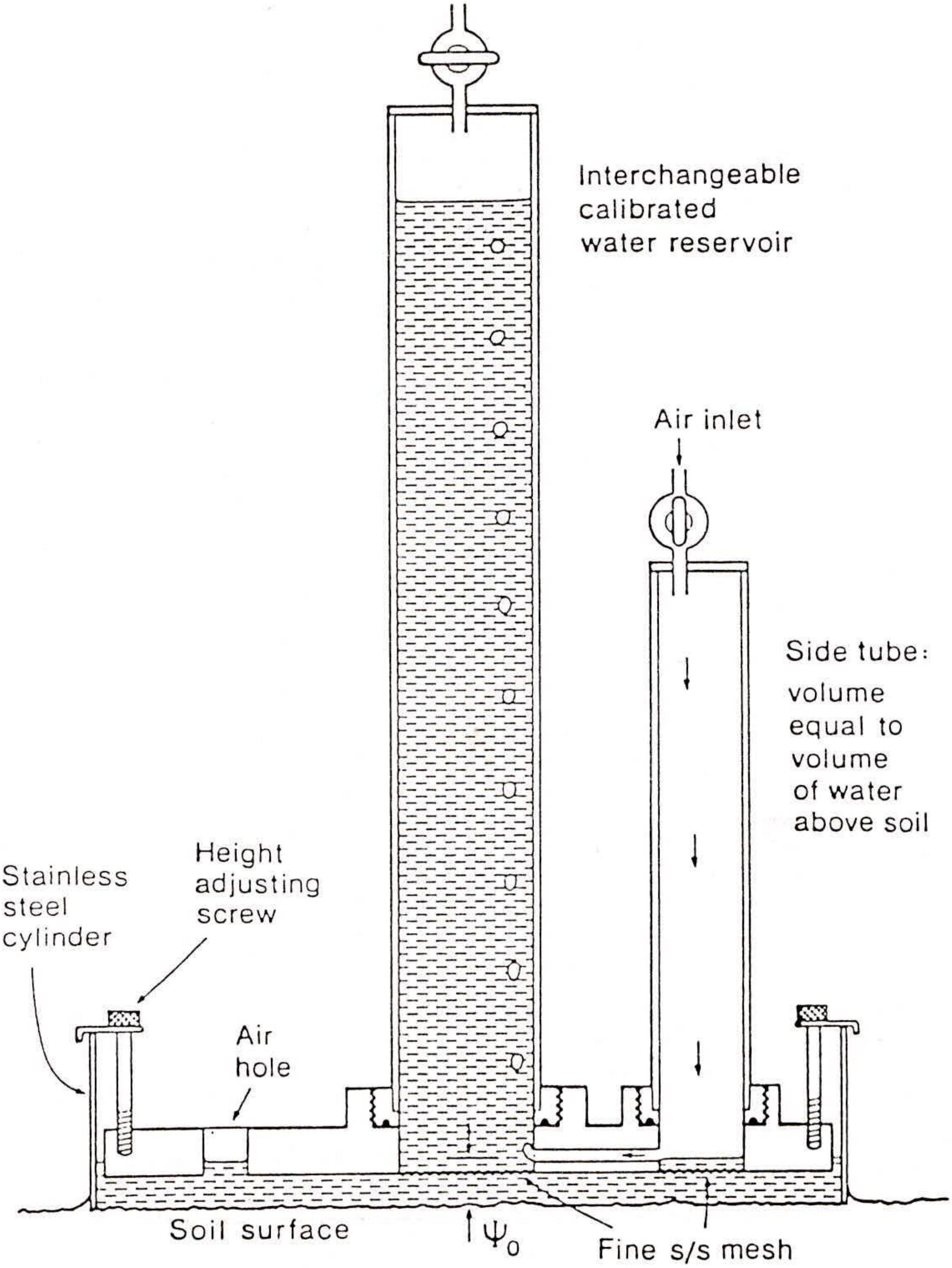
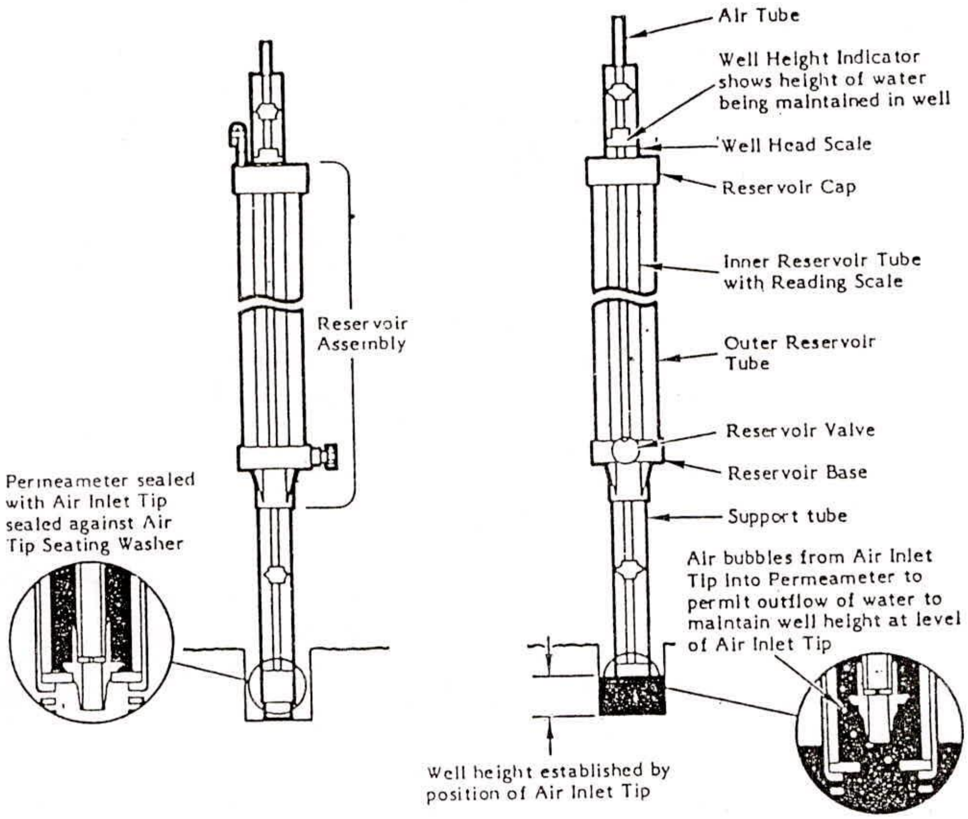
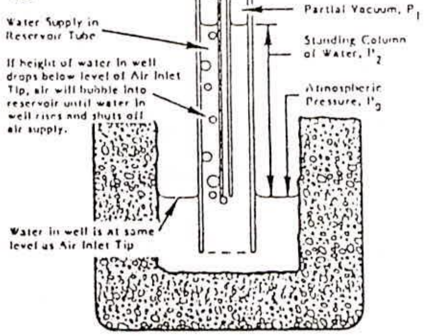
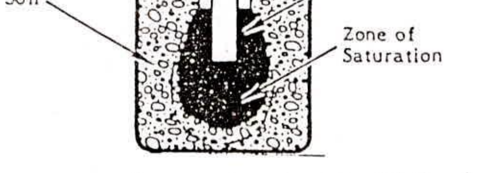


Fig. The disc permeameter for ponded measurements.



Details of reservoir assembly (A) closed or sealed state with air inlet tip sealed against air tip washer (B) when air tube is uplifted permitting of flow of water.





Permeameter in operation (A) Equilibrium is established (B) A view of bulb in zone of saturation

Fig. Guelph Permeameter Reservoir assembly.

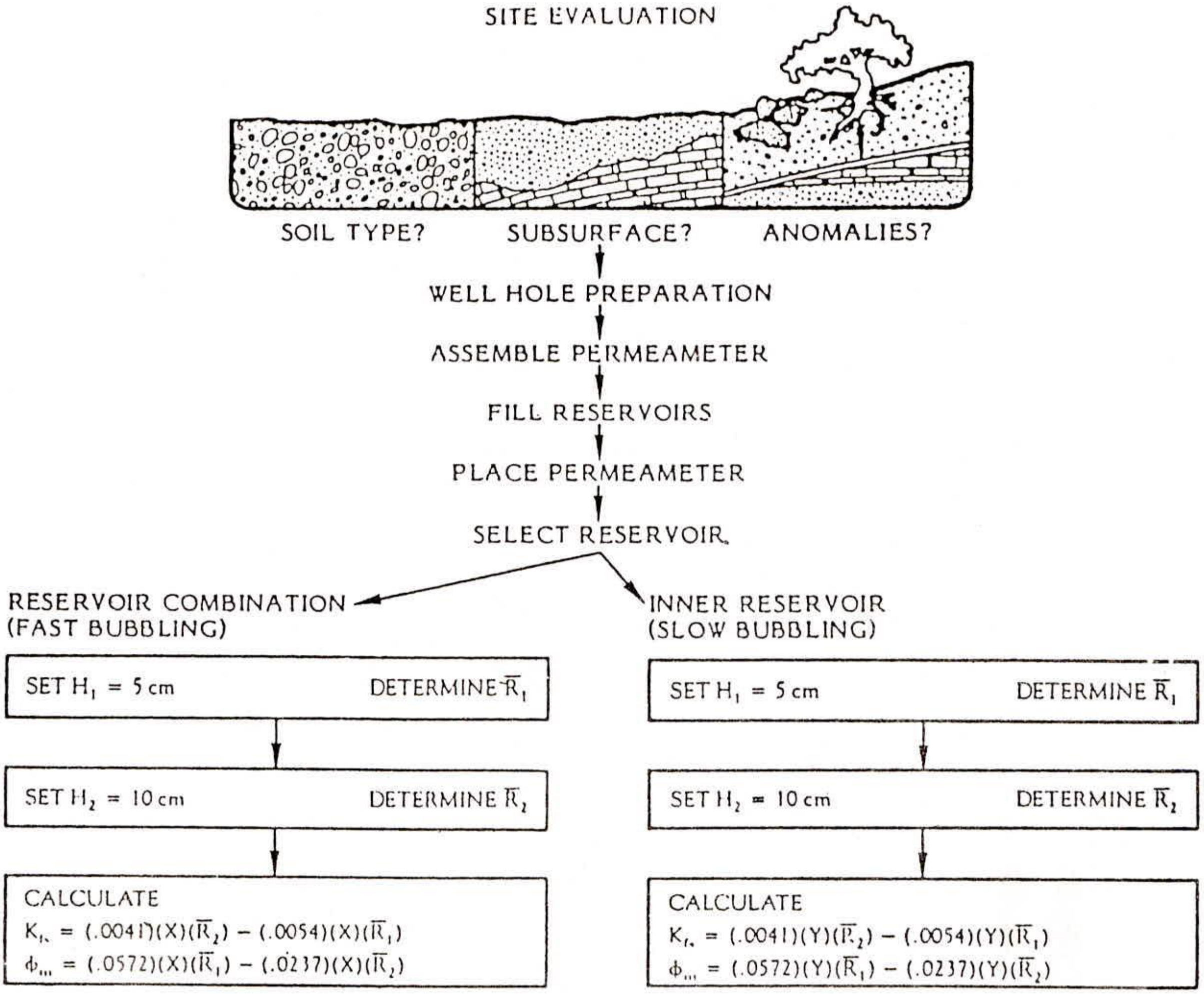


Fig Flow chart of procedure for standardized method of measurement using the Guelph Permeameter

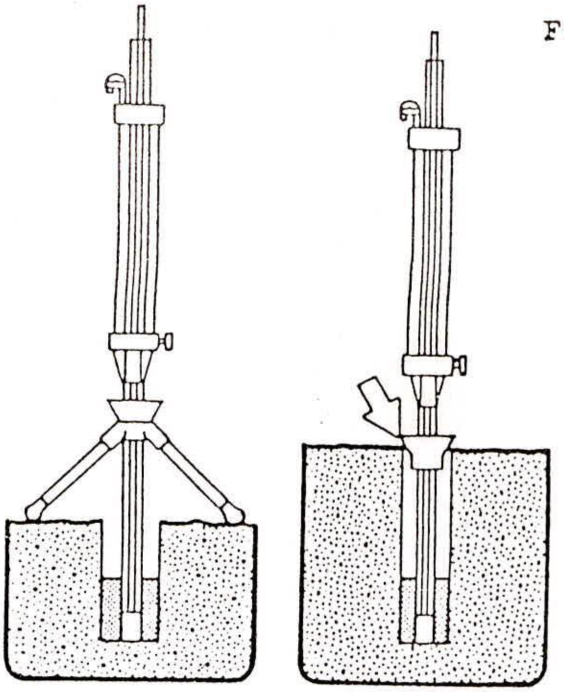


Fig Placement of permeameter in well hole

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