

SPRING DISCHARGE AS WATER RESOURCE FOR AGRICULTURE IN A REGION IN THE STATE OF TRIPURA

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CERTIFICATE

This is to certify that the work recorded in the thesis entitled "**Spring discharge as Water Resource for Agriculture in a region in the State of Tripura**", submitted by Shri Pradip Kumar Saha for the award of the Degree of Doctor of Philosophy in Agriculture (Soil and Water Conservation) of the Bidhan Chandra Krishi Viswavidyalaya, is the faithful and bonafide research work carried out under my personal supervision and guidance. The results of the investigation reported in the thesis have not so far been submitted for any other Degree or Diploma. The assistance and help received during the course of investigation have been duly acknowledged.

(R.K.Ghosh)

Supervisor

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LIST OF ABBREVIATION

Ag.	Agriculture
Agril.	Agricultural
A.A.I	Assistant Agricultural Inspector
Approx.	Approximate
B.C.K.V	Bidhan Chandra Krishi Viswavidyalaya
C.L	Casual Labour
Contd.	Continued
C.G.W.B	Central Ground Water Board
Ch.	Chapter
Col.	column
cm.	Centimeter
Deptt.	Department
ed.	Edition
Engg.	Engineering
Eqn.	Equation
Estt.	Estimated
etc.	Etcetera
Expt.	Experiment
Fig.	Figure
g.	Gallon
ICAR	Indian Council of Agricultural Research
Km.	Kilometer
lit.	Litre
L.I.A.T	Land Sat Imagery and Toposheet
mm.	Milimetre
m.	Meter
m ³ .	Cubicmetre
M.Sc.	Master of Science
M.S.L.	Mean Sea Level

N.E.C	North Eastern Council
N.E.H	North Eastern Hill
N.E.R	North Eastern Region
N.I.H	National Institute of Hydrology
N.R.S.A	National Remote Sensing Agency
Obs.	Observed
pm.	Per minute
ppm.	Parts per million
R.Ls.	Reduced Levels
Res.	Research
Sci.	Science
Sec.	Second
S.W.C	Soil and water conservation
Vol.	Volume
W.B.	West Bengal

LIST OF SYMBOLS

A	Area of recharge zone
	Coefficient of the equation $Q = aRc^b$
b	Exponent of the equation $Q = aRc^b$
a	
b	
a ₀	
a ₁	Empirical constants
a ₂	
a ₃	
a _A	
a _B	Cross Sectional area of flow at Stations A and B, m ²
c	Velocity correction factor
CaCo ₃	Calcium Carbonate
CaSo ₄	Calcium sulphate
D	Distance between stations A and B, m
Da	Monthly average groundwater depth m
°E	Degree East
Fe	(OH) ₃ Ferrous hydroxide
h	Height of channel
ha	Hectare
K ₁	
k ₂	Value of range
L ₁	Length of transition zone
mg	Magnesium
°N	Degree North
S	Aquifer storativity (Eqn. 2.2)
q	Mean monthly spring discharge, lit/sec
q _a	Average spring discharge, lit/sec (Table. A-2 to A-11)

q_{aym}	Spring yield averaged over number of springs and years for a particular month
q_n	Naturally available spring yield
q	Mean monthly spring yield, lit/sec
q_c	Cumulative value of q , lit/sec
Q_0	Initial spring flow
Q	Non-chronological mean monthly spring yield corresponding to R , lit/sec
Q_c	Cumulative value of Q , lit/sec
Q_{max}	The maximum discharge
Q_{min}	The minimum discharge
$Q(t)$	Spring flow at any time 't' after instantaneous recharge
r	Mean monthly rainfall (chronological), cm
R	Rigging of 12 monthly rainfall (r) in an ascending order, cm
R_c	Cumulative value of R , cm
S	Aquifer storativity
So_4	Sulphate
α	Coefficient incorporating aquifer geometry and aquifer parameters commenced
t	Time since the instantaneous recharge
t_m	Time in month e.g. Jan=1, Aug=8, Dec=12 etc.
t_1 :	
t_2 :	Time of travel from station A to B, sec
t_3 :	
T	Time lag (month)
$<$	less than
V_f	Velocity of float m/sec
v_m	Mean velocity of flow
V_p	Variability in percent
w	Width of the channel
W	Width of aquifer

ABSTRACT

Springs as viable water resources in hilly states have tremendous scope specially in valley agriculture. If tapped appropriately this will be of immense help to the people of Tripura in general and tribals of Tripura in particular. As a first step to study this aspect ten springs in Tripura were chosen arbitrarily. With reference to time the discharges of these springs and the subsurface water table depths below ground surface were measured. Rainfall data on the contributing areas were collected from the concerned agencies. Models as given below were established on the basis of the collected data :

$$Q_c = aRc^b$$

$$q_c = a_0 + a_1t_m + a_2t_m^2 + a_3t_m^3$$

Where, Q_c = Cumulative value of Q , lit/sec

Q = Non-chronological mean monthly spring yield corresponding to R , lit/sec

R = Rigging of 12-monthly rainfall (r) in an ascending order, cm

R_c = Cumulative value of R , cm

q = Mean monthly spring yield, lit/sec

q_c = Cumulative value of q , lit/sec

t_m = Time in month e.g. Jan. = 1, Aug. = 8, Dec.=12 etc.

and a , b , a_0 , a_1 , a_2 , a_3 are empirical constants obtained through actual data fitting by least square method. These vary from spring to spring depending on various unknown and known situations. As usual these are the weakest components in our attempts of modeling as no guidelines could be provided to estimate these values.

It is also found on graphical representation that in majority of the cases the average spring-discharge influences the groundwater depth (level) which goes

down with the rise of spring-discharge in general. The relationship is more or less linear.

The available water resources from ten springs have been calculated to estimate the increase in gross cropped area. It is found that in all 173 ha may be covered by water from ten springs. There are quite a good number of springs in Tripura. So if harnessed appropriately a large area can be placed under irrigated agriculture.

This study has helped in planning of monthly and annual spring water utilisation which has a tremendous scope in Tripura and ^{Other} similar ~~other~~ hilly regions.

CHAPTER - I

INTRODUCTION

Tripura is predominantly an agricultural State. About 15.5 Lakhs ^{people} (75% of total population) depend on agriculture (1981 census). Proper and optimum use of water is essential for a stable and growing economy in the State. About two third of the geographical area of Tripura is hilly. The altitude of the state ranges from 60 to 600m. above M.S.L. A sizable portion of cultivable land is situated in the valleys between the hillocks ~~land~~ and locally known as "lunga land, where mainly tribal people of the state live. A part of this land is cultivated by tribals using spring water (chhara, a local name of spring) through various indigenous techniques. The state can be divided into 12 river basins nearly all the rivers have originated from spring or seepage water. Innumerable streams with small catchment area are flowing down the hills and hillocks to the plains.

Springs have fascinated mankind since the beginning of human history. The Greek and Roman philosophers tried to explain origin of springs and groundwater with theories ranging from fantasy to nearby correct propositions. Discharge of groundwater occurs when water emerges from underground through a crack or fissure. Most natural discharge occurs as flow into surface water bodies such as streams, lakes and oceans; flow to the surface appears as a spring.

Springs are the source of cleanest and most attractive water supplies available to men residing nearby. Utilization of spring water for irrigation, drinking and power generation needs less investment and is ecofriendly. Springs have been subjected to scientific and pseudoscientific

tific study from a number of view points. As their origin is related to stratigraphy and structure of rock, geological study is essential to get an accurate idea of their origin. Springs could occur in various sizes from small trickle to large stream based on water table and artesian conditions. Springs which ooze or percolate out of many small openings are generally called seepage springs in which discharge may be so little that they are hardly noticeable. A seepage spring may flow at night or on cloudy day but may stop entirely in hot sunny days due to evaporation loss. A large spring that issues from a definite opening gathers its runoff from inconspicuous but wide spread seepage. A few large springs indicate the existence of thick transmissive aquifer whereas frequent small springs are indicative of thin aquifer of low transmissivity.

Central Ground Water Board ^{and the} Ministry of Agriculture and Cooperation, North Eastern Hill Region submitted a report (1980) for exploitation of groundwater resources through open wells to meet the water requirement at Barapani Research Farm (Assam). They estimated that through this source about 40 percent of the total requirement can be met and for the remaining they suggested harnessing of surface water resources. Their proposal was quite costly. In a separate study. Agricultural Engineering Division, ICAR Research Complex for North East Hill Region, Shillong, Meghalaya carried out water yield observations from natural springs existing in many places in the area adjacent to Barapani Research Farm. From this study it was revealed that sufficient quantity of water can be harnessed from springs which were found to be cheaper and so the costly proposal for open wells was dropped and spring sources were tapped to meet the total water requirement of the Farm. (Singh and Tewari, 1989).

This proposition is a good pointer for many regions such as Tripura, Nagaland, Manipur, Meghalaya etc. where land configuration, rainfall and geomorphological features resemble that of Barapani leading to spring-flow (perennial or intermittent). In the state of Tripura three large springs popularly known as Dewanchhara, Tuiarsong and Shilachhari are being harnessed by the Department of Agriculture Engineering, Government of Tripura, following "flow irrigation method" (Fig. 2.6 and Plates. 2.1 to 2.4) to irrigate approximately 800 ha of land for three crops annually at a nominal cost of Rs. 700 /ha (approximate). Thus spring has been proved to be a cheap source of water (Ghosh, 1990).

There are innumerable springs (large or small, perennial or intermittent) in Tripura, Nagaland, Manipur, Meghalaya and other North Eastern States. If harnessed appropriately, they can cause dramatic change in the socio-economic scenario of ^{the} entire North East Hill Region of India. For assessment and planning purposes it is essential to have all the necessary information including seasonally variable water yield and location data of all such springs. This is a must for any country or state for judicious management of this bounty of nature

Spring-flow gauging in remote places is time consuming, laborious and costly. Hence empirical models can be helpful in such an impasses. It is also to be noted that comprehensive empirical models of Mero, (1962), Bear, (1979) and Bhar, (1989) need accurate measurements of many parameters which can be done with great difficulty. Financial constraint does exist in such attempts. Thus a simple but workable model like that of Pradhan, (1992) is essential for our country. Studies on water availability from springs is a

relatively new concept and is the most recent one in the different phases of hydrological studies. Such studies are important from the points of view of agricultural and non-agricultural purposes. Only a few works have been done on these aspects.

With this background in view the present study was taken up to:

- (i) examine the effect of spring discharge on groundwater levels
- (ii) establish workable models of spring discharge based on rainfall and time.
- (iii) estimate the gross-cropped area to be covered by irrigation water from the spring resources under study.

CHAPTER - II

Review of Literatures

2.1 Preamble

Springs are very fascinating natural object for mankind since the dawn of human history. They occur in great variety with many spectacular features. Their origin has appeared mysterious and indeed providential. They are generally surrounded with verdure giving rise to the term "living" streams, and for ages they have been the source of cleanest and most useful water supplies available to man. Springs provide a viable and ready source of clean water for rural communities especially in hilly area where there is logistic difficulties in creating storages of water. Spring discharge can also be used for irrigation, power generation and recreation purpose. The lore of healing properties of water from spring is ancient in origin and deep-seated in human consciousness. Since the beginning of geology springs have been of great scientific interest, because of their close relation to rock stratigraphy and structure and to the changes that have taken place within the rocks. Thus it is not surprising that springs have been objects of scientific and pseudoscientific study from a number of view points. A simple hydrologic monitoring of spring flow is essential not only from the points of view of collection of historical data, but also to provide a complimentary land use strategy for sustained development of rural community.

Springs are part of ground water system and can be taken as a flowing well with constant draw. Hence, these are among the hydrologic surface features that can assist in evaluating ground water potential of the area where there are natural outlets (through which groundwater from an

aquifer emerges out as concentrated discharge at the ground surface).

A few large springs indicate the existence of thick transmissive aquifer where as frequent small springs are indicative of thin aquifer of low transmissivity. The process of spring flow gauging and analysing the spring flow data with different factors governing the flow is complex. Many earlier works like classification and modelling of spring flow are well documented in literature (Keilhack, 1935; Tolman, 1937; Meinzer, 1942; Tolman, 1937; Bear, 1979 and Bhar, 1991).

Their works were on the basis of geology, geomorphology of spring areas and aquifer parameter (Viz. aquifer storativity, aerial extent, thickness) of spring which could be measured with great difficulty and used for scientific application.

2.2 Origin of springs

A spring is a natural outflow from the ground surface, usually from a definite opening. A seep is similar to a spring but differs in that it has no definite opening. A spring or seep is formed where groundwater outcrops at the land surface (USDA, 1979). Natural springs and seep originate at the base of steep slope where break in topography occurs. It occurs where down gradient part of the aquifer or other water carrying materials are exposed to the surface as in outcrops at mountain side and canyon wall or shallow waterable reaching the surface at the base of long slope. Springs also originate with discontinuity caused by faults, dykes which form hydraulic barrier and force ground water to flow upward and reach the surface if the piezometric

surface in the aquifer is sufficiently high. Fractured rock fissure can be filled with rain water, which then flow through same fissure system to form springs at the lower points. Rock piles and similar debris at the foot of mountain can temporarily store water in period of rainfall and gradually release water via spring or seep along their base (Bauwer, 1958).

Bryan (1919) has emphasised that the first main sub-division and sub-heads of origin should be made according to ^{the} geologic formation and structure. ~~These are~~ Accordingly, *the following two groups of springs have been described:*

1. Springs due to gravitative pressure transmitted through a continuous body of ground water.
2. Springs of deep origin flowing as a result of agencies other than gravity, operative deep within earth, largely the expulsion water during the crystallization of igneous rock.

The first group is subdivided into four subgroups

- a. Depression spring due to land surface cutting watertable in permeable rocks.
- b. Contact spring due to permeable water bearing rock overlying relatively impermeable rock.
- c. Artesian springs due to a permeable water bearing bed between relatively impermeable confining bed.
- d. Springs in impermeable rocks (tubular and fracture springs)

The second group was divided into two sub-groups.

- a. Springs associated with volcanism or volcanic rocks.
- b. Springs due to fault or fissure extending deep into earth.

The best illustration on conditions of forming the several springs may be glanced through Fig. 2.1 to 2.5

2.3 Classification of springs

The purpose of classifying the spring is

1. To arrange and classify all data so that the processes that cause spring flow and the factors that affect it may be discovered.
2. To group together the spring of like origin and characteristic for the purpose of description.

Classification of the springs were made by keilhak (1935) which were based on origin or source of spring water and subdivisions were on combination of hydraulic and geologic factors governing spring flow. His (Keilhak, 1935) Classifications were-

A. Descending (non-pressure water)

1. Formed as a result of squeezing of water bearing stratum.
2. In place of natural wedging out of the water bearing stratum.
3. Strata in place where the water bearing stratum has been exposed by erosion.
4. Overflowing.
5. Dam or sill
6. Fissure
7. Waste water effluent

B. Ascending (water under lead of pressure)

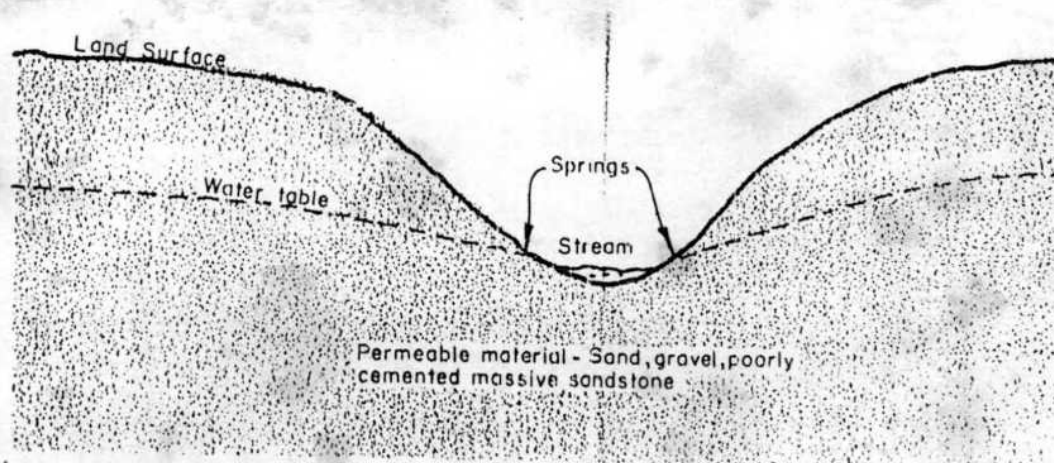


Fig. 2.1 A line sketch of depression spring, along the outcrop of water table at the edges or in bottom of valleys, basins and depressions in morains filled with alluvium (stream deposits of gravel), sand, silt and clay) and in valleys cut in massive, permeable sandstone with irregular spaces between grains of the permeable material. Its flow depends upon permeability of the water bearing material and size of tributary area. Flow may range from less than one to several gallons per minute (gpm). The type of flow may be either perennial or intermittent, depending upon rise or fall of the water table. If the contributing area is small the flow will depend on local precipitation. Usually fair to excellent quality of water but may be materialised if the aquifer contains soluble substances. Usually no fractures are produced in valleys. In windswept arid and semiarid basins the wetted area and the vegetation growing around the spring may cause deposition materials around the spring resulting in a mound of loose and organic matter (vide Fig. 3.4).

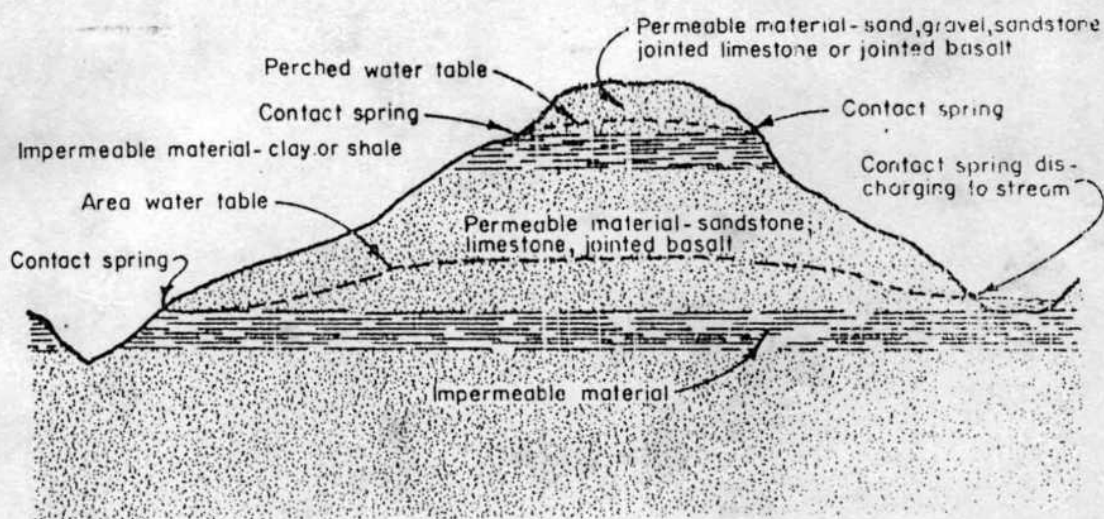


Fig. 2.2 A typical contact spring. This may occur on hillside or in valleys wherever the outcrop of an impermeable layer beneath a water bearing permeable layer occur. Openings in sand or gravel are irregular, intergranular spaces. Openings in rocks are joints or fractures. Opening may be tubular in limestone gypsum and basalt. Volume of flow may range from less than a gallons per minute to several thousand gallons per minute, depending upon permeability of the water bearing material, the volume of aquifer tributary to the spring, and conditions of water intake. Type of flow usually perennial for contact springs supplied by the areas water table. If the contact spring is supplied by a perched water table, the flow may be intermittent. Usually fair to excellent quality of water, but may be mineralised if water bearing material is soluble. Travertine (calcaum carbonate) will be deposited as described under Fracture and Tubular springs.

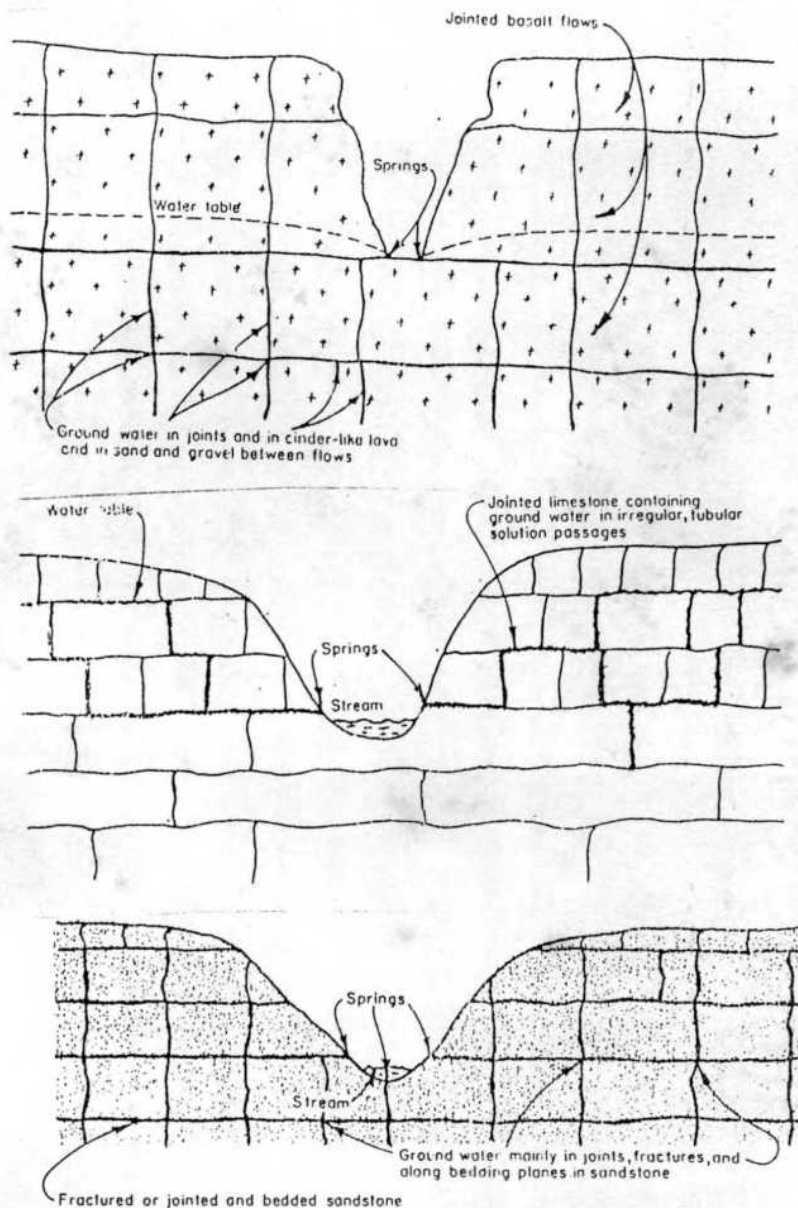


Fig. 2.3 Line sketches of Fracture and Tubular spring. These may occur on hill side or in valleys or wherever land surface is below the water table. fractures in all kinds of rocks and sometimes tubular openings in limestone, gypsum and lava. Water bearing material fractured or jointed rocks. Flow may range from less than one to hundreds of gpm, depending upon the extent of fracturing or joint system tributary to the opening. Usually perennial, type of flow, may fluctuate with precipitation if the contributing area is small. Usually good to excellent quality of water, may be hard, due to calcium carbonate, if spring issues from or percolates through limestone. Travertine will be deposited about the spring opening if the water is warmer than the mean annual temperature and has percolated through limestone on the way to the point of discharge. Water from other materials usually produces no surface features.

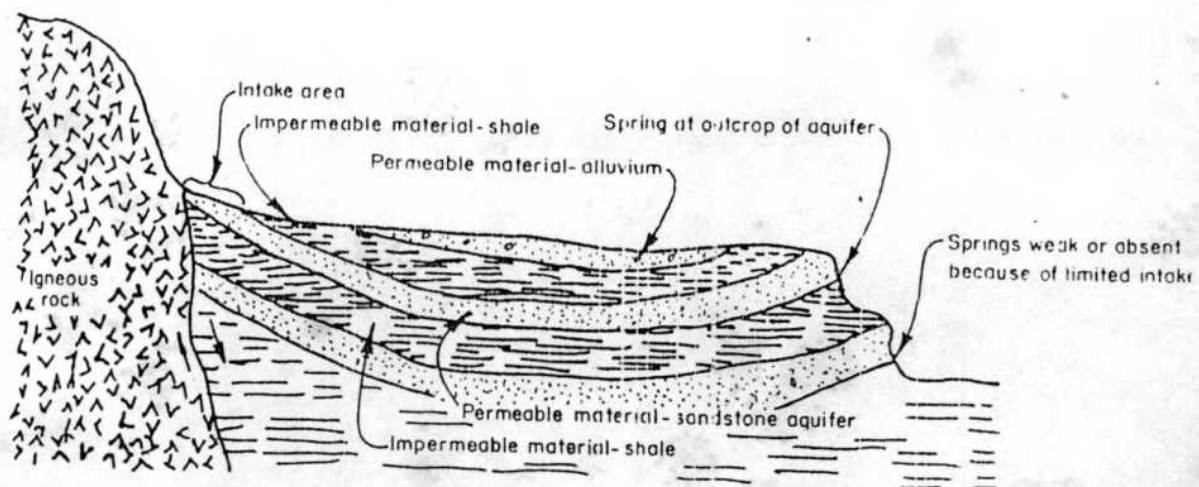
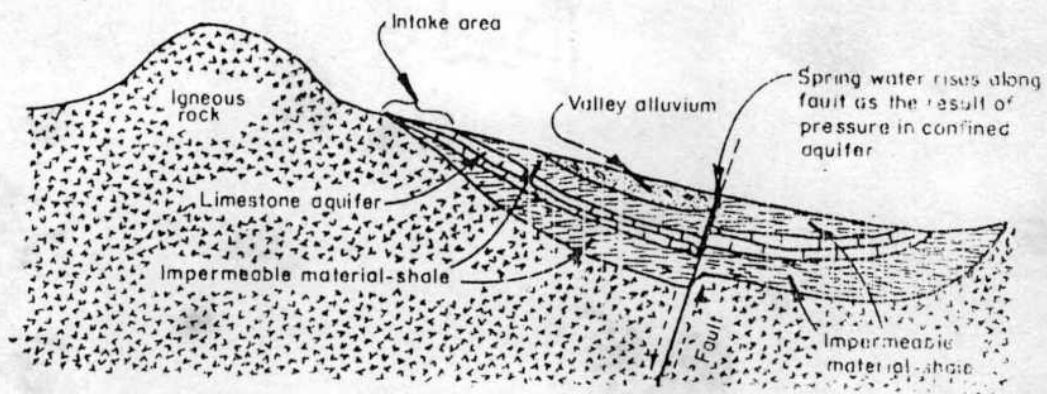


Fig. 2.4 Artesian springs at outcrop of aquifer. This may occur in any topographic position along outcrop of aquifer. Type of opening will depend upon nature of water bearing material. If aquifer is sandstone, water may seep from spaces between grains or from joints or tubular openings. Water bearing material may be sandstone, limestone, or jointed basalt. Flow may range from a few to several thousand gallon per minute. Type of flow is perennial, usually constant. Quickly affected by well drawing from same aquifer. May be affected by long drought. Usually good to excellent quality of water. Water may be hard if aquifer is limestone. If water is from a limestone aquifer and is warmer than the mean annual temperature, travertine will be deposited. The reduction of pressure in an artesian aquifer that occurs as the water reaches the surface also causes deposition of dissolved solids about the spring opening.



2.5 Fig A sketch of fault spring (artesian spring). This may occur at any location along a fault or related fractures. Type of opening will depend upon the nature of materials at the land surface. If the surface is alluvium, water will issue from space between grains. If the surface is rock water will issue from fractures. Water bearing material may be sandstone, limestone or basalt. Surface material may not indicate the nature of the aquifer. Volume of flow may range from a few to several thousand gallon per minute. Type of flow is perennial, constant and only affected by long period of drought, quickly affected by pumping from well drawing upon the source aquifer. Usually good to excellent quality of water, water may be hard if aquifer is limestone. Fracture produced is as described under artesian spring at out crop of aquifer .

1. Because of occurrence of hydrostatic pressure

- (a) Stratal
- (b) Waste water effluent

2. Water moves under the force of gas pressure

- (a) Water vapor
- (b) Carbon dioxide
- (c) Hydrocarbon

Springs are classified by Meinzer (1942) into 9 order according to their mean discharges as follows

Magnitude	Discharge (lit/sec)
1st	28356.48
2nd	283.56 to 2835.65
3rd	28.36 to 283.57
4th	6.31 to 28.36
5th	0.63 to 6.31
6th	0.06 to 0.63
7th	0.02 to 0.06
8th	<0.02

Tolman (1937) classified the springs according to the type of water bearing formation (where granular, pervious materials are involved) or according to the type of opening (fractures or solution channels) and brought together spring groups of similar hydraulic behaviour.

The major groups selected are as follows:

Class I Spring issuing from pervious venur formation. Here water issues from an aquifer underlain by an exposed impervious formation. This class of spring has been called as

general contact spring and gravity spring. This class includes.

1. Perched springs
2. Springs from the lower edge of an old soil on a mountain upland.
3. Talus spring
4. Spring at the edge of land slides
5. Springs form a body of old alluvium cut by most recent canyon.
6. Pocket spring from the lower edge of any deposit of pervious materials filling an irregularity in the bed rock.
7. Mesa spring
8. Cuesta springs
9. Water holds of desert above rock rufs which cut across and may protrude above the sand or dry washes.
10. Barrier spring formed above a fault between raised bed-rock block and depressed block covered thick deposit of alluvium.
11. Spring from pervious cap of wind blown sand on pervious sand stone.
12. Spring issuing at the edges of thin morain materials.

Class II Springs issuing from a thick pervious formation. In this case the water table outcrops on the ground surface so that water flows on the surface.

The common occurence of this type of spring are as follows:

1. Channel springs occur on the bank of streams which have cut channel, below the water table.
2. Valley springs are developed on the sides of valleys the out crop of water table.

3. Cliff springs are developed at the intersection of water table with a cliff.
4. Dimple springs are formed in any small depression reaching below water table.
5. Boundary or alluvial slopes springs occur on the lower slopes of an alluvial core at the point where the water table slope and the surface gradient are equal.

Class III Springs issuing from interstratified pervious and impervious formation. The aquifers are strataform beds, may be at any altitude - horizontal unlinked regularly or irregularly folded and faulted. This class of springs may be subdivided according to structure of water bearing formation. It includes

1. Monoclinical springs
2. Synclinal springs
3. Anticlinal springs
4. Unconformity springs

Class IV Springs issuing from solution opening. This type of springs issues from solution channel out cropping in limestone. Aquifers are solution conduit and caverns formed along fractures and joint system. It is connected with a tubular aquifer in which water moves as subsurface stream. This class includes many large springs.

Class V Springs in lava. The great spring of this type issues from the edge of lava plains or in canyons that have been excavated in them.

Class VI Spring issuing from fractures

This class includes three main groups

- A. Fractures intersecting pervious materials.
- B. Fractures in impervious materials
 - a. Springs issuing from superficial zone of fractures opened up by weathering.
 - b. Springs received water largely from deep unknown sources, They include geysers, terrace hot springs or boiling springs.
 - c. Fractures supplied largely or partly by water of deep seated unknown origin.

Besides these, springs are further classified into thermal and non-thermal springs. Thermal springs discharges periodically a column of boiling water called geysers. It is a tubular opening in consolidated lava with internal temperature above boiling point of water. The majority of springs are nonthermal which may be classified as cold springs, ordinary temperature springs, cold springs and may originate from melting of ice. Particularly from glaciers or snow accumulated in caves.

Mineral springs

The common variety of mineral springs are

1. Saline spring (carrying chiefly common salt)
2. Epsom spring (carrying MgSO_4 MgSO_4)
3. Calcareous springs (CaCO_3) (CaCO_3)
4. Gypsum springs (CaSO_4) (CaSO_4)
5. Boron spring
6. Chalybeate spring Fe(OH)_3
7. Acid spring (acid sulphate radical)

8. Soda spring (sodium carbonate or bicarbonate)

9. Alum spring (aluminium sulphate)

Medicinal springs - These are those of reputed therapeutic properties. **Radioactive spring** - The water has abnormal high and easily measurable radioactivity (Tolman, 1937)

The springs can also be classified according to variability of perennial springs and permanence of discharge; Meinzer (1923) suggested the classification of perennial springs according to variability of discharge. He defined variability as the ratio of the discharge fluctuation to its average discharge within a given period of record

$$\text{Thus, } V_p = \frac{Q_{\max} - Q_{\min}}{Q_a} \times 100$$

Where, v_p = Variability in percent,

$Q_{\max}$ = the maximum discharge

$Q_{\min}$ = the minimum discharge and

Q_a = the average discharge

The classification of perennial springs on the basis are -

- a) Constant - Springs with a variability of not more than 25 percent.
- b) Sub-variable - Spring with a variability of more than 25 percent but less than 100 percent
- c) variable - Spring with a variability of more than 100 percent.

Classification of spring according to their exits into another waterbody:

The natural discharge centres of the groundwater exits in the form of spring (freshwater, carbonated, saline and thermal etc.) and pour out at the bottom of rivers, seas or overflow into bearing layers of higher elevation. Springs, as such, could be classified according to their hidden center:-

- 1) Sub fluvial
- 2) Sub marine
- 3) Sub surface

Some springs occur in permafrost region and region of volcanic activity. The condition of spring discharge in permafrost area and those in regions of contemporary volcanic activity are regionally specific.

As a result of freezing of water bearing layers in the active zone above the permafrost in water, many springs function only seasonally. Discharging centres of unfrozen water below the permafrost are in active round the year. This forms icings around the discharge point.

For a concise and workable classification, it is better to follow USDA (1979) as illustrated in Figs.2.1 to 2.5.

2.4 Topographic and geologic features of spring.

According to Meinzer (1942) Springs by their own activity developed minor topographic and features. Ground water is always active as an agent of erosion, deposition or

replacement. It produces two types of features viz destruc-tional -erosion and constructional -depositional features.

As a rule, those streams which originate from springs are not effective in erosion, for the following reasons.

1. Devoid of suspended matter, less fluctuation in spring discharge mineralised water and tend to deposit than dissolve. Ordinary streams accomplish most of their erosion by means of sands, pebbles and boulders which they carry in suspension and roll along the stream bed.
2. Two principle types of erosion features
 - i) Channels or valleys eroded at the point of discharge by spring water.
 - ii) Large and definite tunnels formed by the solvent action of spring water in limestone or gypsum, may cause flow.

Springs also act as an agent of deposition and have built mound or terraces.

2.5 Fluctuation of spring flow:

Different factors are responsible for fluctuation of spring flow. According to Tolman (1937) important factors controlling the direction of movement of effluent water current and quantity of out flow are

1. Rainfall
2. Hydrologic character (chiefly permeability) of the materials at the ground surface.
3. Topography

4. Hydrologic character of water bearing formation.
5. Geologic structure. Valdiya and Bartarya (1991) stated that the seasonal fluctuation were mainly due to variation in rainfall and more precisely due to variation in quantum of rainwater that infiltrates the ground. Following rains water starts to percolates down through the weathered mantle. The recharge of ground water augments the discharge of the springs, and thus causes more rapid outflow of ground water. The high rate of discharge lower the water table, reduced its gradient and diminishes the pressure on pore space. This alternation of recharge and discharge cause the seasonal, local and short term fluctuation.

A balanced precipitation and attendant recharge produce uninterrupted discharge of water in the month of July, August and September and a gradual decrease and eventual deficit in the subsequent months. Snow melt in upper catchment area causes local recharge and a slight increase in discharge during winter.

Spring fed by shallow subsurface water emplaced above the water table are subject to greatest fluctuation, and they completely disappear at certain times. However, springs fed by ground water have more or less steady supply, even though their discharge vary seasonally (Valdia and Bartarya, 1991).

Bhar (1991) stated that fluctuation of spring flow is due to variation in the rate of recharge and prevailing geologic and hydrologic conditions. During dry season spring discharge is derived from water stored in the aquifer, so the water-level in the aquifer gradually falls and spring discharge declines. During the period of precipitation the

aquifer gets recharged and water table rises and spring discharge increases. Thus the rise and fall follow a cyclic pattern. The relationship between the rate of decrease and increase with time depend on storage characteristic (storativity) and geometry of aquifer (areal extent). Meinzer (1942) mentioned that the fluctuations are produced by the rate of evaporation and transpiration. Some springs respond promptly and decisively to recharge, others do so with a significant lag. Some springs declined quickly in drought, but other are slightly affected even by severe droughts. Springs which obtain their supplies from surfacial materials of low specific yield show daily fluctuation. The flow (yield) is generally being least in afternoon, when the vegetation makes its heaviest demand. The yield (flow) is greatest at night when there is almost no transpiration.

Springs that obtain their supplies from surfacial material with high specific yield may have relatively constant flow and have small fluctuation. Springs of artesian type are relatively constant in flow, because they are supplied from the storage in deep reservoir, which dose not fluctuate greatly with fluctuation in recharge and is protected from depletion by evaporation and transpiration. This type of springs fluctuate with change in atmospheric pressure and with change in different agencies that induce pressure on the artesian aquifer which supplies water to the spring. Limestone springs differ in the amount of fluctuations as they are fed by reservoirs having large storage or are the outlet of underground drainage system with little storage.

2.6 Permanent changes in spring:

Permanent changes of the springs may be caused

either by artificial or natural agencies. Constant changes in springs during geologic time, changes by streams and wind, uplifting of regions from sea and erosion cycle advancing towards maturity may cause development of ground outlet. Surface erosion and sub-terranean solution tended constantly to drain higher springs and develop new small springs. Interruption in spring flow occurs due to earthquakes and may have been followed by following changes.

1. Rise and fall of
 - (a) Water level in well
 - (b) Temperature of water in spring.
2. Increase or decrease in amount of gas emitted by spring
3. Changes in mineral character of spring water
4. Rise of ground water table to surface because of subsidence of land and opening of fissure.

2.7 Assessment of watershed development on spring flow

Occurrence of springs in hilly areas is very common and this sources of water are used for drinking, irrigation and power generation. But various activities for development often require removal of the vegetative cover and top soil. These affected the spring flow adversely because of the following reasons (Chow, 1964):

1. Vegetation develops on open soil structure which greatly increases the infiltration capacity and water holding capacity of the soil layer in the root zone.
2. Vegetation hinders run-off and increases retention time of water on the ground surface providing more opportunity for infiltration. Soil erosion is also reduced.
3. Vegetation provides partial or complete cover of undecomposed or partly decomposed organic matter which resist

soil erosion and protects pores of the soil from being clogged. These help in infiltration.

Public recognition of the close relationship between vegetation and water began in Europe on the flow of springs and stream and their connection with forest destruction.

~~A trade off~~ Needs to be maintained between the developmental works requiring removal of vegetation and soil cover and their adverse effect on the spring flow. The destruction of the internal hydrological system is also reflected by the fact that spring sources of 18 villages in the Baldi valley have registered a sharp decrease of about 50% in their discharge over the last two decades Bandyopadhyay and Shiva, (1984) vide Dewan, (1990) in the saproon valley near solan.

Bhar (1991) observed that 50 percent of the reduction of recharge area due to urbanisation led to 35 percent reduction of spring flow for six months period and 50 percent reduction of spring flow on the 12 months basis.

In areas devoid of vegetation or possessing only a thin vegetation cover, run-off will occur whenever rainfall intensity exceeds the infiltration capacity of the top soil. This situation often prevails in cultivated fields in high rainfall areas in hilly terrain and in areas of compacted top soil.

The removal of vegetative cover from the forest land during construction activity, quarrying etc. lowers the infiltration capacity and results in more run-off and less ground water recharge. Urbanised area also produces high

runoff.

Bhar (1991) observed that the dynamic storage inside a spring goes on decreasing as the percentage of rainfall recharge reduces and this causes reduction in spring flow.

Vegetation in forest land protects the soil, because the humus and micro-fauna activities create and maintain an open soil structure. Thus in those conditions when rainfall intensities often do not exceed infiltration capacity and spring flow domain get good amount of recharge which subsequently comes out as spring flow.

2.8 Existing spring flow model

Some conceptual linear hydrologic models are available to analyse the spring flow domain and the spring flow for instantaneous recharge (Mero 1962; Bear, 1979). These models assume that the spring flow is linearly proportional to the storage inside the spring. These models provide solutions for spring flow for unsteady one dimensional flow. The equation for spring flow that are available from these models are of the following nature.

$$Q(t) = Q_0 \exp(-\alpha t) \text{ ----- (2.1)}$$

Where, $Q(t)$ = Spring flow at anytime 't' after instantaneous recharge

Q_0 = Initial spring flow

t = time since the initial spring flow is measured

α = a coefficient incorporating aquifer geometry and aquifer parameters.

A mathematical model for analysing the unsteady flow of a spring has been developed to take into account the variability in recharge. The spring flow domain has been hydrologically decomposed into 2 domains

- i) Recharge zone
- ii) Transition zone

The spring threshold point lies at the end of transition zone. In the recharge zone the flow has been assumed to be in vertical direction and in the transition zone, the flow has been assumed to satisfy Dupuit Forchmies condition as cited by Bhar (1989). For solving the problem, the unsteady state has been assumed to be succession of steady state. An expression for spring discharge due to an instantaneous recharge in the recharge zone has been derived by Bhar (1989) and expression is given by

$$Q(t) = \frac{WTN}{L_1\phi} e^{-WTt/AL_1\phi} \text{ -----(2.2)}$$

where T = Transmissivity of the aquifer in the vicinity of spring

Q(t) = Spring flow at any time 't' after instantaneous recharge

W = Width of the aquifer

ϕ = Aquifer storativity

L_1 = length of transition zone

N = Instantaneous recharge quantity per unit area to aquifer.

A = Area of recharge zone.

t = Time since the instantaneous recharge commenced

The basic assumption of the model is that the

outflow from the spring is linearly varied with storage inside the spring and is identical with Bear's (1979) assumption for his model.

But modifications incorporated in this model are

1. The flow domain of the spring is hydrologically decomposed into recharge zone and transition zone.
2. The model has only one parameter i.e depletion time
3. The model is capable of analysing the case for variable recharge and can predict spring discharge both for dry and wet season.

Pradhan (1992) worked for six springs very close to each other and situated at Barapani (Assam). He analysed four years' data and proposed a model of the form:

$$q_{aym} = k_1 r^{k_2} \text{ -----(2.3)}$$

where q_{aym} = Spring yield averaged over number of springs and years for a particular month

r = Rainfall for any particular month averaged over the period of years of observation.

k_1 = Value of range

k_2 = Value of range

His model may be useful for planning water availabilities from springs. ~~A few lines on critical evaluation of these models should be added.~~

2.9 Spring yield and water management in agriculture

This may be viewed from two angles viz.

- (i) Development of springs and seeps;
- (ii) Naturally available spring yield (q_n)

The usual objectives of springs development are increased yield (q_n), improved usability and protection from contamination. In most instances an increase in q_n is the primary need. If q_n is adequate, the other objectives may be reached by building suitable collection and storage (USDA, 1979). Preliminary information needed is the volume and reliability of the present flow; nature of the water bearing material; and if possible the hydrologic and geologic conditions which cause the spring to flow. The second step is to locate the obstruction (if any) to flow. This may be cemented deposits of travertine, loose fine-grained materials (sand, silt, or clay) brought to the outlet by spring flow or slope wash materials deposited on the outlet by surface water. Vegetation growing in or around the outlet may obstruct flow and will consume water which would otherwise issue as q_n . Usually the removal of such materials or growths will increase the flow of springs. A hump is desirable for desilting the water in case spring water carries sediment. Diversion drains to direct runoff of the area situated above (at higher elevation) the springs site are needed to prevent clogging of outlets by slope wash materials. The third step is the collection and storage structure, because the spring flows continuously ~~w~~ whether you need the water or not. Though costly but some arrangement to collect and store the flow (when it is not needed) is essential from the point of view of water management at the time of need. There are various systems and structures for this purpose the details of which may be had from USDA (1979). The fourth step in spring development is improved usability and protection from contamination. This usually require some means of collecting the flow (e.g. tile or perforated pipeline laid

in a gravel filled ditch; drainage ditch back filled with gravel or sand; infiltration galleries; tunnels etc.) and conveying it to the point of use. Pipelines may be of plastic, copper, galvanized iron or asbestos cement through which water may be stored well away from the spring box and collection system and where it is easy to get by livestock. It may be located to serve more than one field. Protection should be afforded to the spring from flood using diversions (USDA 1979).

In many situations there is no need to develop the spring and seep but to improve the usability of naturally available spring water. The state of Tripura has tried to make use of atleast three large springs viz Silachhari, Dewanchara and Tuiarsong. These three springs are originating at higher elevations and the water is flowing slowly as hill stream into a deep valley with vertical walls on both sides till it reaches the plain land. The difference in R.L_s between the bottom of the stream and its top of the bank is about 10 metre in some situations where agricultural land in plenty is available. Very close to origin of the stream and on the steep flowing stream a concrete weir (rectangular) has been installed. The weir has an opening (which can be closed or opened) at the bottom. A pipe (diameter 6") fitted with foot valve at one end has been fitted at about 30 cm height above the bottom - the other end comes out of the weir. A second piece of pipe is then fitted with the other end of the first piece, a third piece is fitted with the second piece and so on so forth till it reaches the desired piece of land at a much lower elevation (12 m) than the first piece of pipe. All such pipes are either clamped with U-bolts on the valley wall or on a specially installed stand where wall is not available at suitable position. An workable sketch to expluin-this is given in Fig 2.6, plates

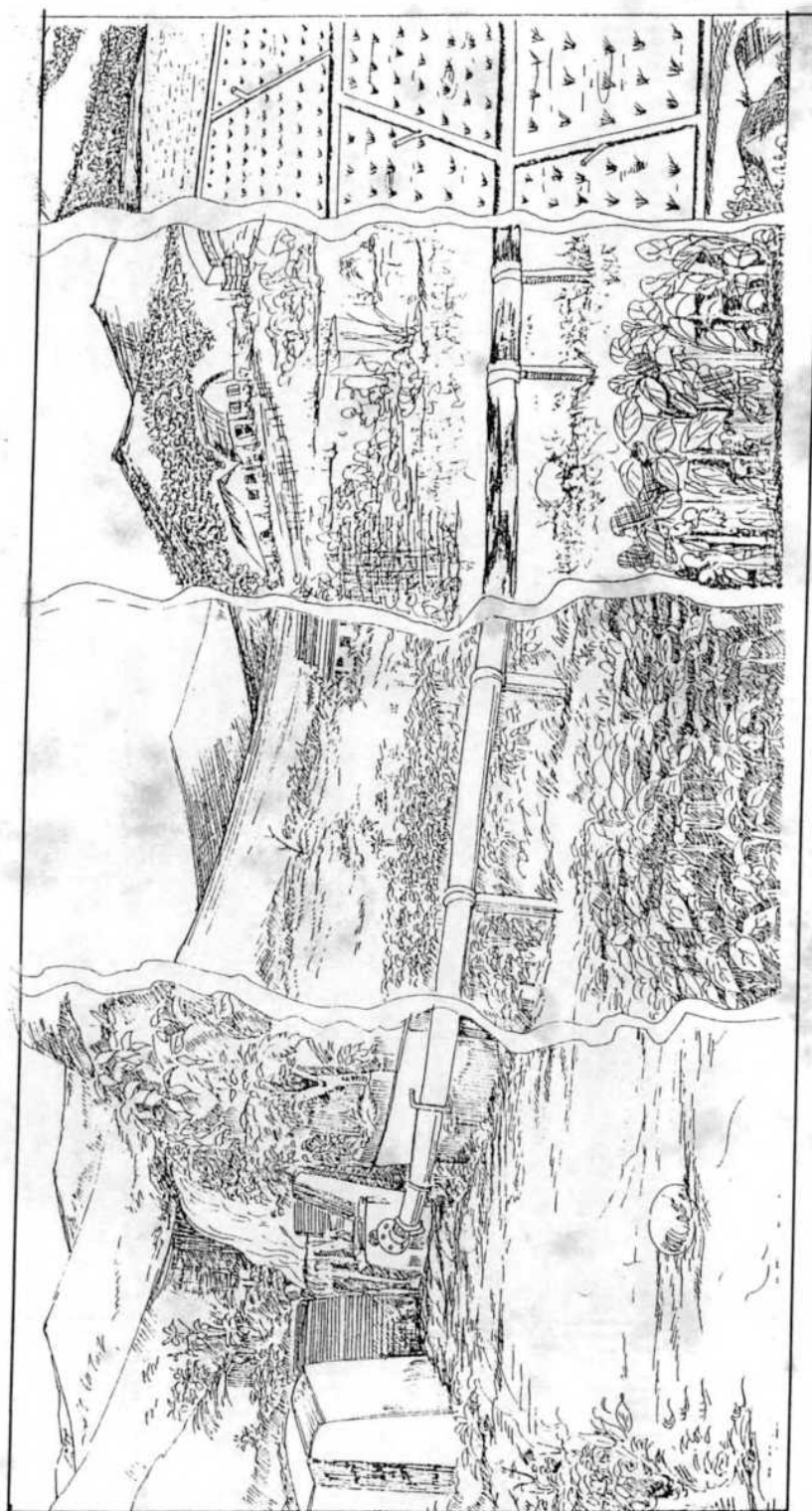


Fig 2.6 Pictorial sketch of the "flow irrigation" net works in Shilachhari-1, 2 and 3. The difference in elevation in picture the points of water entry into the pipe and water outlet from the pipe is about 12m and linear pipe length is about 2.5 k.m.. This sketch along with Fig 3.3 and plates 2.1 to 2.4 may be looked into for better understanding.

2.1, 2.2, 2.3 and 2.4 may also help to understand the actual position. This is popularly known as a "flow irrigation" in Tripura. As and when irrigation is required the hole in weir is closed. Water gets accumulated and starts over flowing in the weir. Pipe gets submerged and water flows through the pipe and by gravity reaches the land where it is required. The cost of irrigation is estimated at about Rs. 700/ha for one crop considering three crops in a year.

The above is a narration of ingenuity and perseverance of indigenous technique to improve the usability of large spring waters. If majority of springs in Tripura are harnessed following such or any other technique the cropping intensity on every bit of soil will be very high.

Thus spring yield and water management in agricultural lands having topographic features like that of Tripura are the head and tail of a same coin if used appropriately in order to improve the quality of life.

2.10 Some features of Tripura vis-a-vis water resources surface hydrology

1. There are 10 major rivers in the State of Tripura and total annual river flow generated within the state is about 793 million m³.
2. They are perennial in nature and their flows are directly related to rainfall. During summer months their flow is less and become brimful during rainy seasons.
3. The principal rivers originate from the hill ranges and flow through the valleys lying between the principal hill ranges, The rivers fed by numerous tributaries arising from the catchment areas.



Plate 2.1 - "Flow Irrigation" networks in Shilachhari-1, 2 and 3



Plate 2.2 - "Flow Irrigation" networks in Shilachhari-1, 2 and 3



Plate 2.3 - "Flow Irrigation" networks in Shilachhari-1, 2 and 3



Plate 2.4 - "Flow Irrigation" networks in Shilachhari-1, 2 and 3

4. The rivers are :

- (i) Longai - rises from the Jampai range, flow length 98 km.
- (ii) Juri - rises from the Jampai hills
- (iii) Deo - rises from the Jampai range, 98 km length
- (iv) Manu - originate from Sakhan range, length 167km
- (v) Dhalai - Longtharai range, 117 km long
- (vi) Khowai - Longtharai range, receive water from different sources
- (vii) Haora - rising from eastern side of Baramura
- (viii) Gumti - from the southern part of Longtharai and Atnaramura range
- (ix) Muhari - from Deotamura
- (x) Feni - from 3 (three) streams Asalong, Rangafeni and Taindung.

Geological control

(a) the state is underlain by folded sedimentary formations ranging from lower Tertiary to recent. Tightly folded anticlines and synclines traverse the most parts of the state roughly in a N - S direction. The anticlinal crests are occupied by Bokabil series of rocks, which is argillaceous in nature. The valley areas are underlain by the Tipam group of rocks with a superficial capping of Dupitilla formation. Tipam sediments consists of semiconsolidated, medium to coarse grained sandstones with intercalations of argillaceous lenses. The argillaceous sands occurring in upper horizons form the shallow aquifer.

Tipam sediments occurring in deeper horizon constitute the principal aquifer.

(b) water bearing formations occur both in the shallow Quarternary alluvial formations and Tertiary coarse elastics occurring in the deeper horizons.

Chemical quality of ground water used for irrigation:

Ground water in the state is generally fresh and potable with low total dissolved solids as indicated by specific conductivity varying from 65 to 358 micromhos/cm. Ground water is mildly alkaline in reaction with PH ranging from 7.3 to 8.3 Bicarbonate is also very low in concentration varying from 60 ppm to 130 ppm. Groundwater is characterised by low chloride contents of 4 ppm to 31 ppm. Sulphate concentration is also low being restricted to only 10 ppm. The Ca and Mg contents vary from 6 to 59 ppm and 1 to 20 ppm respectively. Based on the values of cations and anions the groundwater occurring in the state may be classified as Calcium - bi-carbonate type of water. All these chemical characteristics render the ground water suitable for irrigational uses. Groundwater from shallow zones is however, characterised by iron-content higher than the specified limit for drinking water purpose in some places, Particularly in Dharmanagar and Kailashahar valleys. Such water needs treatment for elimination of iron so as to make it suitable for community use.

Various inputs in the form of fertilizers and pesticides are being applied to the irrigated fields for stepping up food production. These inputs contain many harmful constituents which may find their way to shallow groundwater body through irrigation waters seeping through surface formations.

2.11 Comments

Studies on water availabilities from springs is a relatively new concept and is young among the different phases of hydrological studies. Such studies are important from the points of view of agriculture and / or non-agricultural purposes. Very little works have been done on this aspects and have not been well documented or widely circulated even if some information are available in various remote parts of the world. Tripura is no exception from this main trend. Surface topography of Tripura is not conducive to retain and use surface runoff. Hence alternative water resources during non-rainny period is predominantly important. Spring yield is one such source which needs attention.

CHAPTER - III

METHODOLOGY AND PROCUREMENT OF DATA

The present investigation was carried out in a region of the state of Tripura, India, situated within $22^{\circ}56'N$ to $24^{\circ}32'N$ (latitude) and $90^{\circ}10'E$ to $92^{\circ}21'E$ (longitude) covering an area of 10,491 square kilometers. The elevation above MSL varies from 780m to 15m. The mean annual temperature varies from $10.5^{\circ}C$ to $35^{\circ}C$. The average annual rainfall in the state is 2200 mm. Some of the land features relevant to the springs are described in Table 3.1.

Ten springs were chosen randomly depending on accessibility and the convenience of measuring the discharges. Type of springs, location, behaviour and size of each of the selected ten springs are described in Table 3.2.

3.1 Land use and soil maps

The soil maps was taken from Biswas et al, 1989 (Fig 3.1) while land use and drainage map (Fig 3.2) were prepared from the records available from Landsat Imagery and Toposheets made by National Remote Sensing Agency for North Eastern Region (1978). Some information were collected from the Department of Agriculture, Govt. of Tripura.

3.2 Survey and map

Actual field survey using plane Table method was conducted in respect of Shilachhari-1,2,3 , Kajashi and Belbari. Contour survey was conducted following grid point method using Dumpy Levels and partial contour maps were sketched (Figs. 3.3 and 3.4). The positions of the springs, their land features along with some contour lines of Hazachhari-1,2,3,4 and Panchhara springs have been mapped on the

**Table 3.1 Some features of the land use of Tripura as on 1989-90
(all areas are in ha)***

1. Area Under Forest.	6,06,168
2. Barren and non agricultural land.	1,32,300
3. Permanent pasture, other grazing land and land under miscellaneous tree crops.	3,8084
4. Culturable waste land.	770
5. Fallow land other than current fallow.	800
6. Current fallow.	13047
7. Net area sown.	2,58,000
Total	10,49169
8. Gross cropped area.	4,35,000
9. Area sown more than once.	1,77,000
10.Total cultivable.	2,72,617
11.Cropping intensity.	168.80%

* Department of Agriculture Tripura.

Table 3.2 Some of the geographic chracters of the chosen springs.

SN	Springs+	Type of Spring	Location	Distance from main road k.m. (Approx)	Behaviour	Size*
1	Hazachhari-1	Depression	23°07'N 91°39'E	3.25	Perennial	Small
2	Hazachhari-2	Depression	23°06'N 91°41'E	3.30	Perennial	Small
3	Hazachhari-3	Depression	23°06'N 91°42'E	2.75	Perennial	Small
4	Hazachhari-4	Contact	23°03' N 91°40'E	3	Perennial	Large
5	Panchhara	Depression	23°05'N 91°41'E	2	Perennial	Small
6	Shilachhari-1	Fracture and Tubular	23°06'N 91°45'E	2.5	Perennial	Medium
7	Shilachhari-2	Fracture and Tubular	23°07'N 91°45'E	2.5	Perennial	Medium
8	Shilachhari-3	Contact	23°07'N 91°44'E	2.5	Perennial	Large
9	Kazshi	Contact	23° 9'N 91°43'E	2.25	Perennial	Large
10	Belbari	Depression	23°35'N 91°31'E	.0003	Seasonal	Small

(+) Spring names are given according to the name of the location. But numbers are arbitrarily allotted. Except Belbari all other nine springs are located within 7 Km (Areal) and are about 130 Km away from Agartala, the State Capital. While the spring at Belbari is readily accessible, it is difficult to reach to other nine spring sites because of hillside and forest. (Figs 3.3 to 3.5).

* The size of springs depends on its discharge. Assuming as small (0-0.5 lit/sec), medium (0.5-2.0 lit/sec) and large (above 2 lit/sec).

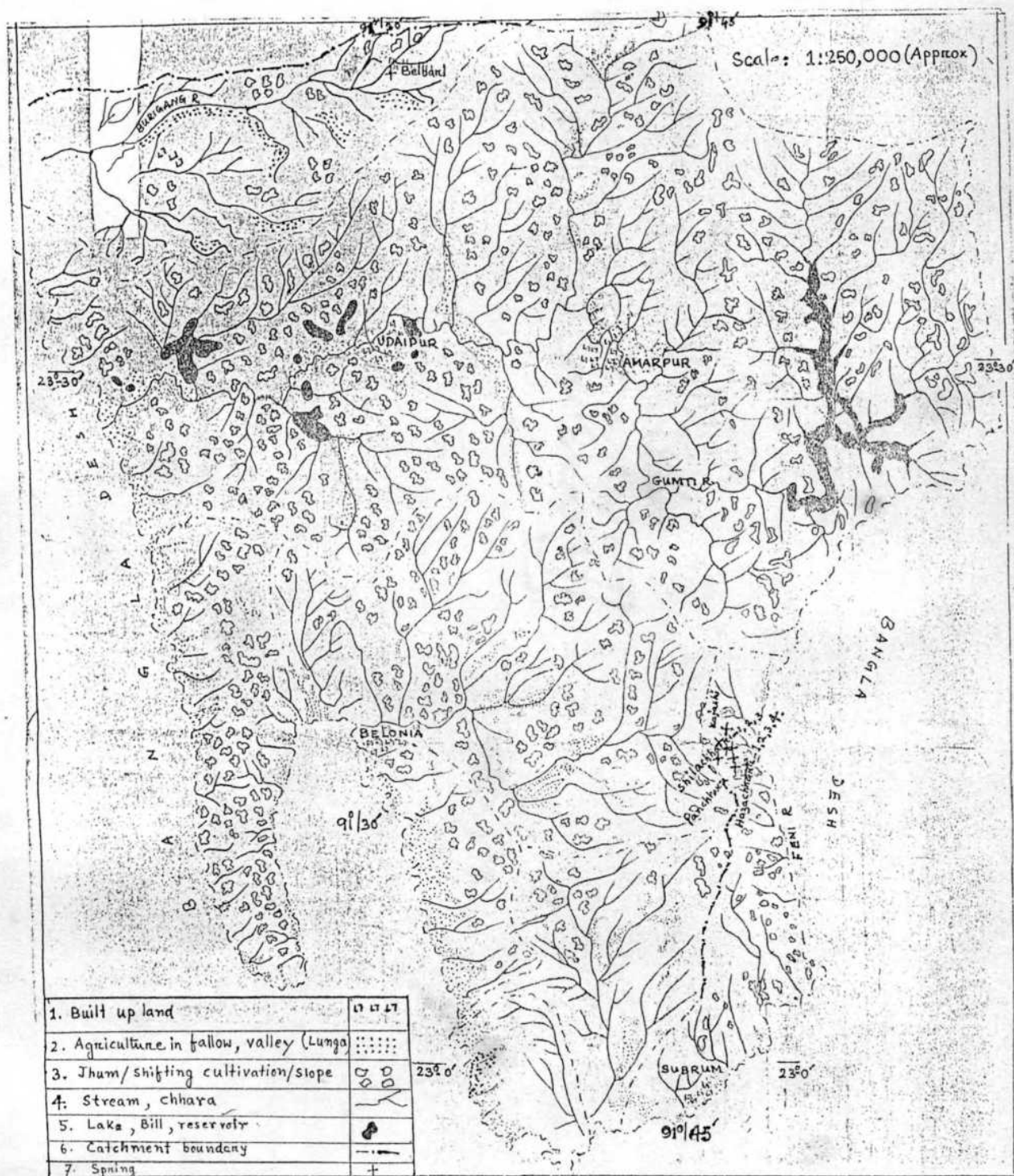


Fig 3.2 Land use and drainage map of the district of South Tripura and a part of West Tripura along with spring locations.

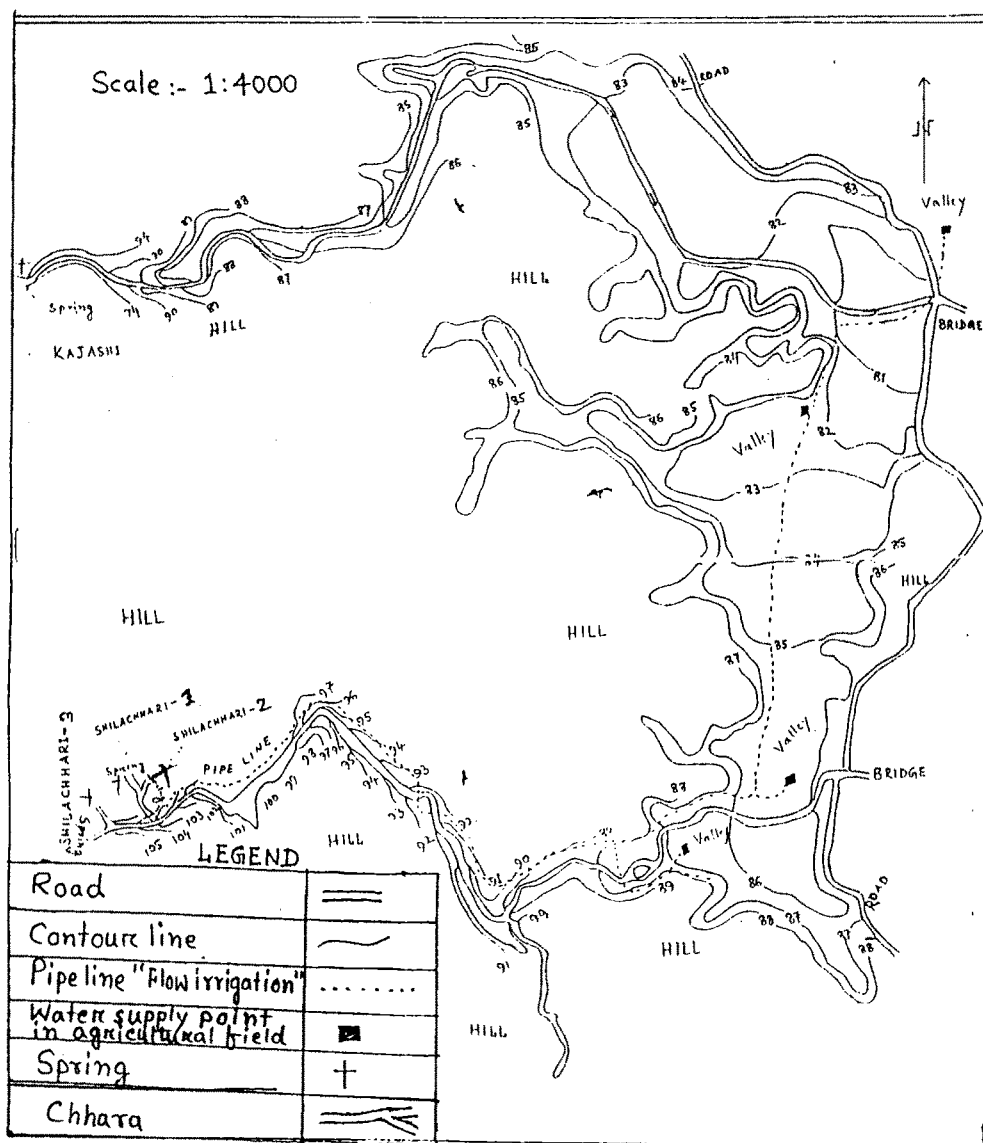


Fig 3.3 Location of four springs (Shilachhari 1,2,3 and Kajashl). shown on the contour map. The dotted lines indicate the pipe lines for irrigation structure (Art 2.8) and arrow heads on these lines give the direction of water flow gravity from the spring Shilachhari-1,2 and 3. Spring Kajashl have not yet been tapped by irrigation structure. At four locations (black squares) the water of Shilachhari-1,2 and 3 is being delivered to the agricultural land may be had from Fig. 2.6 and plate nos. 2.1 to 2.4.

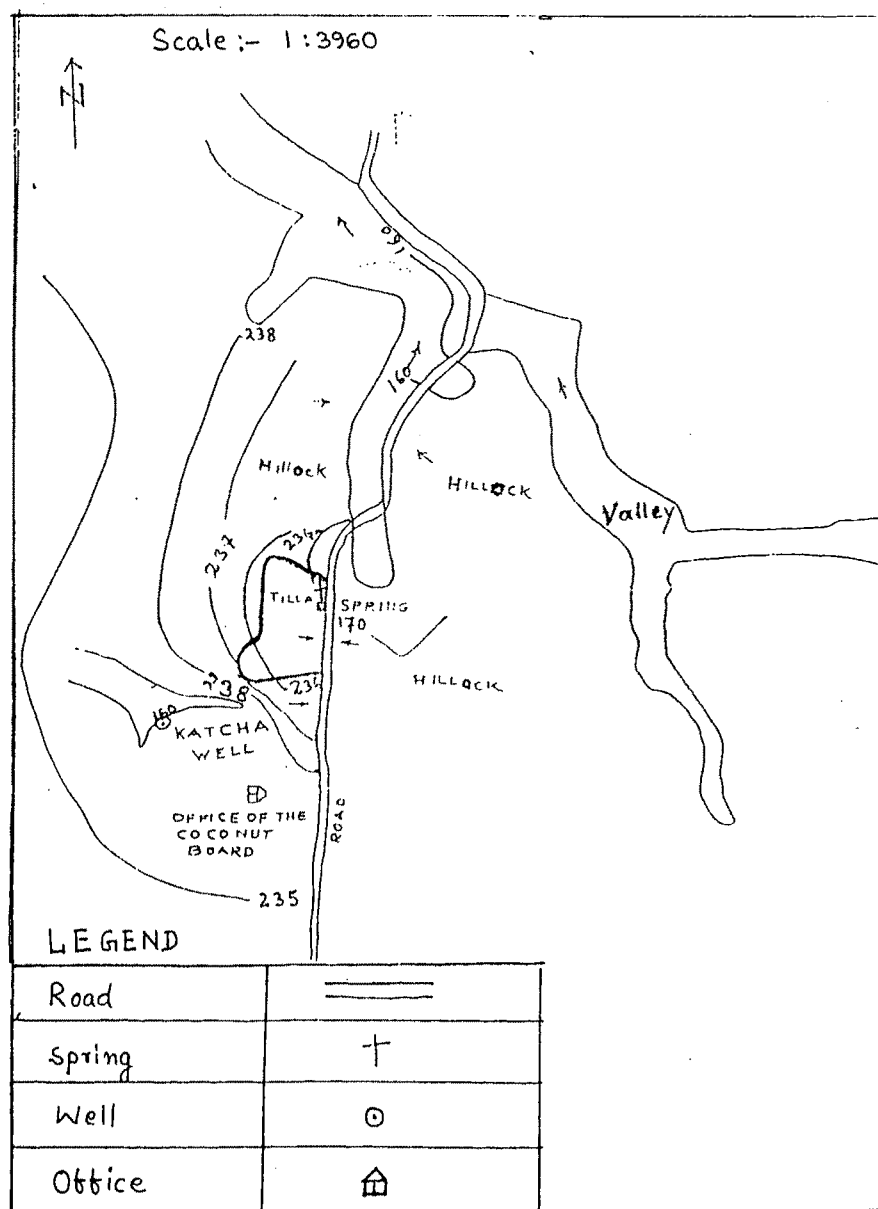


Fig. 3.4 Location and contour map of the area in and around an Ideal depression spring named here as Bel-bari which is the smallest spring reported in this thesis. The area enclosed by the thick black line is the tilla (hillock) or recharge area of the spring oozing out from the road side lowest point. The road is passing through a valley line.

basis of records available from different sources and presented in Fig 3.5.

3.3 Rainfall (r)

Since there is no rain gauge station near to spring sites, rainfall (r) data were collected from Sabroom rain gauge station under South Tripura district, located 22 Km away from all spring sites excepts Belbari. For Belbari spring rainfall data was collected from Sadar rain gauge station under West Tripura district, located 32 Km away from Belbari the 3 years average data from both Sabroom and Sadar have been presented in Table-3.3

Table 3.3 Mean monthly rainfall data (cm) from Sabroom and Sadar

Month	Sabroom	Sadar	Month	Sabroom	Sadar
Jan	0.733	0.393	July	85.270	37.220
Feb	18.460	12.327	Aug	62.220	18.753
Mar	30.420	5.64	Sept	49.530	29.133
Apr	18.950	11.675	Oct	27.880	23.270
May	64.200	47.773	Nov	1.360	1.366
June	78.440	36.710	Dec	1.500	0.000

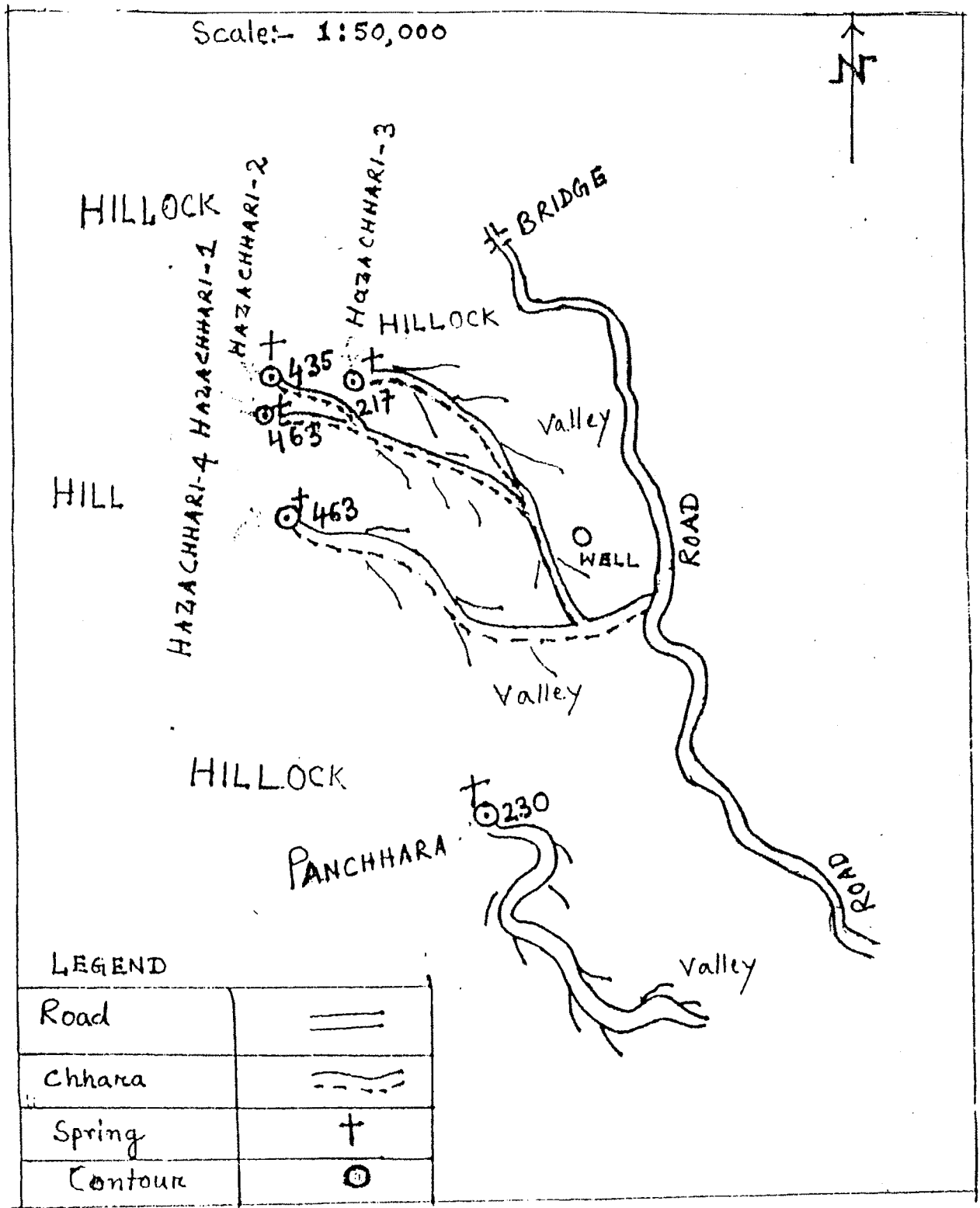


Fig 3.5 Map along with some contour lines in and around the springs named as Hazachhari 1, 2, 3, 4 and Panchhara.

3.4 Spring discharge (q)

For Shilachhari numbers-1,2; Hazachhari numbers-1,2,3; Panchhara and Belbari spring discharges were collected in a metal can of capacity 5 lts for specific time noted by stop watch. The collection was then measured by measuring cylinders. The discharge was then determined as follows

$$q = \frac{1}{3} \left[\frac{V_1}{t_1} + \frac{V_2}{t_2} + \frac{V_3}{t_3} \right] \quad \text{..... (3.1)}$$

where

q = Spring discharge, lit/sec or m^3 /sec.

v_1, v_2 and v_3 = Volume in liters or m^3 collected for the time period t_1, t_2, t_3 sec respectively.

The time differences between collections of v_1, v_2 and v_3 were about 2-3 min.

The measurement of q as mentioned above were done at an interval of 2 to 15 days, in majority cases the interval was 3-4 days. The time schedule could not be maintained at a regular frequency because of various practical limitations in the outdoor field works. for large springs viz. Shilachhari- 3, Hazachhari-4 and kajashi actual collection in a can was not feasible because of their condition of oozing out vis-a-vis land configuration. After oozing out this springs are flowing as hill streams. Hence a straight portion (not very true) near the oozing point was chosen e.g. 13.40m for Shilachhari-3; 10.30m for Kajashi and 8.45m for Hazachhari-4 stations A and B were marked with the help of pegs placed suitably on both sides of the stream and a thread was tied on the top of this. Travel times of a float from station A to B were recorded by a stopwatch for three times and for each of the stations cross sections at station

A and B were measured (Ghosh, 1990). The discharge (q) was determined as follows:

$$v_f = \frac{1}{3} \left[\frac{d}{t_1} + \frac{d}{t_2} + \frac{d}{t_3} \right] \dots\dots\dots(3.2)$$

$$v_m = c v_f \dots\dots\dots(3.3)$$

$$q = \frac{1}{2} [a_A v_m + a_B v_m] \dots\dots\dots(3.4)$$

where,

- v_f = velocity of float, m/sec
- D = distance between station A and B
- $t_1 t_2 t_3$ = time of travel from station A to B, sec
- v_m = mean velocity of flow, m/sec.
- q = mean spring discharge, m^3/sec or lit/sec .
- a_A, a_B = cross section area of flow at stations A and B, m^2
- c = velocity correction factor = 0.9 (assumed)

The discharge rate were measured at an irregular time interval varying from 2-15 days depending on the practical feasibilities. The mean monthly discharges of all the ten springs are shown in Table 3.4

3.5 Ground water depth

To determine the influence of ground water fluctuations on spring discharge open wells were located in the nearby sites of Hazachhari-1,2,3,4, Panchhara, Shilachhari-1,2,3, Kajashi and Belbari springs. The ground water depth were measured with the measuring tape with respect to the top of the well at ground surface. The time interval was same as that of measuring the discharge of springs. The data

Table 3.4 Mean monthly spring discharge q in lit/sec of springs

Month	Hazachhari 1	Hazachhari 2	Hazachhari 3	Hazachhari 4	Panchhara
Jan	0.045	0.040	0.464	13.31	0.092
Feb	0.013	0.013	0.096	9.25	0.174
Mar	0.008	0.020	0.073	14.25	0.117
Apr	0.005	0.015	0.088	19.95	0.078
May	0.002	0.010	0.117	18.45	0.246
Jun	0.003	0.011	0.158	15.43	0.324
Jul	0.007	0.013	0.213	26.50	0.441
Aug	0.012	0.013	0.247	43.46	0.279
Sep	0.012	0.011	0.247	35.19	0.267
Oct	0.013	0.016	0.222	22.48	0.293
Nov	0.011	0.004	0.150	15.56	0.148
Dec	0.010	0.003	0.170	13.41	0.087

Table 3.4(cont.) Mean monthly spring discharge q in lit/sec of springs

Month	Shilachhari 1	Shilachhari 2	Shilachhari 3	Kajashi	Belbari
Jan	1.150	0.952	10.13	15.96	*
Feb	1.296	0.931	6.69	9.65	*
Mar	1.472	0.902	9.19	9.25	*
Apr	1.493	0.883	8.15	8.34	*
May	1.502	0.732	12.86	14.24	*
Jun	1.538	0.739	13.15	11.71	0.031
Jul	1.498	0.802	20.30	12.52	0.010
Aug	1.766	0.733	22.18	24.13	0.056
Sep	1.678	0.766	33.90	23.02	0.011
Oct	1.530	0.868	16.45	12.32	0.007
Nov	1.153	0.933	14.66	9.93	0.004
Dec	1.136	0.842	11.60	12.08	*

* Spring discharge not measured as remained dry

on average ground water depths (Da) have been presented in Table 3.5.

Table 3.5 Monthly average ground water depths (Da) on various spring sites

Month	Da, m		
	Hazachhari 1,2,3,4 & Panchhara	Shilachhari 1,2,3	Belbari
Jan	2.375	5.045	*
Feb	2.353	5.085	*
Mar	2.372	5.031	*
Apr	2.305	4.970	*
May	2.155	4.898	*
Jun	2.008	4.734	*
Jul	1.896	4.491	4.566
Aug	1.876	4.391	4.435
Sep	1.839	4.325	4.310
Oct	1.831	4.264	4.060
Nov	1.850	4.229	4.000
Dec	1.885	4.291	4.090

*Not measured because the spring dried up

3.6 Analysis

The data on spring yield (q), rainfall (r), average ground water level (Da) and time (month) thus obtained were processed using tabular, graphical and statistical methods. To determine time lag (T) between peak r and peak q only tabular method was followed (Art 4.1). Various categories of relationships between spring discharge and each of rainfall and time (month) were developed using least square method. To examine the effects of average monthly spring discharge (qa) on (Da) and vice-versa data were plotted on squared paper.

CHAPTER - IV

Results and Discussions

In the state of Tripura, there are large number of springs which need improvement for using spring water for irrigation of crops. The discharge of three large springs namely Silachhari, Dewanchhara and Tuiarsong are now used for irrigation after conveying the flow through suitable irrigation structures (Fig 2.6). There is considerable need to utilise the spring discharge of other springs for which actual discharge of ten springs namely Hazachhari - 1, 2, 3 and 4; Panchhara; Silachhari - 1, 2 and 3; Kajashi and Belbari have been measured for each of 12 months in a year. These data are used in preliminary study. The discharge of each of these ten springs varies monthwise. On an average the discharge(q) varies from less than 0.1 lit to 20 lits/sec. The adjoining ground water levels of three open wells also vary monthwise. It is, therefore, considered necessary to find out (a) the time lag between the maximum discharge and rainfall (b) the effect of discharge on the fluctuation of ground water table (c) the possibility of developing some suitable models to predict discharge of spring considering rainfall as factor and (d) to suggest to the farmers regarding the area of different crops that can be irrigated by using the discharge of springs.

O.K.

4.1 Time lag

While the Belbari spring flows from the month June to November all other nine springs flow for all the 12 months in a year (Table 4.1 and 4.2). The data indicate that for all the ten spring there is monthly variation in their discharge. The data further indicate that there is time lags (T) i.e. time difference between the peak rainfall and peak discharge for each of the ten springs. While there is time

lag of six months for only four springs namely, Hazachhari -1, 2, 3 and Shilachhari - 2, the T is zero month for spring Panchhara the T is one month for Shilachhari-1, Hazachhari - 4, Kajashi and Belbari and for Shilachhari-3, the T is two months, which is quite natural (Pradhan, 1992). The time lag of six months for four springs may be due to quite different character of aquifer from the rest of six springs.

Table 4.1 Mean monthly yield (q) and rainfall (r) in the contributing area

Month	Rainfall (cm) r	Spring yield, q , lit/sec				
		Hazachhari 1	Hazachhari 2	Hazachhari 3	Panchhara	Shilachhari 1
Jan	0.73	<u>0.045</u>	<u>0.040</u>	<u>0.464</u>	0.092	1.150
Feb	18.46	0.013	0.013	0.096	0.174	1.296
Mar	30.42	0.008	0.02	0.073	0.117	1.472
Apr	18.95	0.005	0.015	0.088	0.078	1.493
May	64.20	0.002	0.010	0.117	0.246	1.502
Jun	78.44	0.003	0.011	0.158	0.324	1.538
Jul	<u>85.27</u>	0.007	0.013	0.213	<u>0.441</u>	1.493
Aug	62.22	0.012	0.018	0.247	0.279	<u>1.766</u>
Sept	49.53	0.012	0.011	0.247	0.267	1.673
Oct	27.88	0.013	0.016	0.222	0.293	1.530
Nov	1.36	0.011	0.004	0.150	0.148	1.153
Dec	1.50	0.010	0.003	0.170	0.087	1.136
Average		0.012	0.015	0.187	0.212	1.434

Note : the underlined figures indicate the peak values.

Table 4.2 Mean monthly spring yield (q) and rainfall (r) in the contributing area

Month	Spring yield, q, lit/sec					Belbari	
	Rainfall (cm) r	Shilachhari	Shilachhari	Hazachhari	Kajashi	Rainfall (cm)	Spring yiel q, lit/sec
		2	3	4			
Jan	0.733	<u>0.952</u>	10.13	13.31	15.96	0.393	*
Feb	18.460	0.931	6.69	9.25	9.65	12.327	*
Mar	30.420	0.902	9.19	14.25	9.25	5.640	*
Apr	18.950	0.883	8.15	19.95	8.34	11.675	*
May	64.200	0.732	12.86	18.45	14.24	47.773	*
Jun	78.440	0.739	13.15	15.43	11.71	36.710	0.031
Jul	<u>85,270</u>	0.802	20.30	26.50	12.52	37.220	0.010
Aug	62.220	0.733	22.18	<u>43.46</u>	<u>24.13</u>	18.753	<u>0.056</u>
Sep	49.530	0.766	<u>33.90</u>	35.19	23.02	29.133	0.011
Oct	27.880	0.868	16.45	22.48	12.32	23.270	0.007
Nov	1.360	0.933	14.66	15.56	9.93	1.366	0.004
Dec	1.500	0.842	11.60	13.41	12.08	0.000	*
Average		0.840	14.938	20.603	13.596		0.020

* Spring discharge could not be measured as remained dry

Note : The underlined figures indicate the peak values

Spring flow (q) fluctuates between wide ranges and the reasons of fluctuations are many. The variables (factors) responsible for fluctuations as discussed by Tolman (1937) Meinzer (1942). Chow (1964), Bhar (1991) and Valdiya

and Bartarya, (1991) are (i) rainfall in the contributing area-its intensity, duration and quantum, (ii) infiltration of water into soil mass, permeability of soil and consequently rainfall - recharge to the ground water body with which the spring is interconnected. (iii) topography, (iv) hydrologic character of the water bearing stratum, (v) geologic structures, (vi) storativity and geometry of aquifer, (vii) evaporation and transpiration from the land and vegetation adjoining the springs, (viii) specific yield from the aquifer connected to the spring, (ix) atmospheric pressure, (x) earth quake, (xi) soil erosion from the land adjoining the spring, (xii) change in vegetation of the contributing area, (xiii) gravity, (xiv) heat of the earth, (xv) gases associated with ground water, (xvi) weight of overlying rock, (xvii) expulsion from solidifying magmas etc. The list is not presumably exhaustive. The spring flow is, therefore, very complex hydrological phenomenon specially so because all the above mentioned variables are not free from interactions with each other. Thus it is a Herculean task to tackle this process mathematically or to explain easily on physics-based principles or even empirically.

In some cases the perennial springs may become seasonal due to distortions in the dynamic balance of the above listed variables or exclusively because of insufficient rainfall in the contributing area. It is obvious that if there is no rainfall, there will be no spring flow. This simply means that rainfall (r) is the most dominant single parameter causing changes in q out of 17 parameters listed above. Incidentally rainfall (r) is easily measurable in comparison to others.

4.2 Ground water level and spring yield :

Monthly average ground water depth was measured from three near by open wells. While average spring discharge ~~as designated~~ (q_a) for ten springs obtained following q_c ^{of} that each row (col-5) was divided by the number of months of that particular row in Tables (A-2 to A-11) of Appendix ~~X~~. The average discharge q_a of springs Hazachhari-1, 2,3 and 4 together with that of Panchhara have been presented in the Table 4.3 along with water table depth measured from

Table 4.3 Data on monthly average ground water depth (D_a) and monthly average spring yield (q_a) for spring Hazachhari - 1,2,3,4 and Panchhara

Month	Open well-1 D_a m	Name of springs and average discharge (q_a), lit/sec				
		Hazachhari 1	Hazachhari 2	Hazachhari 3	Hazachhari 4	Panchhara 5
Jan	2.375	0.045	0.040	0.464	13.310	0.092
Feb	2.353	0.029	0.026	0.280	11.280	0.133
Mar	2.372	0.022	0.024	0.211	12.271	0.128
Apr	2.305	0.017	0.022	0.180	14.190	0.115
May	2.155	0.014	0.020	0.167	15.042	0.141
Jun	2.008	0.012	0.018	0.166	15.107	0.172
Jul	1.896	0.012	0.017	0.173	16.730	0.210
Aug	1.876	0.012	0.018	0.182	20.070	0.219
Sept	1.839	0.012	0.017	0.189	21.750	0.224
Oct	1.831	0.012	0.017	0.193	21.830	0.231
Nov	1.850	0.012	0.015	0.189	21.260	0.224
Dec	1.885	0.012	0.014	0.187	20.600	0.212

open well-1, the average discharge q_a of springs Silachhari-1, 2,3 and Kajashi and water table depth from open well-2 as well as the average discharge (q_a) of Belbari spring and water table depths from open well-3 have been presented in Table 4.4.

Table 4.4 Data on monthly average ground water depth (D_a) and monthly average spring yield (q_a) for spring Shilachhari- 1,2, Kajashi, and Belbari

Month	Name of springs and discharge (q_a)lit/sec					(q_a)lit/sec	
	Open Well-2 D_a, m	Shilachhari 1	Shilachhari 2	Shilachhari 3	Kajashi	Open well-3 D_a, m	Belbari
Jan	5.045	1.150	0.9520	10.130	15.96	*	*
Feb	5.085	1.223	0.9415	8.410	12.81	*	*
Mar	5.031	1.306	0.9283	8.671	11.62	*	*
Apr	4.97	1.353	0.9170	8.540	10.80	*	*
May	4.896	1.382	0.8800	9.400	11.48	*	*
Jun	4.734	1.408	0.8565	10.030	11.53	*	0.031
Jul	4.491	1.421	0.8487	11.500	11.67	4.560	0.020
Aug	4.391	1.464	0.8343	12.830	13.23	4.435	0.032
Sept	4.325	1.488	0.8267	15.170	14.31	4.310	0.027
Oct	4.264	1.492	0.8308	15.300	14.11	4.060	0.023
Nov	4.229	1.461	0.8401	15.180	13.75	4.000	0.020
Dec	4.291	1.434	0.8403	14.940	13.59	4.090	*

* Spring discharge and Groundwater depth not measured as remained dry

The data (Tables 4.3 and 4.4) indicate that irrespective of the month there is variation in both water table depth (D_a) and the average discharge (q_a) from all nine springs. The data further indicate that the open well-3 remains dry upto the month of June while the discharge of Belbari spring starts from June and ends at November. The fluctuations in the rate of discharge of spring depends mainly on the quantum of rainfall penetrating the soil and its rate of movement through aquifer. The data (Tables 4.3 and 4.4) must be examined in depth to find out the relationship between the water table depth and spring discharge if any.

The data (Figures 4.1 to 4.4) indicate that the except for Panchhara, Hazachhari-4, Shilachhari-1 and 3, there is no distinct relation between ground water level and spring discharge. The relationship between depth of ground water level and spring discharge for Panchhara, Hazachhari-4, Shilachhari-1 and 3, is mainly due to the fact that the open well-1 and 2 are located at higher elevation. For the other springs the wells are situated at much lower elevation. Questions may naturally arise as to how spring flow continues in all other 5 springs round the year. This may be due to the stored water in the aquifer (Bhar, 1991). The physical condition of Belbari is quite different from that of other nine springs it is depression spring (Vide Fig 2.1). Hence Belbari spring operates due to rain water seepage which is supposed to join ground water but could not join because of special land configuration. It is also noted that ground water will have to rise about 10 m to reach the elevation of spring mouth. This is not possible. Hence this

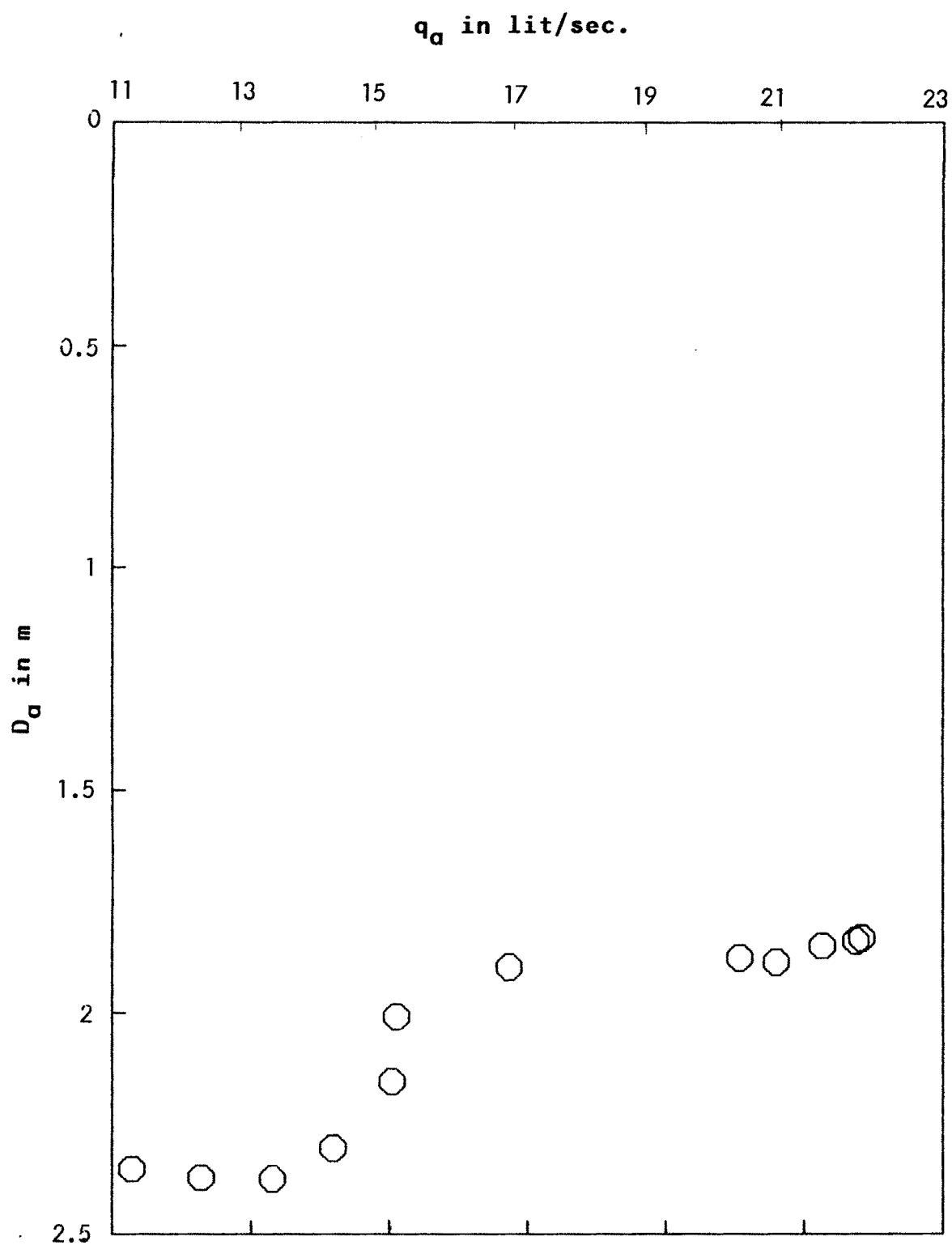


Fig. 4.1 Annual variation of average groundwater levels (D_q) with respect to ground surface in comparison with the average spring yield (q_a) for Hazachhari-4 (Table 4.3)

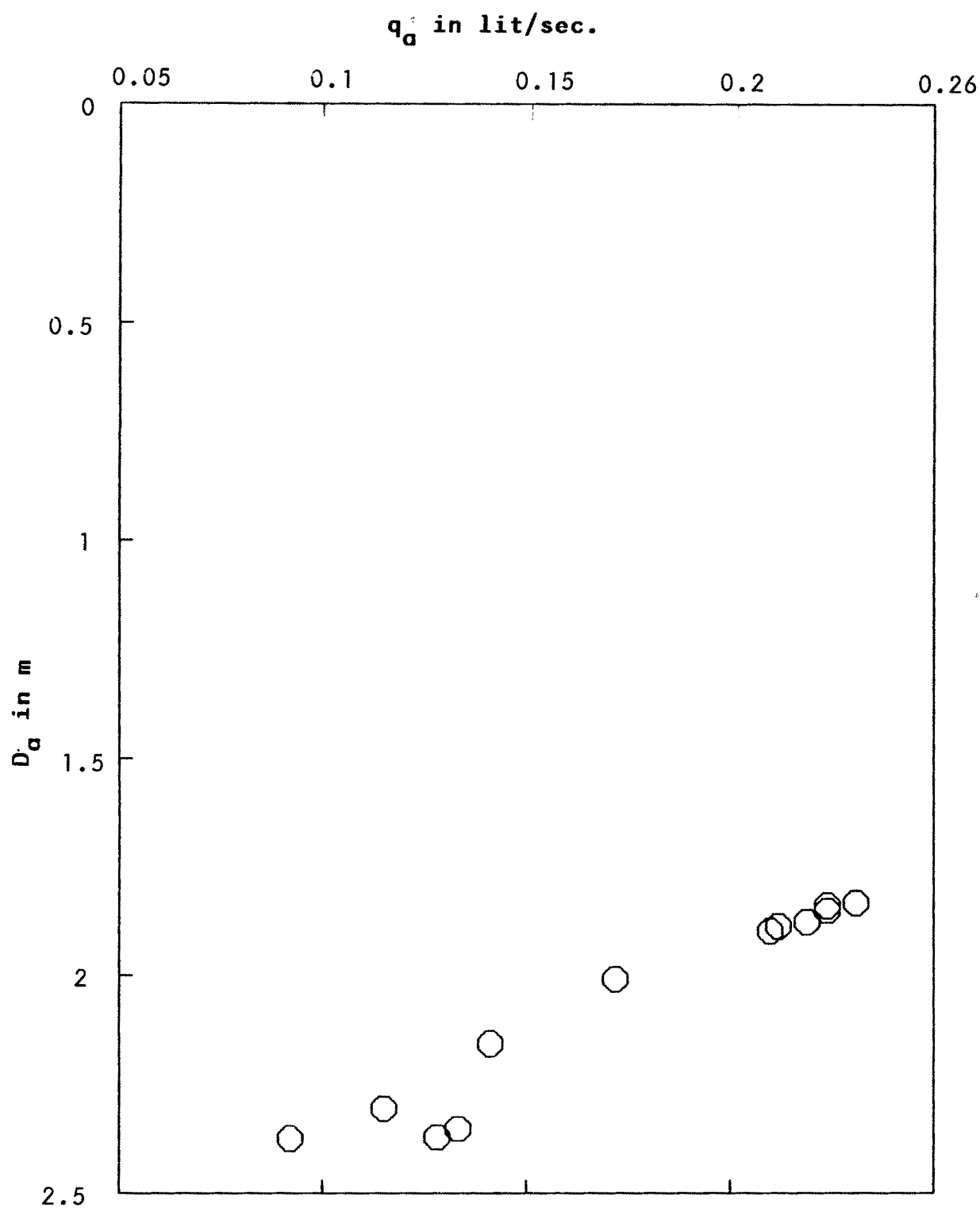


Fig. 4.2 Annual variation of average groundwater levels (D_q) with respect to ground surface in comparison with the average spring yield (q_q) for Panchhara (Table 4.3)

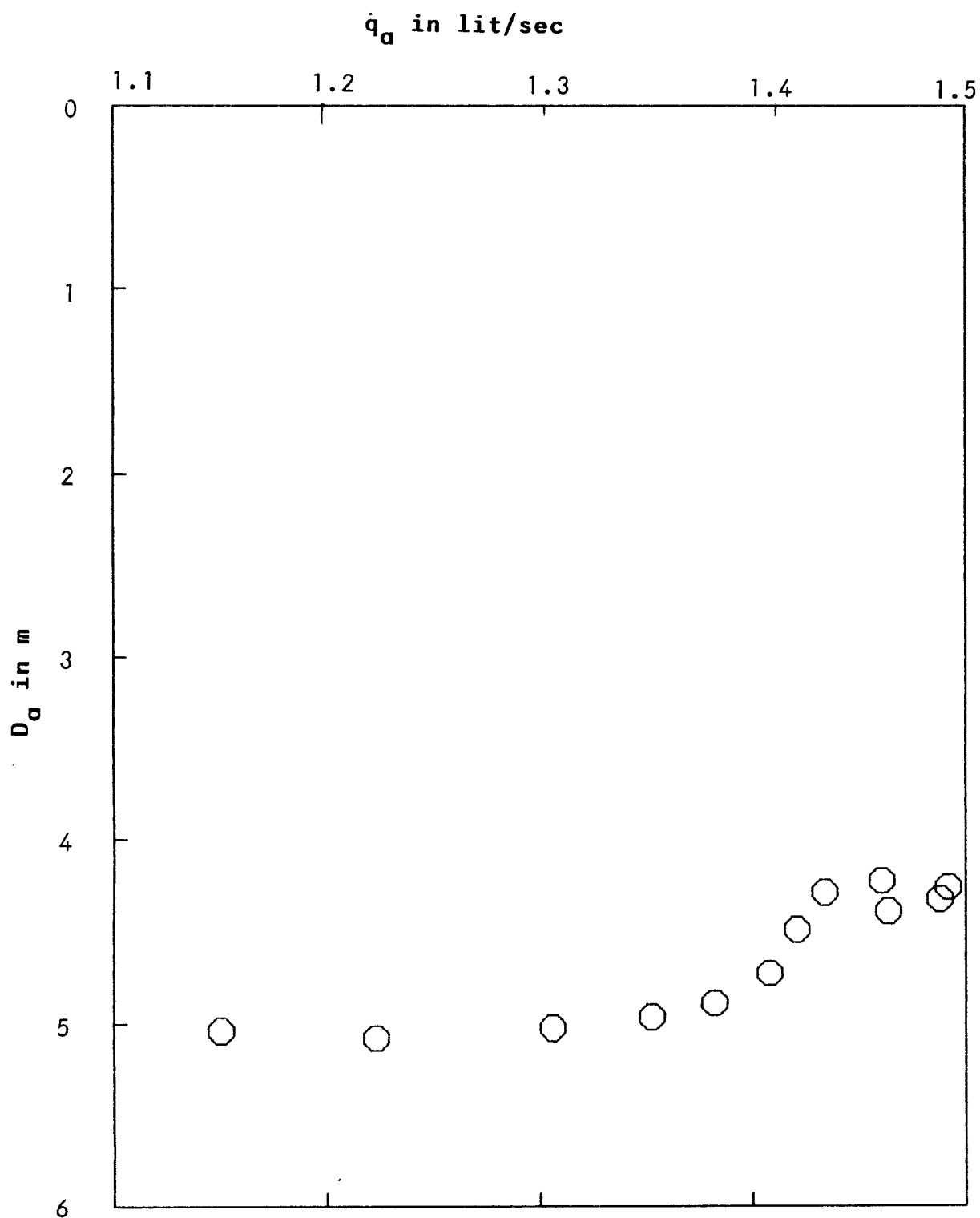


Fig. 4.3 Annual variation of average groundwater levels (D_q) with respect to ground surface in comparison with the average spring yield (q_q) for Shilachhari-1 (Table 4.4)

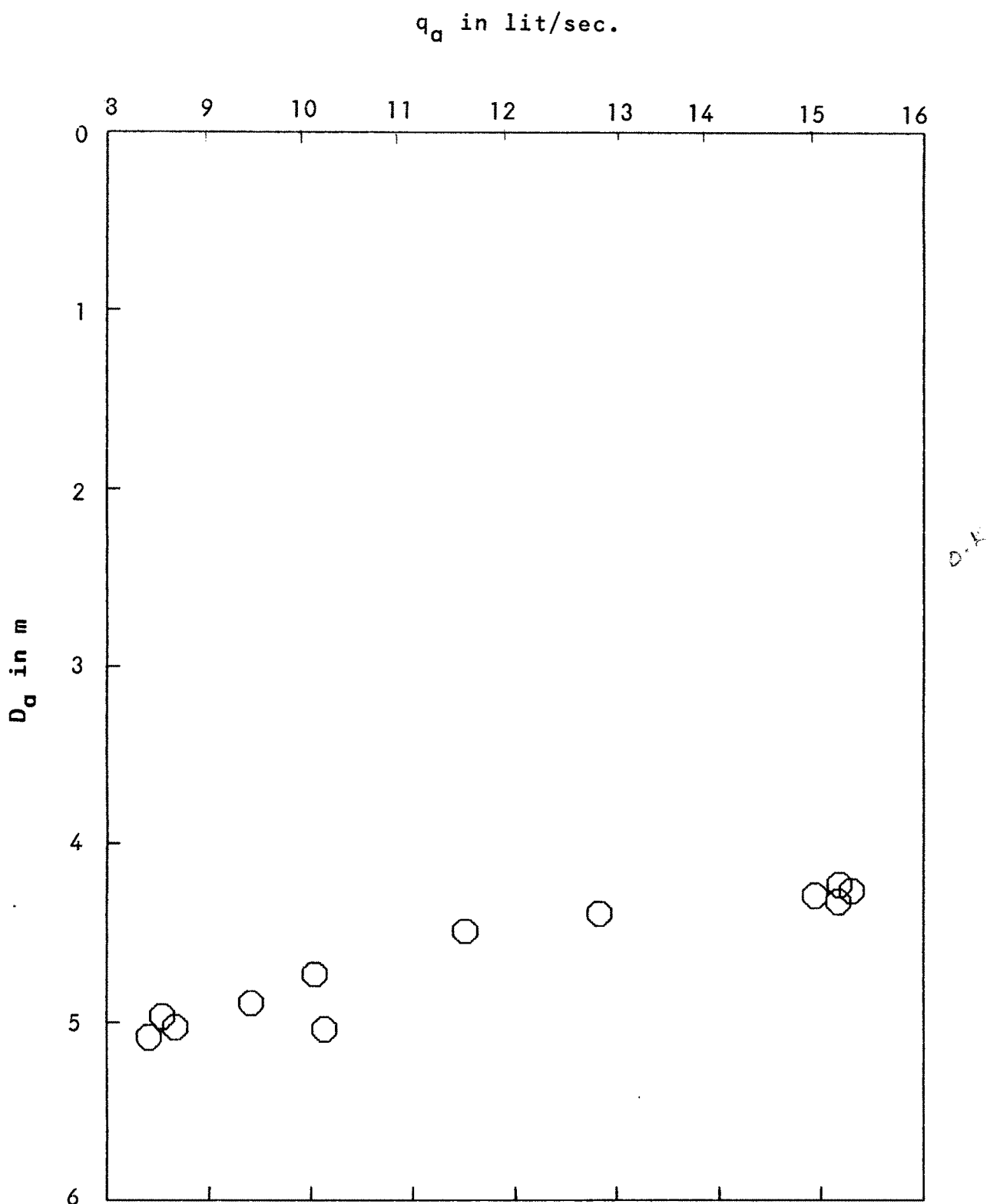


Fig. 4.4 Annual variation average groundwater levels (D_a) with respect to ground surface in comparison with the average spring yield (q_a) for Shilachhari-3 (Table 4.4)

spring has no connection with the ground water level, and, therefore there is no relationship between the ground water level fluctuation and the spring discharge of Belbari.

4.3 Spring Yield Models

4.3.1 Mean monthly cumulative model

Since the plot of mean monthly spring yield (q) and mean monthly rainfall (r) data (Tables 3.3, 3.4) on squared paper, semi-log and log log paper failed to reveal any plausible relation between these two parameters in predicting the spring yield, attempt was, therefore, made to find out acceptable relationship between mean monthly cumulative spring yield (q_c) and mean monthly cumulative rainfall (r_c) starting from January and ending at December. The plots of q_c against r_c on squared, semi-log and log log papers failed.

Afterwards, the rainfall (r) data (Table 3.3) is arranged in ascending order ignoring its chronology and called as R . The spring yield (q) data of each spring for each month (Table 3.4) have been entered against the R values named as Q . The cumulative values of both rainfall (R_c) and spring yield (Q_c) have been calculated. The procedure followed in calculating both Q_c and R_c is given in Table A-1 of Appendix-A for Hazachhari-1 spring.

Table 4.5 Mean monthly rainfall (r), spring yield (q) and their special processing to get cumulative rainfall (R_c) and cumulative spring yield (Q_c) for Hazachhari - 1 spring

Arranged chronologically			Arranged against ascending order of r values				
Month	-----		Month	-----			
	r	q		R	Q	R _c	Q _c
	cm	lit/sec		cm	lit/sec	cm	lit/sec
Jan	0.733	0.045	Jan	0.733	0.045	0.733	0.045
Feb	18.460	0.013	Nov	1.360	0.011	2.093	0.056
Mar	30.420	0.008	Dec	1.500	0.010	3.593	0.066
Apr	18.950	0.005	Feb	18.460	0.013	22.053	0.079
May	64.200	0.002	Apr	18.950	0.005	41.003	0.084
Jun	78.440	0.003	Oct	27.880	0.013	68.883	0.097
Jul	85.270	0.007	Mar	30.420	0.008	99.303	0.105
Aug	62.220	0.012	Sep	49.530	0.012	148.833	0.117
Sep	49.530	0.012	Aug	62.220	0.012	211.053	0.122
Oct	27.880	0.013	May	64.200	0.002	275.253	0.131
Nov	1.360	0.011	Jun	78.440	0.003	353.693	0.134
Dec	1.500	0.010	Jul	85.270	0.007	438.963	0.141

Since the rainfall data collected from Sabroom rain-gauge station for all springs except Belbari spring, the values of R_c remains unchanged. Therefore, in the subsequent Tables (4.6 and 4.7) against R_c values, Q and Q_c values of each spring have been presented. For Belbari spring, since r is different, detail calculations have been given separately in Table 4.8..

Table 4.6 Mean monthly non-chronological cumulative rainfall (R_c) and cumulative spring yield (Q_c)

Month	R_c^* (cm)	Hazachhari-2		Hazachhari-3		Hazachhari-4		Panchhara	
		Q (lit/ sec)	Q_c (lit/ sec)	Q (lit/ sec)	Q_c (lit/ sec)	Q (lit/ sec)	Q_c (lit/ sec)	Q (lit/ sec)	Q_c (lit/ sec)
Jan	0.733	0.040	0.040	0.464	0.464	13.310	13.310	0.092	0.092
Nov	2.093	0.004	0.044	0.150	0.614	15.560	28.870	0.148	0.240
Dec	3.593	0.003	0.047	0.170	0.784	13.410	42.280	0.087	0.327
Feb	22.053	0.013	0.060	0.096	0.880	9.250	51.530	0.174	0.501
Apr	41.003	0.015	0.075	0.088	0.968	19.950	71.480	0.078	0.579
Oct	68.883	0.016	0.091	0.222	1.190	22.480	93.960	0.293	0.872
Mar	99.303	0.020	0.111	0.073	1.263	14.253	108.213	0.117	0.989
Sep	148.833	0.017	0.128	0.247	1.510	35.190	143.403	0.267	1.256
Aug	211.053	0.018	0.146	0.247	1.757	43.460	186.863	0.279	1.535
May	275.253	0.010	0.156	0.117	1.874	18.450	205.313	0.046	1.581
Jun	353.693	0.011	0.167	0.158	2.032	15.430	220.743	0.324	1.905
Jul	438.963	0.013	0.180	0.213	2.245	26.500	247.243	0.441	2.346

* Arranged against ascending order of r values (Table 4.5).

Table 4.7 Mean monthly non-chronological cumulative rainfall (R_c) and cumulative spring yield (Q_c)

Month	R_c^* (cm)	Shilachhari-1		Shilachhari-2		Shilachhari-3		Kajashi	
		Q (lit/ sec)	Q_c (lit/ sec)	Q (lit/ sec)	Q_c (lit/ sec)	Q (lit/ sec)	Q_c (lit/ sec)	Q (lit/ sec)	Q_c (lit/ sec)
Jan	0.733	1.150	1.150	0.952	0.952	10.130	10.130	15.960	15.960
Nov	2.093	1.153	2.303	0.933	1.885	14.660	24.790	9.930	25.890
Dec	3.593	1.136	3.439	0.842	2.727	11.600	36.390	12.080	37.970
Feb	22.053	1.296	4.735	0.931	3.658	6.690	43.080	9.650	47.620
Apr	41.003	1.493	6.228	0.883	4.541	8.150	51.230	8.340	55.960
Oct	68.883	1.530	7.758	0.868	5.409	16.450	67.680	12.320	68.280
Mar	99.303	1.472	9.230	0.902	6.311	9.190	76.870	9.250	77.530
Sep	148.833	1.678	10.908	0.766	7.077	33.900	110.770	23.020	100.550
Aug	211.053	1.766	12.674	0.733	7.810	22.180	132.950	24.130	124.680
May	275.253	1.502	14.176	0.732	8.542	12.860	145.810	14.240	138.920
Jun	353.693	1.538	15.714	0.739	9.281	13.150	158.960	11.710	150.630
Jul	438.963	1.498	17.212	0.802	10.083	20.300	179.260	12.520	163.150

* Arranged against ascending order of r values (Table 4.5)

Table 4.8 Mean monthly rainfall (r), spring yield (q) and their special processing to get cumulative rainfall (R_c) and cumulative spring yield (Q_c) for Belbari spring

Month	Arranged chronologically		Month	Arranged against ascending order of r values			
	r cm	q lit/sec		R cm	Q lit/sec	R_c cm	Q_c lit/sec
Jan	0.393	*	Dec	0.000	*	0.000	*
Feb	12.327	*	Jan	0.393	*	0.393	*
Mar	5.640	*	Nov	1.366	0.004	1.759	0.004
Apr	11.675	*	Mar	5.640	*	7.399	*
May	47.773	*	Apr	11.675	*	19.074	*
Jun	36.710	0.031	Feb	12.327	0.000	31.404	
Jul	37.220	0.010	Aug	18.753	0.056	50.154	0.060
Aug	18.753	0.056	Oct	23.270	0.007	73.424	0.067
Sep	29.133	0.011	Sep	29.133	0.011	102.557	0.078
Oct	23.270	0.007	Jun	36.710	0.031	139.267	0.109
Nov	1.366	0.004	Jul	37.220	0.010	176.487	0.119
Dec	0.000	*	May	47.773	*	224.260	*

* Spring discharge could not be measured as remained dry.

The values of both Q_c and R_c have been plotted at first on squared paper (Figs. 4.5 to 4.14) which show a significant trend in case of all the springs.

However, to obtain a straight line relationship the data of both R_c and Q_c for each of ten springs have been

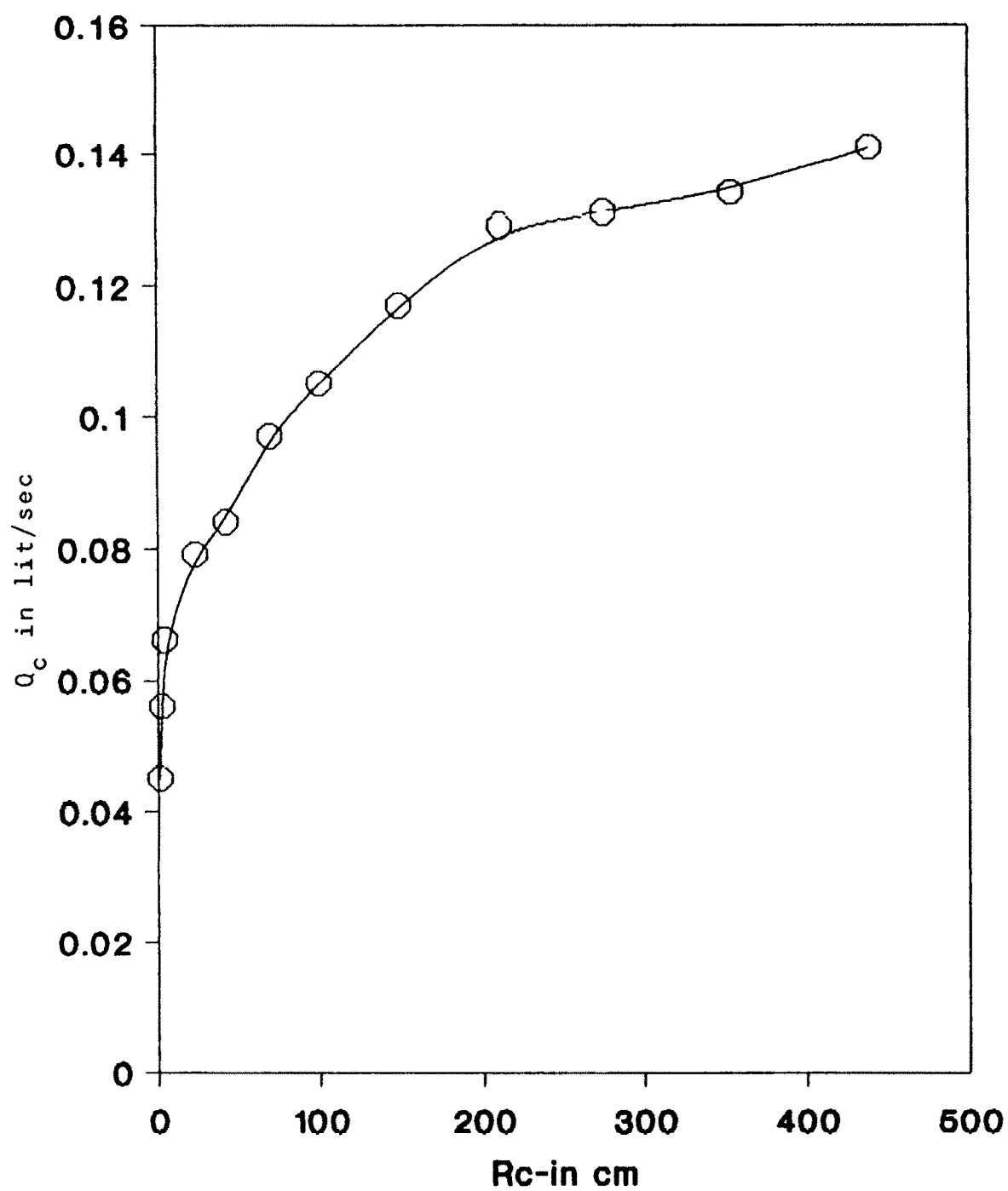


FIG. 4.5 The plot of Q_c against R_c (Table-4.5) for spring Hazachhari-1

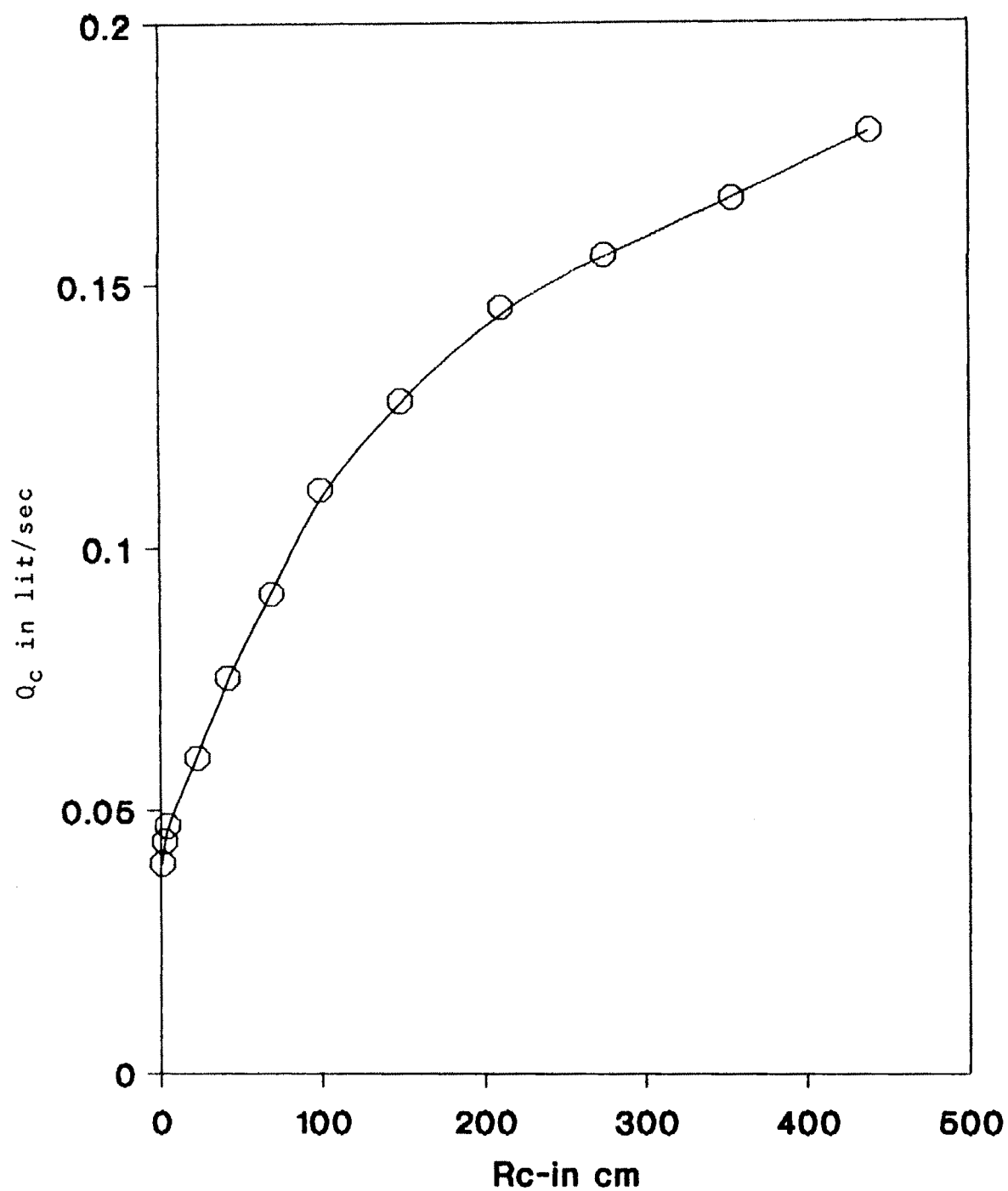


FIG. 4.6 The plot of Q_c against R_c (Table-4.6) for spring Hazachhari-2

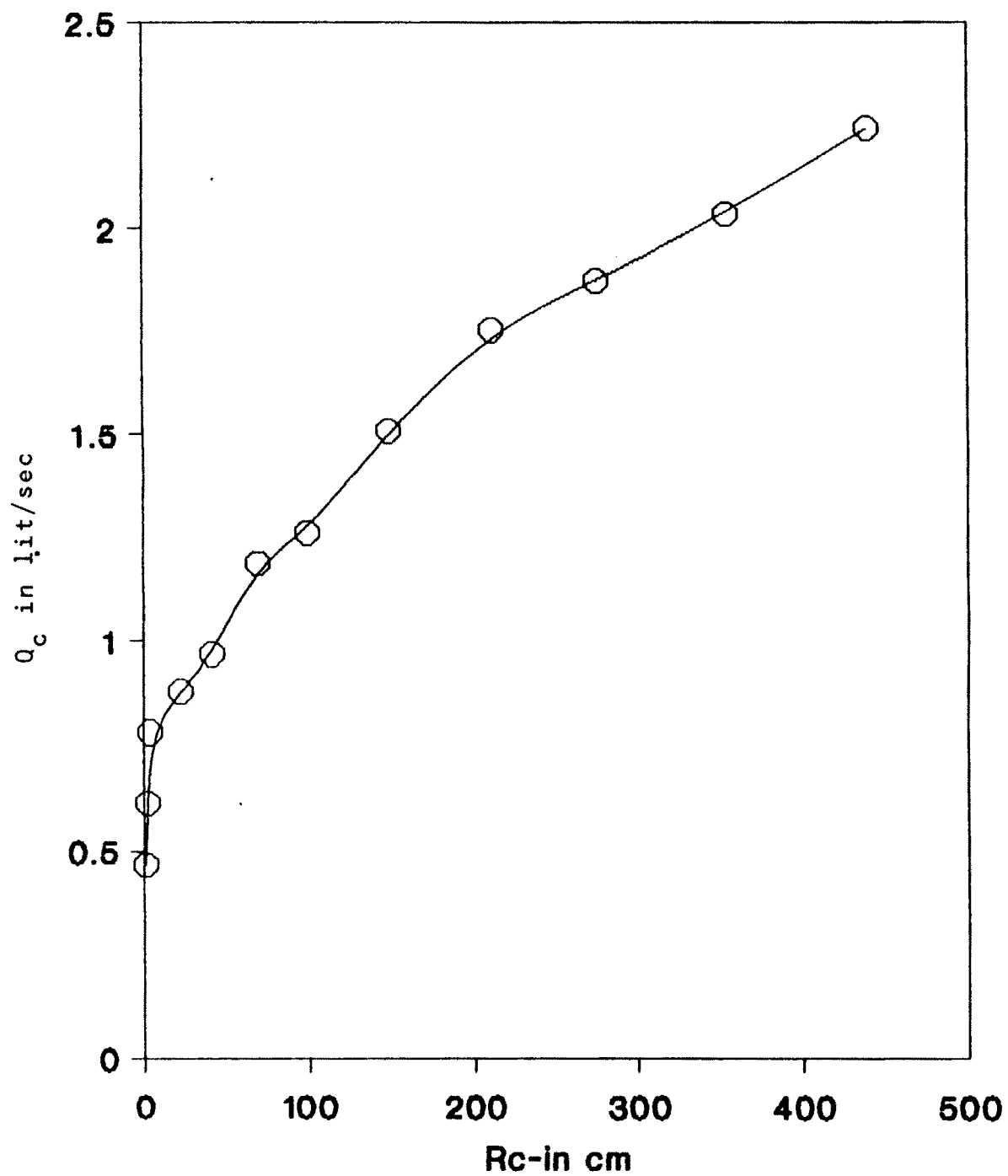


FIG. 4.7 The plot of Q_c against R_c (Table-4.6) for spring Hazachhari-3

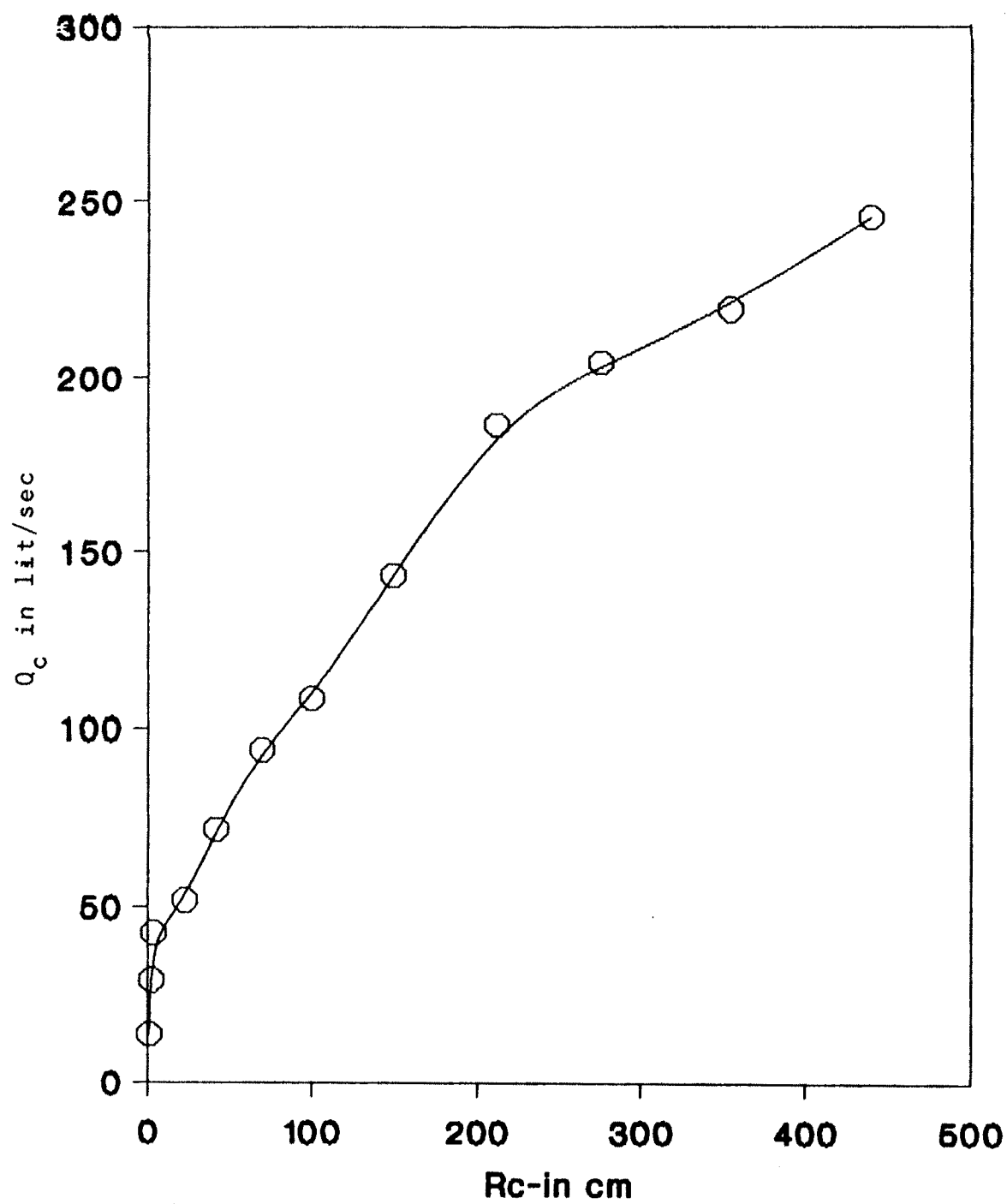


FIG. 4.8 The plot of Q_c against R_c (Table-4.6) for spring Hazachhari-4

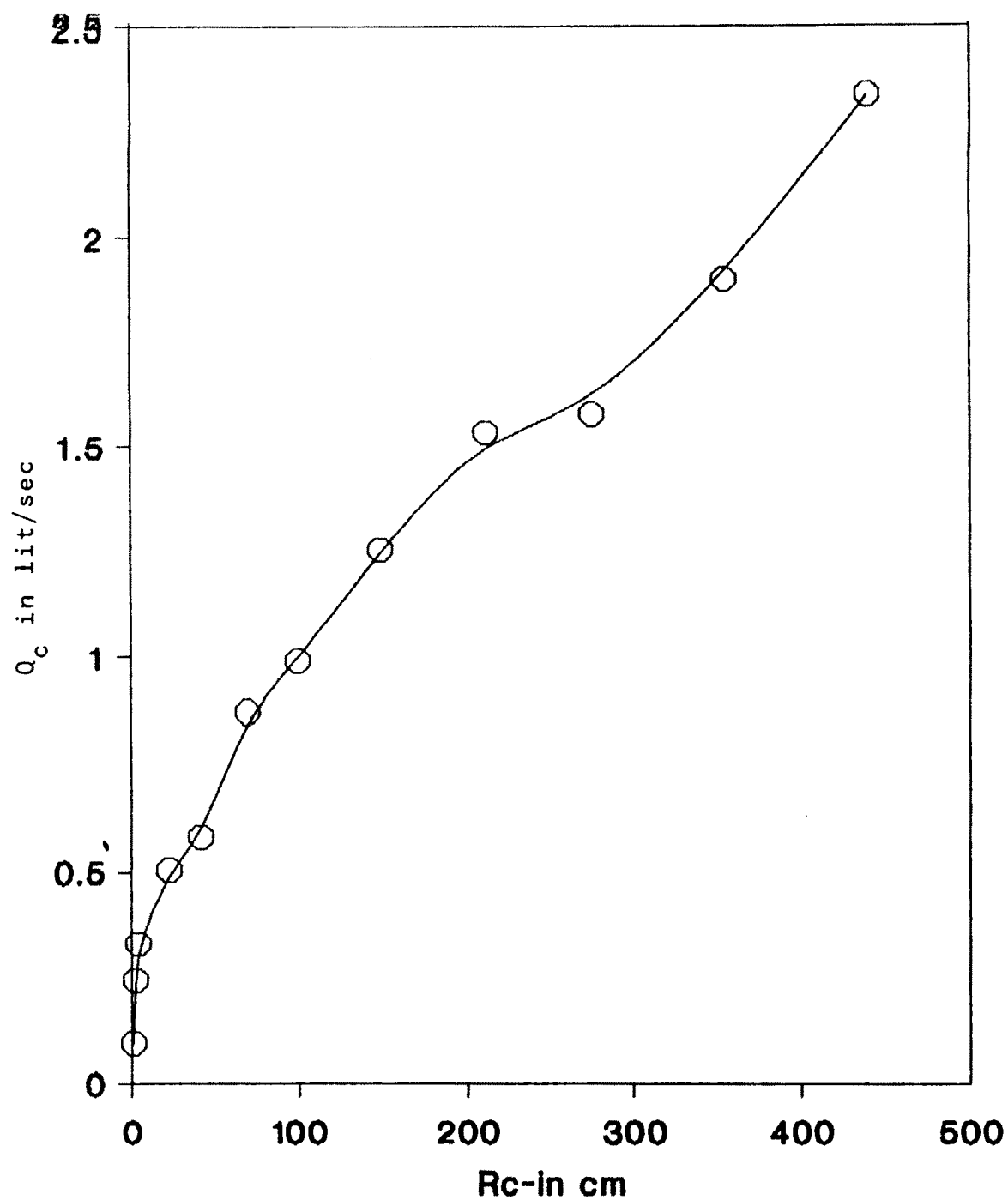


FIG. 4.9 The plot of Q_c against R_c
(Table-4.6) for spring Panchhara

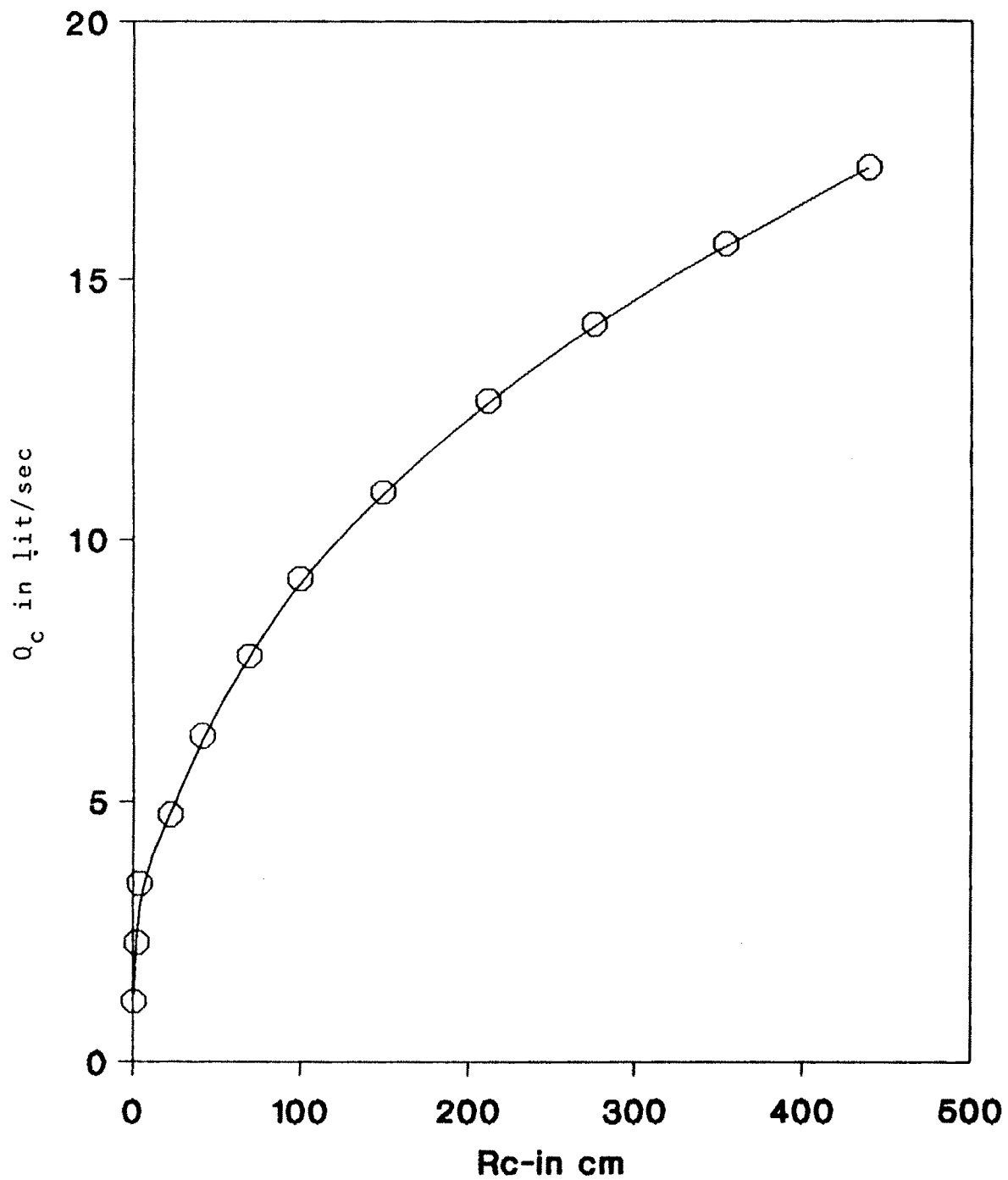


FIG. 4.10 The plot of Q_c against R_c (Table-4.7) for spring Shilachhari-1

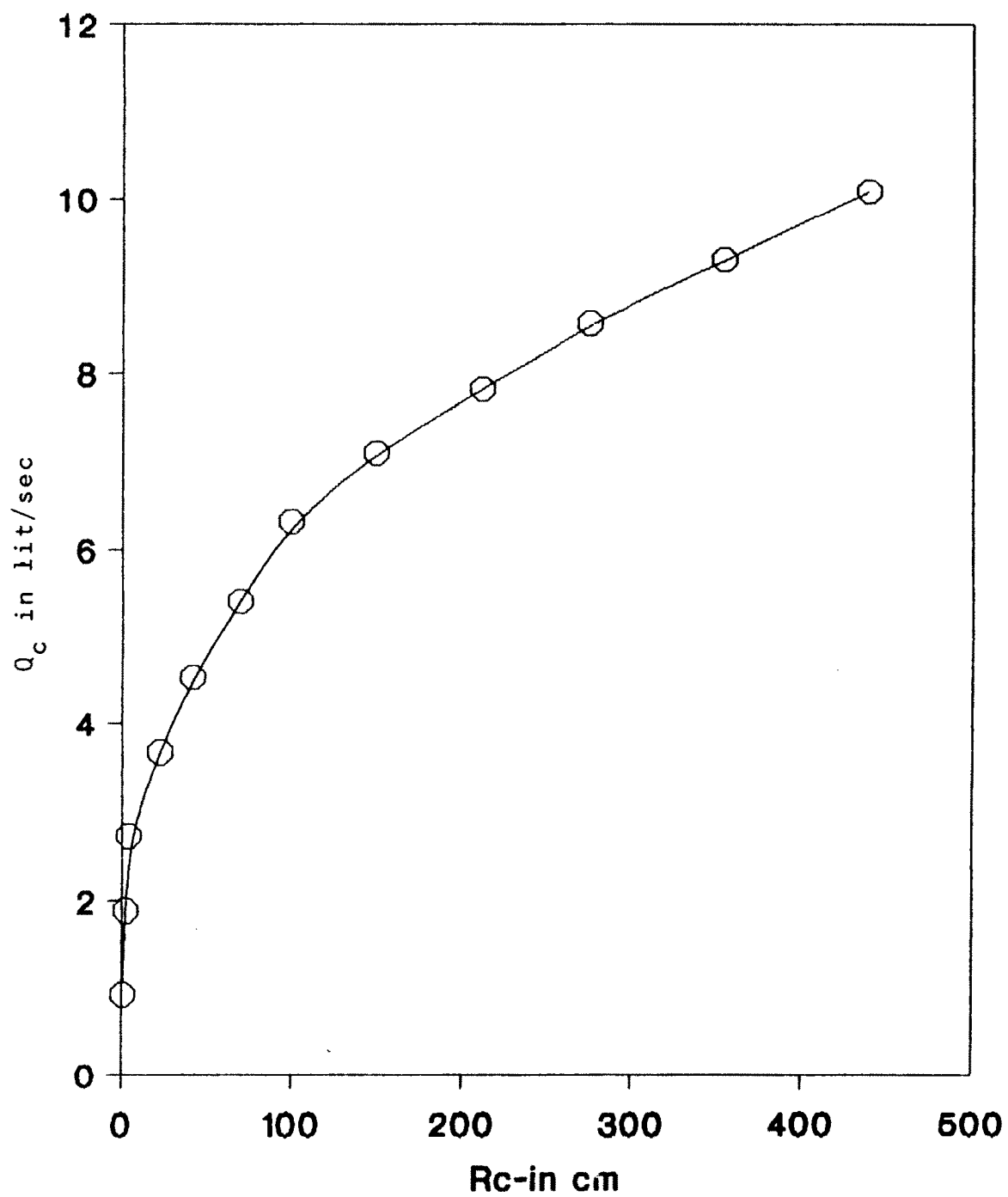


FIG. 4.11 The plot of Q_c against R_c (Table-4.7) for spring Shilachhari-2

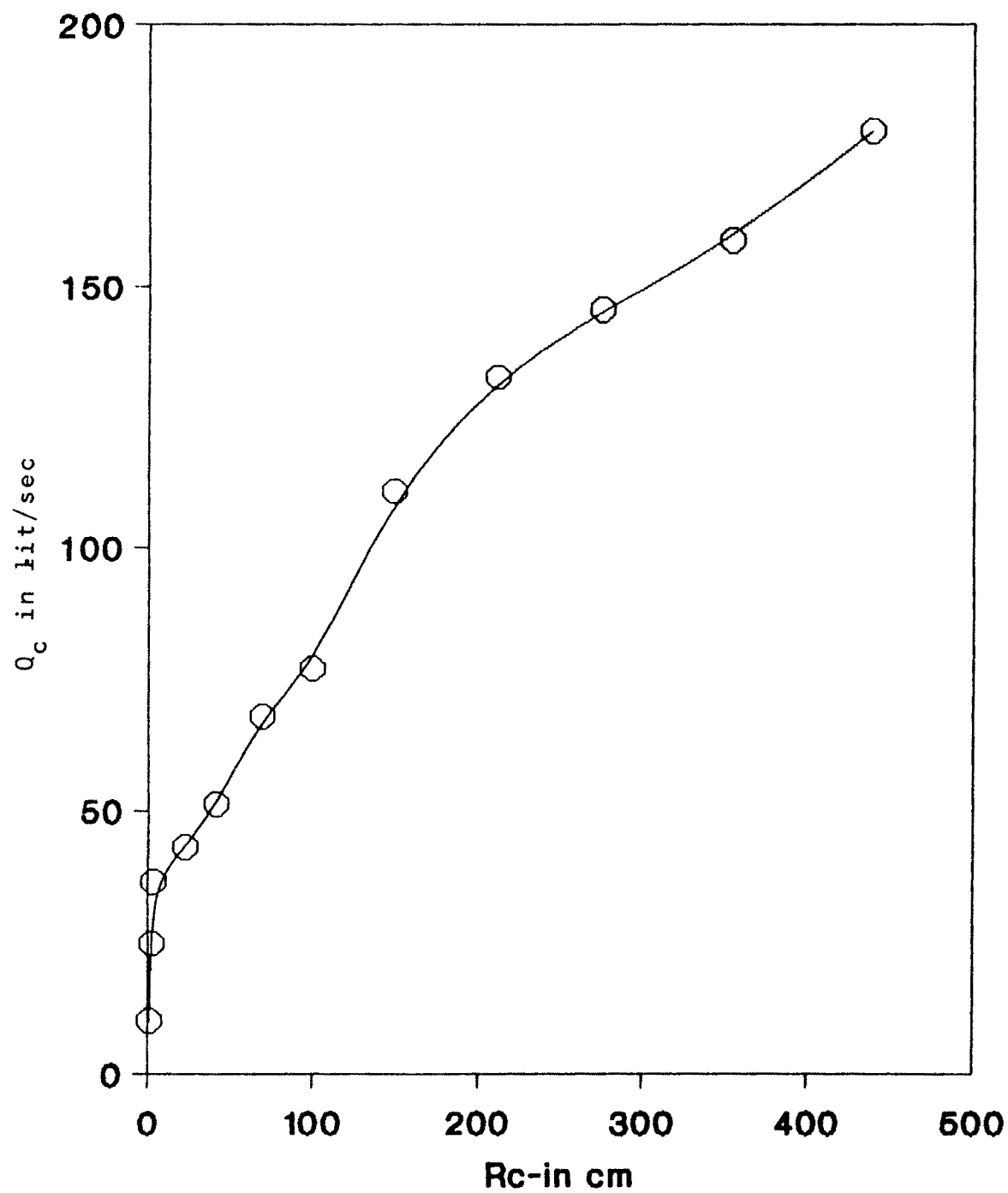


FIG. 4.12 The plot of Q_c against R_c (Table-4.7) for spring Shilachhari-3

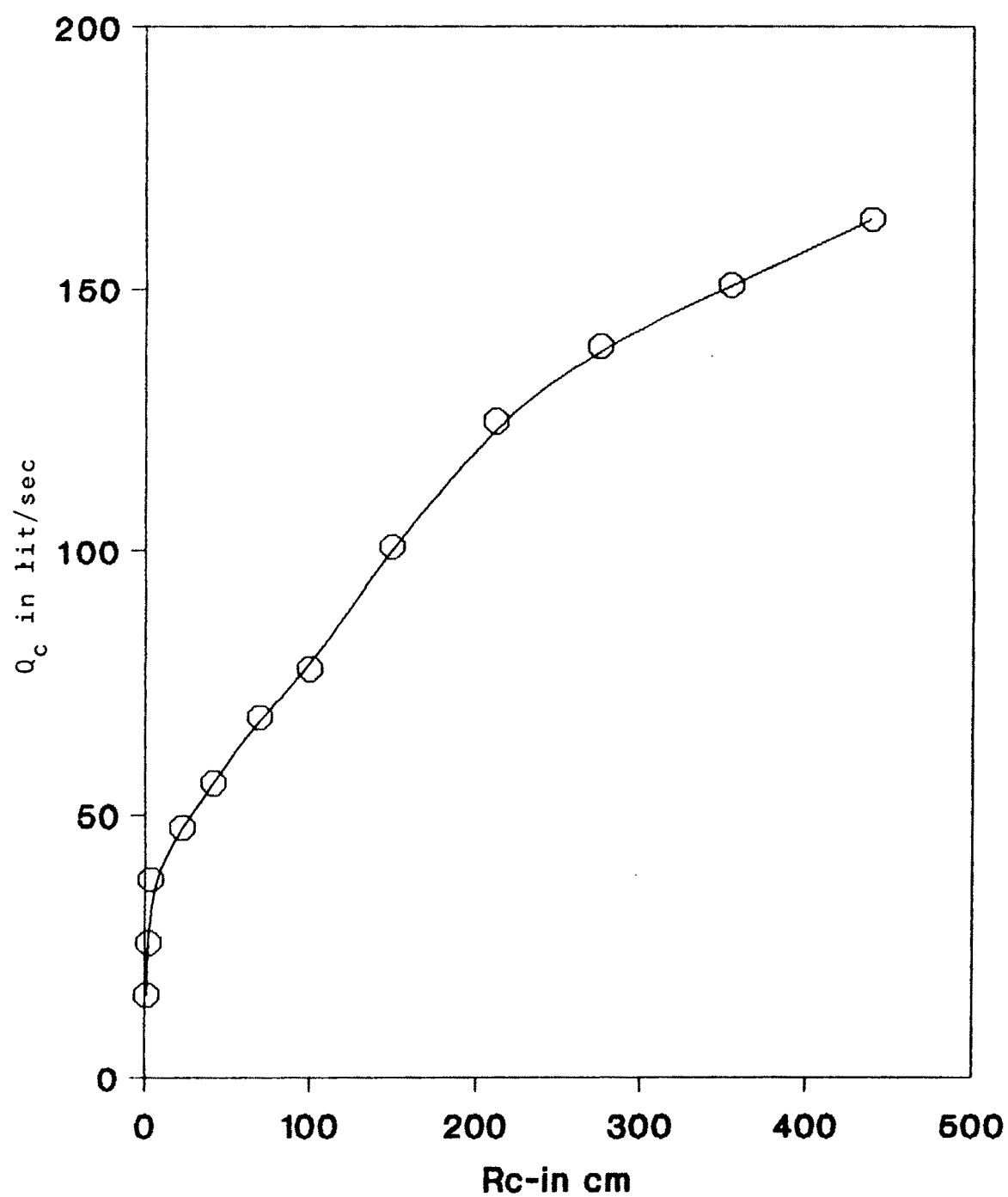


FIG. 4.13 The plot of Q_c against R_c
(Table-4.7) for spring Kajashi

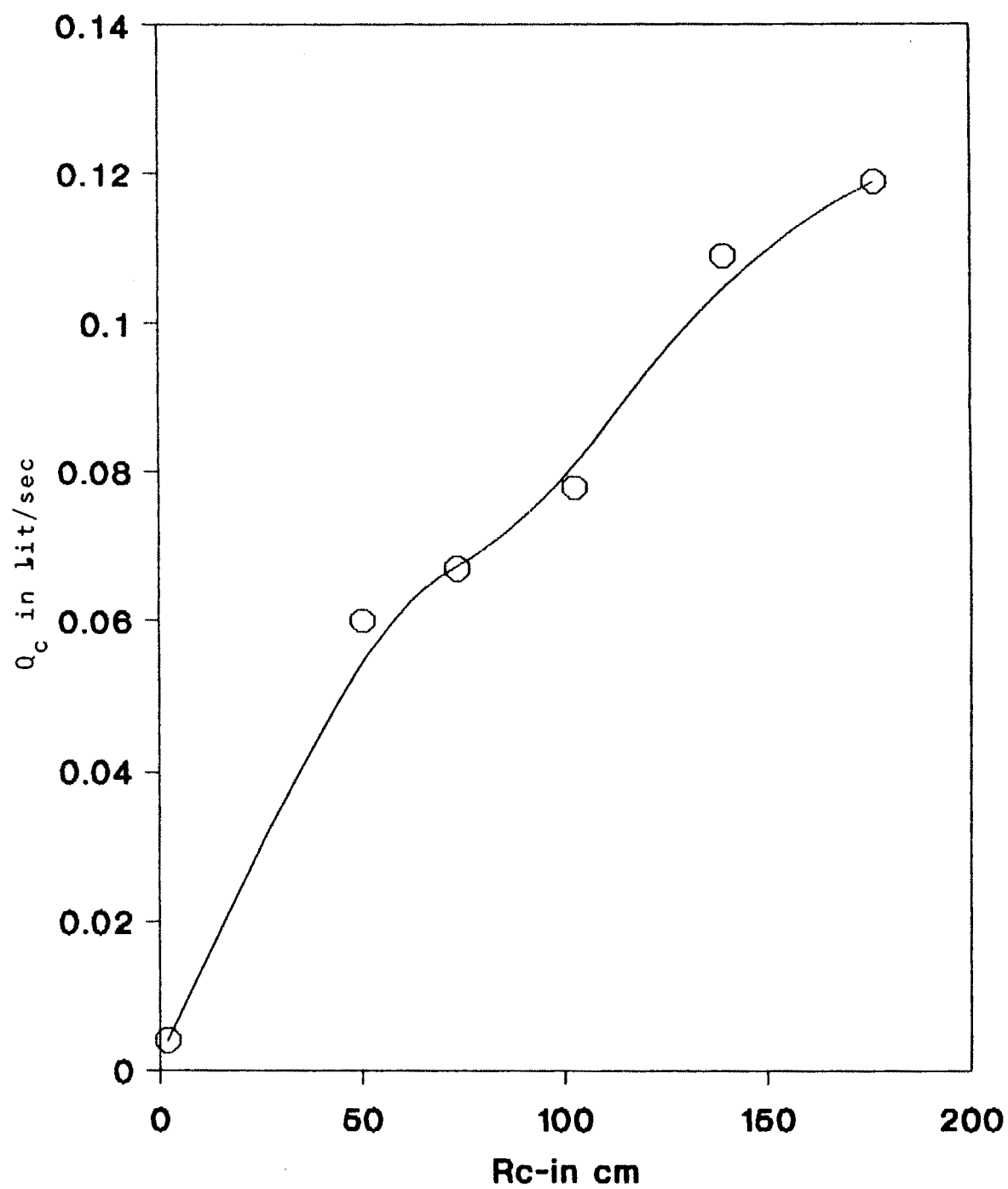


FIG. 4.14 The plot of Q_c against R_c (Table-4.8) for spring Belbari

plotted (Figs 4.15 and 4.16) in log log papers. Following the least square method the relationship between the mean monthly cumulative spring yield (Q_c) and mean monthly cumulative rainfall (R_c) has been derived in the following form :

$$Q_c = a R_c^b \quad \dots\dots\dots (4.1)$$

where,

- Q_c = Cumulative value of Q , lit/sec
- Q = Non-chronological mean monthly spring yield corresponding to R , lit/sec
- R = Rigging of 12 monthly rainfall (r) in an ascending order, cm
- R_c = Cumulative value of R , cm
- a, b = empirical constants

The maximum allowable months in Eq (4.1) is 12 when an year ends (Details of calculations for one spring are given in Appendix)

The equations for each of ten springs are given below :

Hazachhari-1 $Q_c = 0.0484 R_c^{0.1730}$
 $R^2 = 99.2\%$

Hazachhari-2 $Q_c = 0.0354 R_c^{0.2505}$
 $R^2 = 97.3\%$

Hazachhari-3 $Q_c = 0.4960 R_c^{0.2272}$
 $R^2 = 97.7\%$

Hazachhari-4 $Q_c = 17.9134 R_c^{0.4183}$
 $R^2 = 98.3\%$

Panchhara $Q_c = 0.1381 R_c^{0.4429}$
 $R^2 = 98.5\%$

Shilachhari-1 $Q_c = 1.5795 R_c^{0.3878}$
 $R^2 = 99\%$

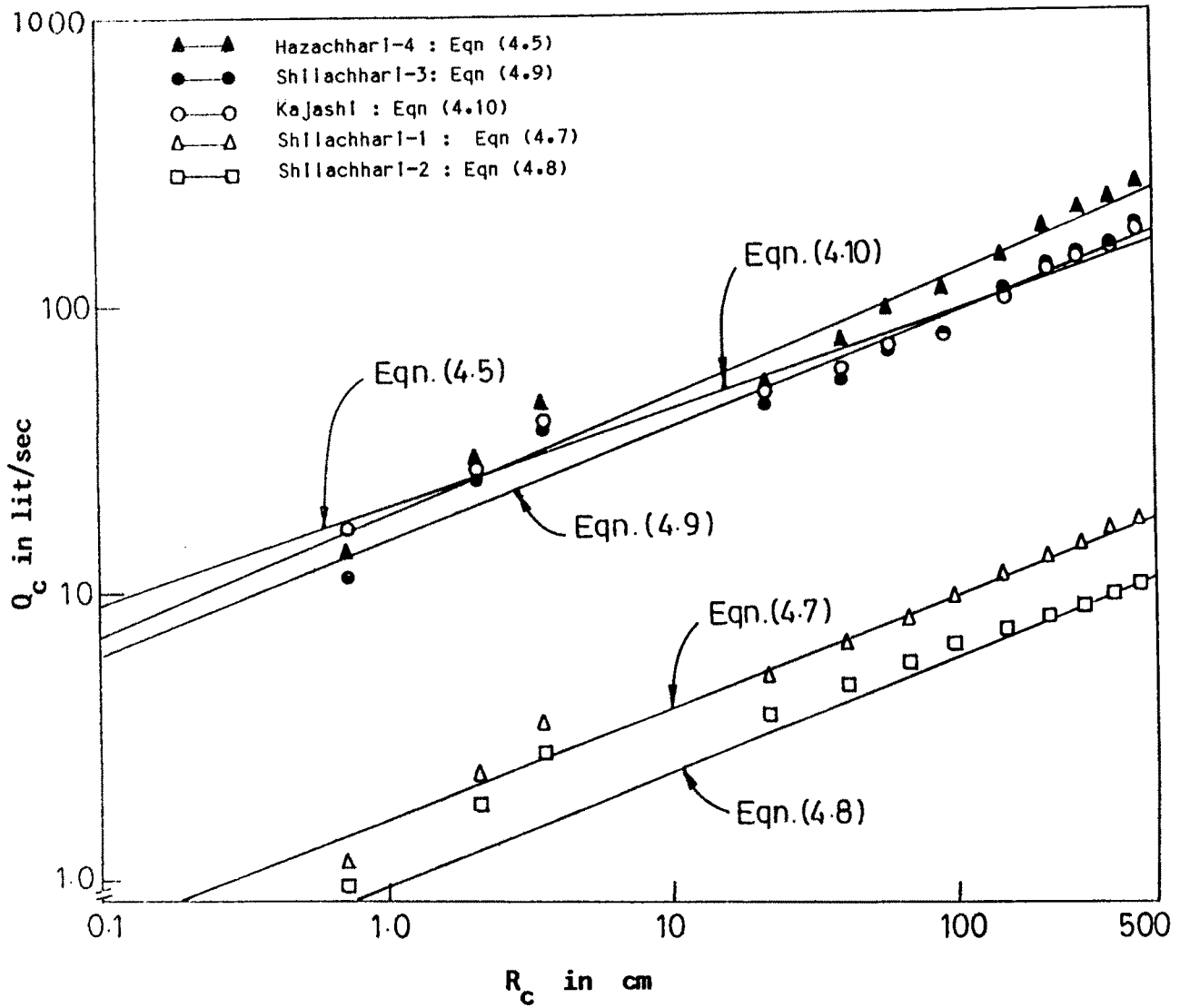


Fig. 4.15 Logarithmic variation of Q_c against R_c (Tables 4.6 and 4.7) and their fitted equations.

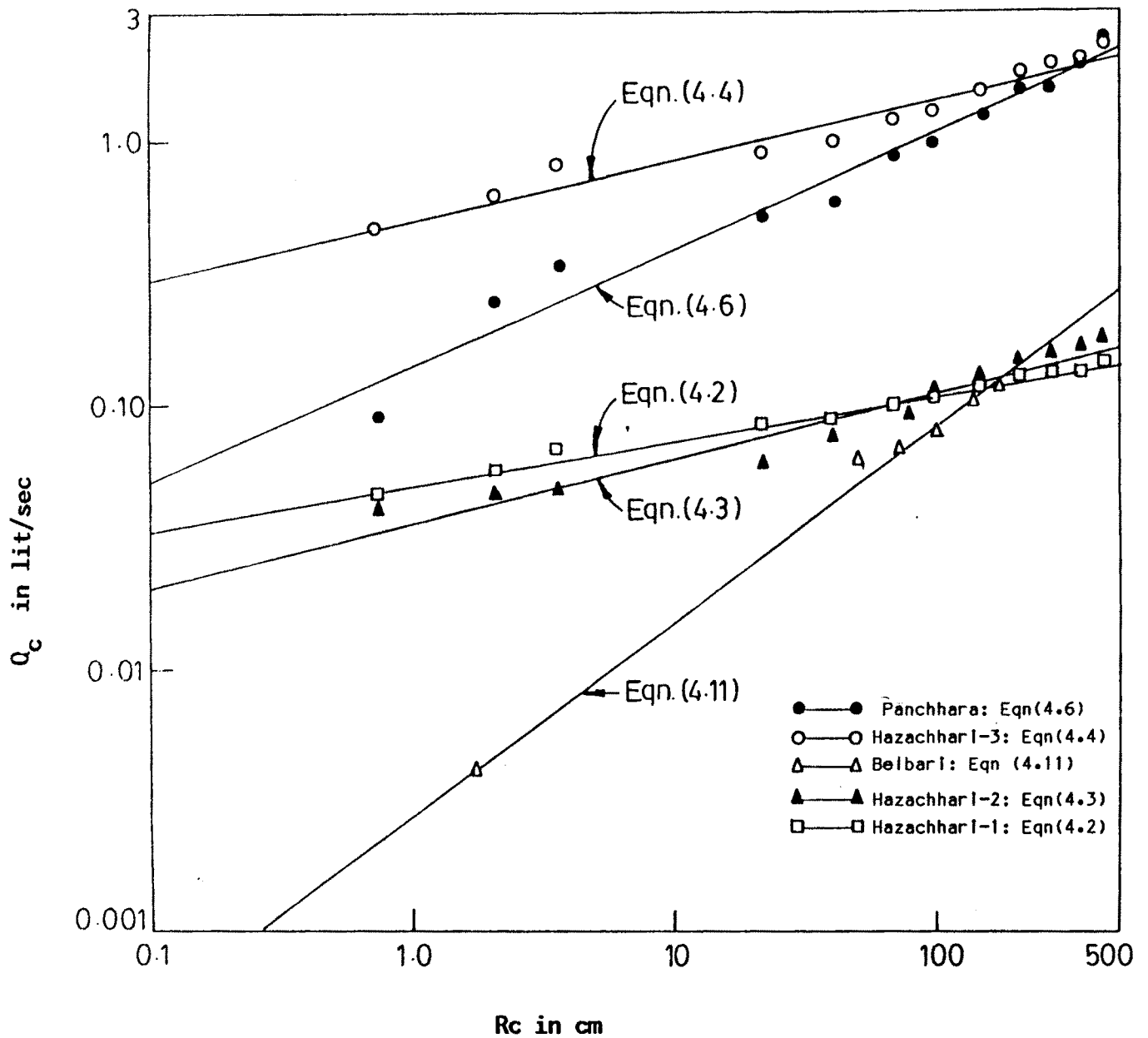


Fig. 4.16 Logarithmic variation of Q_c against R_c (Tables 4.5, 4.6 and 4.8) and their fitted equations.

$$\begin{aligned} \text{Shilachhari-2} \quad Q_c &= 1.3565 \quad R_c^{0.3306} \\ R^2 &= 98.7\% \end{aligned}$$

$$\begin{aligned} \text{Shilachhari-3} \quad Q_c &= 14.8845 \quad R_c^{0.3934} \\ R^2 &= 97.4\% \end{aligned}$$

$$\begin{aligned} \text{Kajashi} \quad Q_c &= 18.9386 \quad R_c^{0.3381} \\ R^2 &= 98.3\% \end{aligned}$$

$$\begin{aligned} \text{Belbari} \quad Q_c &= 0.0027 \quad R_c^{0.7429} \\ R^2 &= 99.7\% \end{aligned}$$

The mean monthly cumulative spring yield values for all ten springs have been estimated using Eqns (4.2) to (4.11).

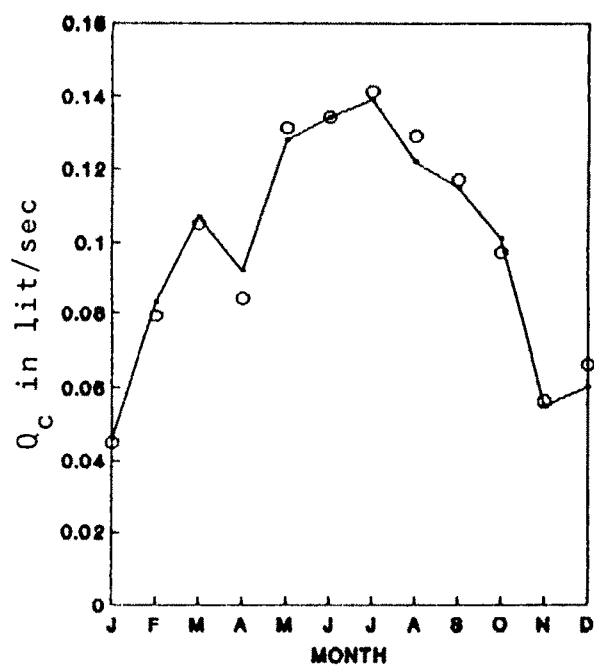
The estimated (using Eqns 4.2 to 4.11) and measured values for each spring are shown in Figs 4.17 to 4.19. This indicates a close relationship between these.

4.3.2 Monthly average model

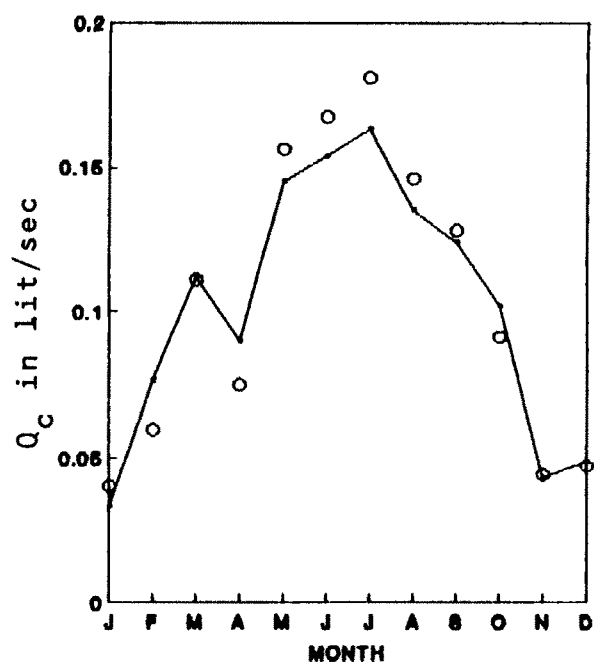
Sometimes data on monthly spring yield is essential for management of water resources. The observed data on spring yield (q) in column - 3 against month (t_m) in column-2 are shown in Table A-2 to A-11 of Appendix. The method of processing by least square is also shown therein. The following type of model is obtained

$$q_c = a_0 + a_1 + a_2 t^2 + a_3 t^3 \dots\dots\dots (4.12)$$

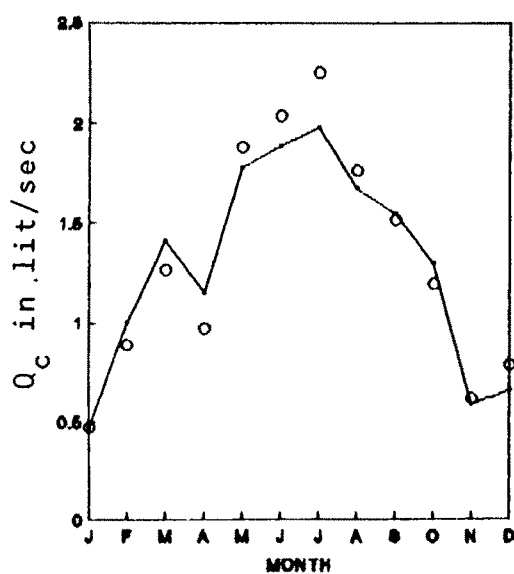
in which q_c = cumulative monthly (chronological)
spring yield, lit/sec.



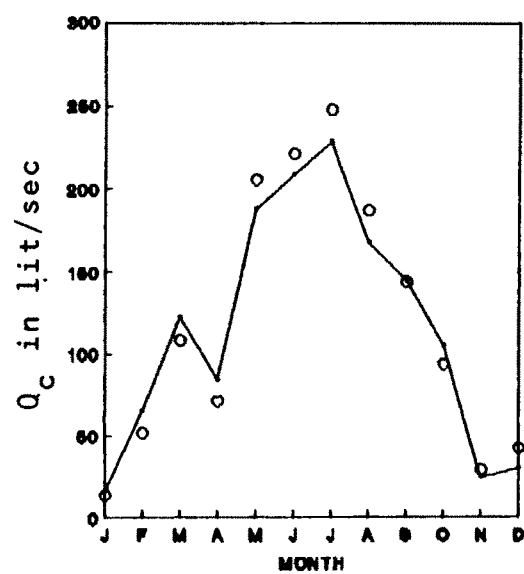
Hazachhari-1



Hazachhari-2

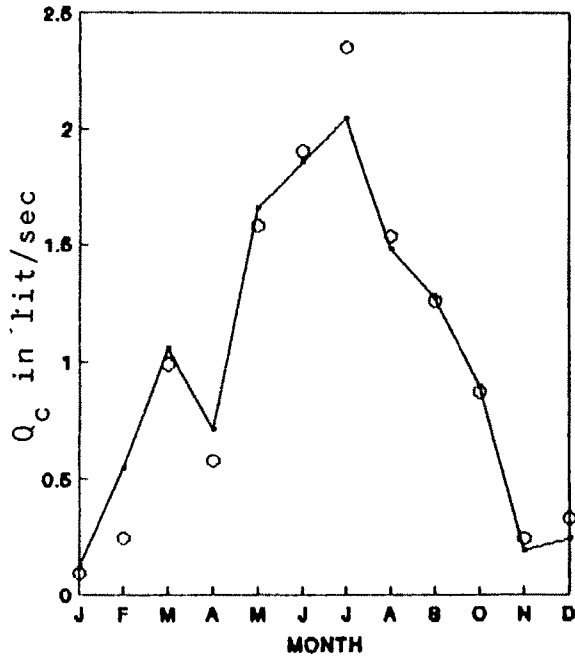


Hazachhari-3

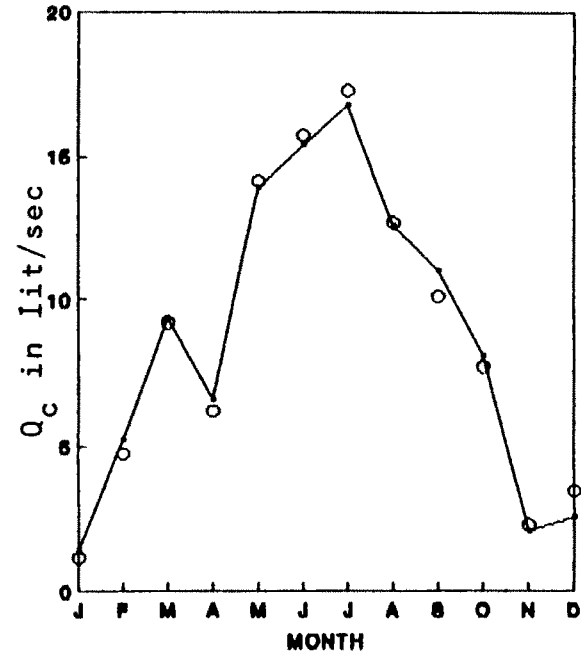


Hazachhari-4

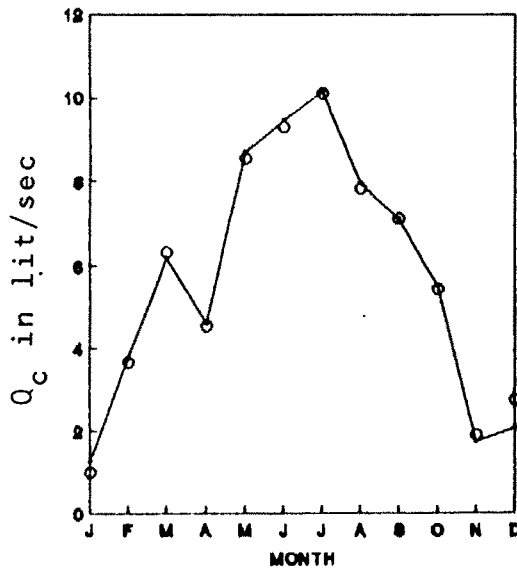
Fig. 4.17 Pictorial view of estimated and actual discharge (mean monthly cumulative). The dotted line represents estimated and open circles represent the actual data points.



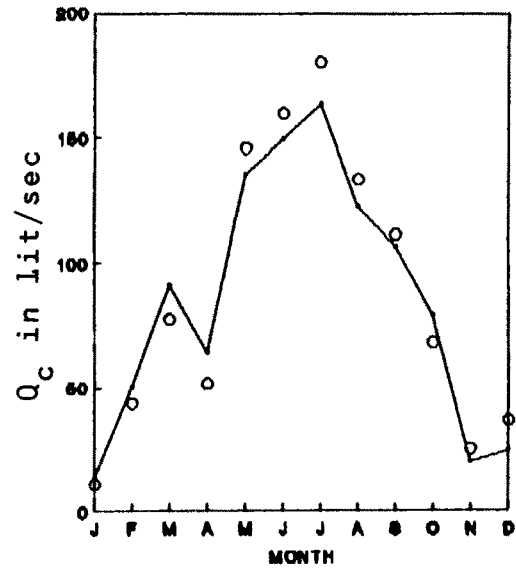
Panchhara



Shilachhari-1



Shilachhari-2



Shilachhari-3

Fig. 4.18 Pictorial view of estimated and actual discharge (mean monthly cumulative). The dotted line represents estimated and open circles represent the actual data points.

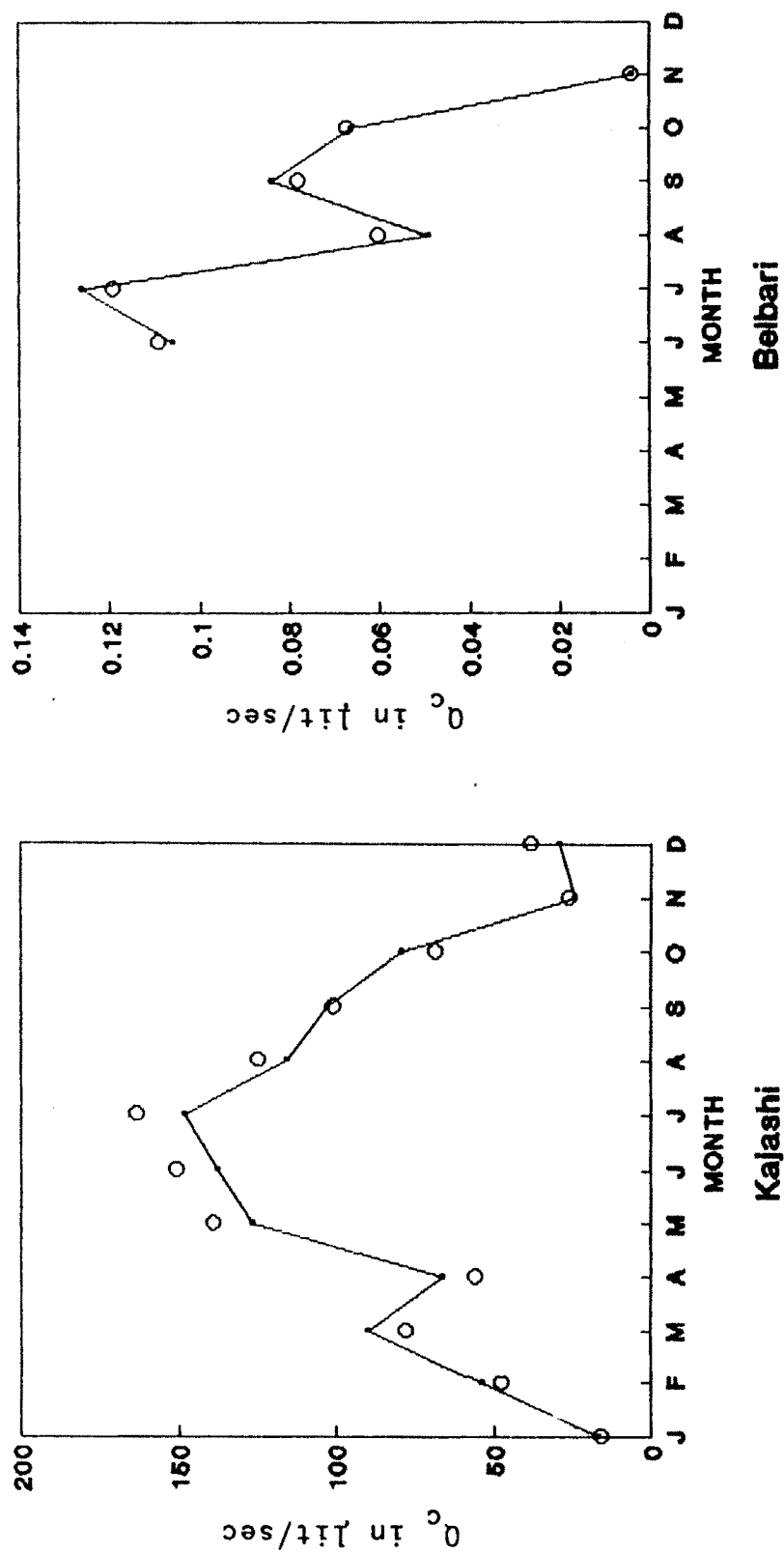


Fig. 4.19 Pictorial view of estimated and actual discharge (mean monthly cumulative). The dotted line represents estimated and open circles represent the actual data points

t_m = month eg. Jan = 1, Aug = 8, Dec = 12 etc.

a_0, a_1, a_2, a_3 = fitted empirical constants.

In 5 (five) out of ten springs a_2, a_3 values are insignificant and in 5 cases it is significant. The actual models for all the ten springs are given below.

$$\text{Hazachhari-1} \quad q_c = 0.0356 + 0.0082 t \quad \dots(4.13)$$

$$\text{Hazachhari-2} \quad q_c = 0.0326 + 0.0127 t \quad \dots(4.14)$$

$$\text{Hazachhari-3} \quad q_c = 0.1162 + 0.1722 t \quad \dots(4.15)$$

$$\begin{aligned} \text{Hazachhari-4} \quad q_c = & 24.68681 + 12.3488 t \\ & + 5.718618 t^2 - 0.26008 t^3 \quad \dots(4.16) \end{aligned}$$

$$\begin{aligned} \text{Panchhara} \quad q_c = & 0.270969 - 0.17963 t \\ & + 0.074253 t^2 - 0.00361 t^3 \quad \dots(4.17) \end{aligned}$$

$$\text{Shilachhari-1} \quad q_c = - 0.5263 + 1.5111 t \quad \dots(4.18)$$

$$\text{Shilachhari-2} \quad q_c = 0.8105 + 0.2245 t \quad \dots(4.19)$$

$$\begin{aligned} \text{Shilachhari-3} \quad q_c = & 21.23666 - 10.7918 t \\ & + 4.03428 t^2 - 0.16794 t^3 \quad \dots(4.20) \end{aligned}$$

$$\begin{aligned} \text{Kajashi} \quad q_c = & 19.43343 - 2.90296 t \\ & + 2.643937 t^2 - 0.11628 t^3 \quad \dots(4.21) \end{aligned}$$

$$\begin{aligned} \text{Belbari} \quad q_c = & 0.287188 - 0.15130 t \\ & + 0.024769 t^2 - 0.00112 t^3 \quad \dots(4.22) \end{aligned}$$

The observed average q_a in column-4 for each month are compared with the estimated average q_a in column-7 of Tables A - 1 to A - 11 of Appendix ~~2~~.

Since rainfall (r) is the most dominant single parameter causing q or changes in q a suitable relationship of q as a function of r has been derived (Eq 4.1) knowing fully well that it is bound to be highly empirical with many weaknesses due to the absence of other influencing variables in the model.

The more is the rainfall intensity, the less is the infiltration of rain water into the soils and vice-versa. Consequently the recharge of ground water is less in intense rainfall and vice-versa. Thus simple accommodation of mean monthly or yearly r devoid of intensity, areawise distribution and other rainfall character in any mathematical or empirical relation for q augments fact that only a tiny fraction of the q - causing variables have been put to use leading to its own peril i.e disastrous failure of the model to sketch the real world conditions. This corroborates the works of Bhar (1991), Valdiya and Bartarya (1991) and Tolman (1937). Thus if one wishes to apply these models in identical areas or even in the areas for which these are developed, one may not get good results. But it is quite surprising that the springs Hazachhari - 1,2,3 and Shilachhari - 2 the time lag (T) is about six months assuming that the r and q of January (Tables 4.1 and 4.2) are the chronologically next to December of the same table as because these are average values. But for other springs T varies from zero to one month which are quite reasonable as per Pradhan (1992).

Mean monthly/yearly r is definitely related with q

but the relationship is neither found to be linear nor geometrically symmetrical (curvilinear) when the data set is plotted on squared paper leading to complex formulation.

Conceptual models of Mero (1962) and Bear (1979) are also not free from such encumbrances. For example, they assumed that the q is linearly proportional to the storage inside and provided an unsteady one dimensional solution as in Eq (2.1) considering three variables. Similarly Bhar (1989) has also prescribed a model in the line of Mero (1962) and Bear (1979) considering seven variables instead of three. Hence Bhar's (1989) model is expected to yield better results than those of Mero (1962) and Bear (1979).

But the variables used by all the three researchers can not be easily measured; consequently the methods are costly and time consuming and direct measurement of q may be cheaper and less time taking. Though the models are handicapped with empirical co-efficients and exponents which must be determined or assessed for each case before use in different springs but are not as tough as those of Mero (1962), Bear (1979) and Bhar (1989). Thus the present models are simpler at the cost of some loss in accuracy. This is true. But field scale accuracy from an empirical model is rarely available specially in case of a complex phenomena like the present one investigated herein.

The principles of the models established herein are same as that of Pradhan (1992). But there is a marked difference between the two. Because the springs considered by Pradhan (1992) were mainly depression springs. In the present cases Belbari, Hazachhari - 1 and Hazachhari - 2 are of this type. But the data collected for the present cases are for short periods in comparison to those of Pradhan

(1992). Hence the models are of different types.

Spring flow (q) in Belbari continues for six months (June to November) every year.

Hence the models developed for Belbari spring can not be useful throughout the year or in other words will be useful for those months for which the model has been developed. Such models may fail to predict the flows in similar situations of other spring.

The size of the spring and the contributing area are the two major factors influencing the models like Eqs (4.13) to (4.22). It may safely be assumed that the spring size will be decided by the natural hydraulic pressure. Thus we may ignore this point in our model but the contributing area can not be ignored. It means the co-efficients of Eqs (4.13 to 4.22) are functions of area singly or jointly with other land parameters. but these are conspicuously absent in the present cases. This is another major drawback of the present model.

It is practically impossible to predict spring flow just from total rainfall unless such models are established separately for each spring. This means model like spring flow against total rainfall in one spring can very rarely be applicable in another spring.

Since the chronology of rainfall is not maintained in Eq (4.1) monthly spring yield can not be estimated from this model. This short coming is overcome in Eq (4.12). Using this model both monthly and annual average spring yield can be estimated. But only t_m parameter can not describe everything. In hydrology rainfall r is one of the

best known parameter which is conspicuously absent in Eq (4.12). Hence the utility of Eq (4.1) is not overruled. It is better to proceed for an annual estimation through both Eq (4.1) and Eq (4.12) and then decide the actual one for annual planning of water resources.

In Eq (4.12) though it is said that monthly average but actually it is an average upto the month under consideration. So, in December one gets automatically the 12-month or yearly average figure. The defect of Eq (4.12) is that it can not predict the individual monthly yield from the points of view of water resources planning.

The Eq (4.1) is a model based on rainfall data (arranged in ascending order and the cumulative values). Both rainfall and spring yield have been considered to find out monthly discharge. The Q_c value need be converted through several manipulations.

The high rate of discharge lowers the water table, reduces its gradient and diminishes the pressure in pore space. This alteration of recharge and discharge is the cause of the seasonal, local and short term fluctuation.

4.4 Projected estimation on management of spring discharge for irrigation

The spring flows continuously and is the cheapest source which the farmers can utilise for the irrigation of crops all through out the year with the help of suitable conveyance structure like pipe, drop inlets etc. (Fig. 2.6).

The discharge of ten springs chosen for preliminary study is different and are classified as large, medium

and small. Hazachhari - 4, Shilachhari - 3 and Kajashi are large (over 2 lits/sec); Shilachhari - 1 and 2 are medium (0.5 to 2 lits/sec) and the remaining springs namely Hazachhari -1, 2, 3, Panchhara and Belbari are small (less than 0.5 lit/sec).

Assuming that the spring discharge can be used for 24 hours a day, the irrigated area for each of ten springs has been calculated. For paddy cultivation, assured large quantity of water is required and since during rainy season crop fields receive rainfall, sample calculation is given only for boro paddy cultivation. Water management practices conducted throughout India clearly indicate that land submergence of 2-4 cm for boro paddy gives the maximum yield. The fields need be irrigated when water level falls to near-about 2 cm. Assuming that irrigation needed is only 2 cm, time required for evapotranspiration of 2 cm of water when the average evapotranspiration rate is 9 mm/day is only 2.2 days. Assuming that the crop period is from February to first week of May, a sample calculation is given only for spring Hazachhari-4.

Assuming that irrigation starts from first February on the plot A, the second irrigation on the same plot A will be on third February. During 1st February the discharge is

$$(9.25 \times 24 \times 60 \times 60 \times 1) / 1000 = 799.2 \text{ m}^3$$

Depth of irrigation is 2 cm or 2 ha cm or 200 m³

Area irrigated = 799.2/200 = 3.996 ha or 4 ha

Since the flow of the spring is continuous the

discharge can be utilized for irrigating the second plot B of the same area i.e. another 4 ha.

Therefore, total area covered by Hazachhari - 4 is 3 ha.

Other method: Available water resources is illustrated in Table 4.9

Table 4.9 The total discharge for the period 1st February to 7th May for boro paddy

Month	Days	g (lit/sec)	Volume of water, m ³
Feb	28	9.25	$=(9.25 \times 24 \times 60 \times 60 \times 28)/1000 = 22377.60$
Mar	31	14.253	$=(14.253 \times 24 \times 60 \times 60 \times 31)/1000 = 38175.24$
April	30	19.95	$=(19.95 \times 24 \times 60 \times 60 \times 30)/1000 = 51710.40$
May	7	18.45	$=(18.45 \times 24 \times 60 \times 60 \times 7)/1000 = 11158.56$
			= 123421.79
			or = 123422

Assuming the water requirement of boro paddy is 150cm or 15000 m³/ha. The area irrigated is $123422/15000 = 8.22$ ha or 8 ha.

It is suggested that for small size springs - Sesamum, Tomato, Potato be irrigated for better use of water and highest return. If any farmer likes to cultivate boro paddy, the area will be too small.

Table 4.10 Projectd estimation on management of spring discharge for different crops together with the areas to be irrigated

Sl. No.	Name of Springs	Size of springs	q (lit/sec)	Crops to be taken	Crop duration (Month and days)	Crop water requirement (cm)	Area to be covered (ha)
1	Hazachhari - 1	Small upto 0.5 (lit/sec)	Jan 0.045	Sesamum	Jan to Mar 90	55	0.031
			Feb 0.013				
			Mar 0.008				
			Aug 0.012	Tomato	Aug to Oct 92	68	0.014
			Sep 0.012				
			Oct 0.013				
2	Hazachhari - 2	Small upto 0.5 (lit/sec)	Jan 0.040	Sesamum	Jan to Mar 90	55	0.057
			Feb 0.013				
			Mar 0.020				
			Aug 0.018	Tomato	Aug to Oct 92	68	0.018
			Sep 0.011				
			Oct 0.016				
3	Hazachhari - 3	Small upto 0.5 (lit/sec)	Jan 0.464	Sesamum	Jan to Mar 90	55	0.304
			Feb 0.096				
			Mar 0.073				
			Nov 0.150	Potato (tuber)	Mid Nov to Feb 105	24	0.880
			Dec 0.170				
			Jan 0.464				
4	Hazachhari - 4	Large above 2 (lit/sec)	Feb 9.250	Boro paddy	Feb to 7th May	120 150	8.220
			Mar 14.253				
			Apr 19.950				
			May 18.450				
			Oct 22.480	Potato (T.P.S)	Oct to Jan	122 20	86.050
			Nov 15.560				
			Dec 13.410				
			Jan 13.310				
			Jan 0.092	Sesamum	Jan to Mar 90	55	0.178
			Feb 0.174				
5	Panchhara	Small upto 0.5 (lit/sec)	Mar 0.117				
			Aug 0.279	Tomato	Aug to Oct 92	68	0.330
			Sep 0.267				
			Oct 0.293				
			Feb 1.296	Boro paddy	Feb to 7th May	120 150	0.998
			Mar 1.472				

Continued

Table 4.10 (Contd.) Projectd estimation on management of spring discharge for different crops together with the areas to be irrigated

Sl. No.	Name of Springs	Size of springs	q (lit/sec)	Crops to be taken	Crop duration (Month and days)	Crop water requirement (cm)	Area to be covered (ha)
6	Shilachhari- 1	Medium 0.5 to 2 (lit/sec)	Apr 1.493 May 1.502				
			Oct 1.530 Nov 1.153	Groundnut	Oct to Nov 61	60	1.180
7	Shilachhari- 2	Medium 0.5 to 2 (lit/sec)	Feb 0.931 Mar 0.902 Apr 0.883 May 0.732	Boro paddy	Feb to 7th May 120	150	0.595
			Oct 0.868 Nov 0.933	Groundnut	Oct to Nov 61	60	0.790
8	Shilachhari- 3	Large above 2 (lit/sec)	Feb 6.690 Mar 9.190 Apr 8.150 May 12.860	Boro paddy	Feb to 7th May 120	150	4.647
			Oct 6.450 Nov 14.660	Groundnut	Oct to Nov 61	60	14.942
9	Kajashi	Large above 2 (lit/sec)	Feb 9.650 Mar 9.250 Apr 8.340 May 14.240	Boro paddy	Feb to 7th May 120	150	7.191
			Nov 9.930 Dec 12.080 Jan 15.960 Feb 9.650	Potato (tuber)	Mid Nov to Feb 105	24	46.380
10	Belbari	Small upto 0.5 (lit/sec)	Aug 0.056 Sep 0.011 Oct 0.007	Tomato	Aug to Oct 92	68	0.020
							172.825

A glance to Table 4.10 will enable one to realize that out of nothing gross-cropped area can be raised to about 173 ha using discharges from ten springs. There are quite a good number of such springs in Tripura. If all these are tapped appropriately gross-cropped area of this state will increase to a high level and much of the economic distress of this state will be reduced. This is true for similar situations in other states of India as well as abroad.

CHAPTER - V

SUMMARY AND CONCLUSION

5.1 Summary

In hilly states springs are the readily available water resources which can cater to the needs such as power generation, drinking and irrigation of the adjacent lands to a large extent. But there are problems like uneven seasonal or temporal distribution of water yields. But this capriciousness coupled with minor uncertainty in spring yield and the imbalance created on account of the same can be overcome with human endeavour, perseverance and ingenuity. This has exactly happened in case of three springs of the state of Tripura viz Shilachhari, Tuiarsong and Dewanchhara. This aspects have been discussed in Chapter-II. There are innumerable springs which need attention by the authorities of the hill states. The origin, classification, topographic and geologic features of the springs, the reasons of fluctuations of spring flows and their development along with the existing spring flow models have been described in Chapter-II.

Ten springs arbitrarily chosen for this study are described in Chapter-III. The present study was taken up to (i) examine the effect of spring discharge on ground water levels or vice-versa. (ii) establish workable models of spring discharge based on rainfall as well as on time (iii) estimate the projected area to be covered under crop using spring-discharges.

The data on spring yield (q) rainfall (r), ground water level (Da) were collected from two rain gauge stations and three open wells near the spring sites for the ten

springs. These springs were of various types viz. seasonal, perennial and depression, contact, fracture and tubular etc. Out of this ten, one (Belbari) is seasonal due to lack of supply of infiltrating rainwater and the remaining nine are functioning as perennial. Graphical attempts have been made to process the data on spring yield versus rainfall. It is found that following a particular arrangement of rainfall (for example arranging twelve monthly rainfall in an ascending order a valid relationship have been obtained to predict mean monthly cumulative spring yield. Mean monthly cumulative spring yield determined in a particular fashion as outlined in Tables A-2 to A-11 of Appendix A is found to have a reasonable relation with time (month). Graphical analysis are made to examine the effects of average ground water level on average spring yield or vise versa. It has been found that the depression spring (Belbari) behaves independent of the ground water position. This is also true for Hazachhari 1,2,3 Shilachhari-2 and Kajashi. In the remaining four springs, the average spring discharge is linearly related with the ground water levels. The projected estimate on management of spring discharges to increase irrigated agriculture in Tripura may be glanced through Table 4.10. The process of spring flow gauging in remote places is time consuming, labourious and costly which can not be borne by a country like ours. Hence empirical models can rescue us from such difficulties. It is also to be noted that a comprehensive empirical model needs many parameters which can be measured with great difficulty and spending a lot of money, a very simple approach has been made to develop empirical model to predict spring discharge. The limitations of empirical models have been discussed.

5.2 Conclusions

From the present study the following conclusions are drawn :

1. Rainfall in the contributing area is directly related with the yields of springs. Mean monthly cumulative spring yield can be estimated from mean monthly cumulative rainfall.
2. Average monthly spring yield can be estimated from time (month).
3. Ground water tables fall down with the increase in spring-yield. This is applicable for those springs which are interconnected with the ground water aquifers.
4. Gross cropped area can be raised upto about 173 ha by ten springs.

5.3 Recommendations for further works

The study conducted here is preliminary in nature. In-depth study with a larger number of parameters may be taken up in various regions. This will enable us to arrive at an universal method which can be applied anywhere in our country.

CHAPTER - VI

REFERENCE

Bauwer, H., 1958, Ground-water hydrology, Mc-Graw Hill, New York, pp. 46-47.

Bear, J., 1979, Hydraulics of ground-water, Mc-Graw Hill, Israel, pp. 53-57.

Bhar, A.K., 1989, "Study of springs and Hydrological modelling of spring Flow (TR-75)", NIH Report

Bhar, A.K., 1991, Development of spring, the hydrological aspect. Hydrology, Journal of IAH vol. XIV. No. 1, 1991.

Biswas, A.B, Saha, A.K., Dasgupta, S.P., Chakraborty, C., 1989, State of environment in Tripura, Prepared by the Center for study of man and environment, Presidency College, Calcutta.

C.G.W.B, Ministry of Agriculture and Cooperation, North Eastern Hill Region, 1930.

Bryan, K., 1919, Classification of springs, Journal of Geology, 27: 530.

Chow, V.T., 1964, Hand-book of applied hydrology, Mc-Graw Hill, New-York.

Dewan, M.L. 1990, "People,s participation in Himalayan ecosystem development". Concept Publishing Company, New Delhi.

Ghosh, R.K. and Swain, S., 1990, Practical Agricultural Engineering, Naya Prokash, 206 Bidhan sarani, calcutta 700006.

Ghosh, R.K., 1990, Practical Agricultural Engineering Unpublished M.Sc. (Ag) class notes, Department of Agricultural Engineering, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia-741252.

Keilhack, K., 1935, Ground-water Hydrology, 3rd ed., Gebudar Borntraiger Barlin, pp. 286-287.

Meinzer, O.E., 1923, Outline of ground water hydrology, U.S. Geological Survey, Water Supply Paper No. 494.

Meinzer, O.E., 1927, 'Large springs in the United States, U.S. Geological Survey, Water Supply Paper No. 494.

Meinzer, O.E., 1932, Method of Estimating Ground Water Supplies, U.S. Geological Survey, Water Supply Paper, 638, pp. 99-144.

Meinzer, O.E., 1942, Hydrology Dover New-York, pp. 416-432.

Mero, F., 1964, Application of the Ground water depletion curves in analysing and forecasting spring discharges influenced by well fields, Symposium on Surface Water, Aug. 63. Publication No. 63, IASH.

Pinneker, E.V., 1952, General Hydrology, Cambridge University Press, pp. 67.

Pradhan, J., 1992, Water yield behaviour of small springs, Unpublished M.Sc. Ag. thesis, Deptt. of Agric. Engg., Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, W.B., pp. 1-46.

Singh, A. and Tewari, R., 1989, Water yield behaviour of small springs (1981-84), Hydrological data series 1/88 AE, Division of Agricultural Engineering, ICAR complex for NEH Region; Shillong, Meghalaya.

Tolman, C.F., 1937, Ground-water, Mc-Graw Hill, New York pp. 446-460.

USDA-SCS, 1979, Springs and wells. Engineering Field Manual for Conservation Practices, United States Department of Agriculture, Soil Conservation Service Ch. 12.

Valdiya, K.S. and Bartarya, S.K., 1991, Hydrological studies of spring in the catchment of Gaula River, Kumaun Lesser Himalaya, India. Mountain Research Development, 11 (3): 239-358.

Appendix

Sample calculations :

Calculation finding out Q_c using Eq 4.1 in respect of Hazachhari-1 spring is given below :-

The equation is in the form of

$$Q_c = a R_c^b \quad \dots\dots\dots (4.1)$$

Table A-1 : Non- chronological mean monthly cumulative rainfall (R_c) and mean monthly cumulative spring discharge (Q_c) for sample calculations

Month	R_c (cm)	Q_c (lit/sec)
Jan	0.733	0.045
Nov	2.093	0.056
Dec	3.593	0.066
Feb	22.053	0.079
Apr	41.003	0.084
Oct	68.883	0.097
Mar	99.303	0.105
Sep	148.833	0.117
Aug	211.053	0.129
May	275.253	0.131
Jun	353.693	0.134
Jul	438.963	0.141

Assuming $y = \log_e Q_c$ and $x = \log_e R_c$

$$\Sigma x^2 = 221.3853; \quad \Sigma x = 45.2701$$

$$\Sigma xy = -98.7571; \quad \Sigma y = -28.4987$$

$$N = 12$$

$$\log_e a = \frac{\Sigma x^2 \Sigma y - \Sigma x \Sigma xy}{N \Sigma x^2 - (\Sigma x)^2}$$

$$= \frac{(221.3853)(-28.4987) + (45.2701)(98.7571)}{12(221.3853) - (45.2701)^2} = -3.0275$$

$$a = 0.0484$$

$$b = \frac{N \Sigma xy - \Sigma x \Sigma y}{N \Sigma x^2 - (\Sigma x)^2} = \frac{12(-98.7571) + (45.2701)(28.4987)}{12(221.3853) - (45.2701)^2}$$

$$= 0.1730$$

$$Q_c = 0.0484 R_c^{0.1730}$$

$$(R^2 = 99.2\%)$$

**Table A-2 Mean monthly spring yield data and its processing
for spring Hazachhari - 1**

Month	t_m Month	q lit/sec	* Observed average ⁺ q_a^+ lit/sec	Cumulative q i.e. q_c lit/sec	^{o} Est q_c lit/sec	* Estimated average q_a lit/sec
Jan	1	0.045	0.045	0.045	0.044	0.044
Feb	2	0.013	0.029	0.058	0.051	0.025
Mar	3	0.008	0.022	0.066	0.060	0.020
Apr	4	0.005	0.017	0.071	0.068	0.170
May	5	0.002	0.014	0.073	0.076	0.015
Jun	6	0.003	0.012	0.076	0.085	0.014
Jul	7	0.007	0.012	0.083	0.093	0.013
Aug	8	0.012	0.012	0.095	0.101	0.013
Sep	9	0.012	0.012	0.107	0.109	0.012
Oct	10	0.013	0.012	0.120	0.118	0.012
Nov	11	0.011	0.012	0.131	0.126	0.011
Dec	12	0.010	0.012	0.141	0.134	0.011

(⁺) = q_c of each row was divided by the number of months of that particular row to get Observed q_a .

Sample calculations for spring Hazachhari-1

$$\Sigma t_m = 78$$

$$\Sigma t_m^2 = 650 \quad \Sigma t_m q_c = 8.101$$

To fit in $q_c = a_0 + a_1 t_m$

$$a_0 = \frac{\Sigma t_m^2 \Sigma q_c - \Sigma t_m \Sigma t_m q_c}{12 \Sigma t_m^2 - (\Sigma t_m)^2} = \frac{650 \times 1.066 - 78 \times 8.101}{12 \times 650 - 6084} = 0.0356$$

$$a_1 = \frac{12 \Sigma t_m q_c - \Sigma t_m \Sigma q_c}{1716} = \frac{12 \times 8.101 - 78 \times 1.066}{1716} = 0.0082$$

$$*R^2 = 99\% \quad \therefore q_c = 0.0356 + 0.0082 t_m \quad {}^oR^2 = 98\%$$

**Table A-3 Mean monthly spring yield data and its processing
for spring Hazachhari - 2**

t_m		Observed *		Cumulative	^0Est	Estimated *
Month	Month	q	average ⁺ q_a	q i.e. q_c	q_c	average q_a
		lit/sec	lit/sec	lit/sec	lit/sec	lit/sec
Jan	1	0.040	0.040	0.040	0.045	0.045
Feb	2	0.013	0.026	0.053	0.058	0.029
Mar	3	0.020	0.024	0.073	0.071	0.023
Apr	4	0.015	0.022	0.088	0.083	0.021
May	5	0.010	0.020	0.093	0.096	0.019
Jun	6	0.011	0.018	0.109	0.109	0.018
Jul	7	0.013	0.017	0.122	0.122	0.017
Aug	8	0.018	0.018	0.140	0.135	0.017
Sep	9	0.011	0.017	0.151	0.147	0.016
Oct	10	0.016	0.017	0.167	0.160	0.016
Nov	11	0.004	0.015	0.171	0.173	0.016
Dec	12	0.003	0.014	0.174	0.186	0.015

+ = q_c of each row was divided by the number of months of that particular row to get observed q_a .

$$\therefore q_c = 0.0326 + 0.0127t$$

$$(^0R^2 = 99.3\%)$$

$$(*R^2 = 98.7\%)$$

Table A-4 Monthly spring yield data and its processing for spring Hazachhari - 3

Month	t_m Month	q lit/sec	* Observed average ⁺ q_a lit/sec	Cumulative q i.e. q_c lit/sec	q_{Est} q_c lit/sec	* Estimated average q_a lit/sec
Jan	1	0.464	0.464	0.464	0.288	0.283
Feb	2	0.096	0.280	0.560	0.460	0.230
Mar	3	0.073	0.211	0.633	0.633	0.211
Apr	4	0.088	0.180	0.721	0.805	0.201
May	5	0.117	0.167	0.838	0.977	0.195
June	6	0.158	0.166	0.996	1.149	0.192
July	7	0.213	0.173	1.209	1.321	0.189
Aug	8	0.247	0.182	1.456	1.494	0.187
Sep	9	0.247	0.189	1.703	1.666	0.185
Oct	10	0.222	0.193	1.925	1.838	0.184
Nov	11	0.150	0.189	2.075	2.010	0.183
Dec	12	0.170	0.187	2.245	2.182	0.182

+ = q_c of each row was divided by the number of months of that particular row to get observed q_a

$$\therefore q_c = 0.1162 + 0.1722t$$

$$({}^0R^2 = 98.6\%)$$

$$({}^*R^2 = 96\%)$$

Table A-5 Mean monthly spring yield data and its processing for spring Hazachhari-4

Month	t_m Month	q lit/sec	* Observed average q_a lit/sec	Cumulative q i.e. q_c lit/sec	q_c lit/sec	* Estimated average q_a lit/sec
Jan	1	13.310	13.310	13.310	17.800	17.800
Feb	2	9.250	11.280	22.560	20.790	10.395
Mar	3	14.253	12.271	36.813	32.100	10.700
Apr	4	19.950	14.190	56.763	50.164	12.540
May	5	18.450	15.042	75.213	73.420	14.684
June	6	15.430	15.107	90.643	100.300	16.720
July	7	26.500	16.730	117.143	129.280	18.470
Aug	8	43.460	20.070	160.603	158.770	19.850
Sep	9	35.190	21.750	195.793	187.200	20.800
Oct	10	22.480	21.830	218.273	213.030	21.300
Nov	11	15.560	21.260	233.833	234.690	21.340
Dec	12	13.410	20.600	247.243	250.620	20.880

+ q_c of each row was divided by the number of months of that particular row to get observed q_a .

$$\therefore q_c = 24.68681 - 12.3438t + 5.718618t^2 - 0.26008t^3$$

$$(^{\circ}R^2 = 99.4\%)$$

$$(*R^2 = 88.3\%)$$

Table A-6 Monthly spring yield data and its processing for spring Panchhara

Month	t_m Month	q lit/sec	* Observed average ⁺ lit/sec	Cumulative q i.e. q_c lit/sec	q_{c}^{0} Est q_c lit/sec	* Estimated average lit/sec
			q_a			q_a
Jan	1	0.092	0.092	0.092	0.160	0.160
Feb	2	0.174	0.133	0.266	0.179	0.089
Mar	3	0.117	0.128	0.383	0.302	0.101
Apr	4	0.078	0.115	0.461	0.509	0.127
May	5	0.246	0.141	0.707	0.777	0.155
June	6	0.324	0.172	1.031	1.086	0.181
July	7	0.441	0.210	1.472	1.414	0.202
Aug	8	0.279	0.219	1.751	1.738	0.217
Sep	9	0.267	0.224	2.018	2.037	0.226
Oct	10	0.293	0.231	2.311	2.290	0.229
Nov	11	0.148	0.224	2.459	2.475	0.225
Dec	12	0.087	0.212	2.546	2.570	0.214

(+) = q_c of each row was divided by the number of months of that particular row to get q_a .

$$\therefore q_c = 0.270969 - 0.17963t + 0.074253t^2 - 0.0036t^3$$

($^0R^2$ = 99.6%)

($^*R^2$ = 86.2%)

Table A-7 Monthly spring yield data and its processing for spring Shilachhari - 1

Month	t_m Month	q lit/sec	* Observed average ⁺ q_a lit/sec	Cumulative q i.e. q_c lit/sec	q_c lit/sec	* Estimated average q_a lit/sec
Jan	1	1.150	1.150	1.150	0.985	0.985
Feb	2	1.296	1.223	2.446	2.496	1.248
Mar	3	1.472	1.306	3.918	4.007	1.335
Apr	4	1.493	1.353	5.411	5.518	1.379
May	5	1.502	1.382	6.913	7.029	1.405
June	6	1.538	1.408	8.451	8.540	1.423
July	7	1.498	1.421	9.949	10.052	1.436
Aug	8	1.766	1.464	11.715	11.563	1.445
Sep	9	1.673	1.488	13.393	13.074	1.453
Oct	10	1.530	1.492	14.923	14.586	1.458
Nov	11	1.153	1.461	16.076	16.096	1.463
Dec	12	1.136	1.434	17.212	17.607	1.467

+ = q_c of each row was divided by the number of months of that particular row to get observed q_a .

$$\therefore q_c = -0.5263 + 1.5111t$$

$$({}^oR^2 = 99.9\%)$$

$$({}^*R^2 = 93\%)$$

O.K

Table A-8 Mean monthly spring yield data and its processing for spring Shilachhari - 2

Month	t_m Month	q lit/sec	* Observed Average q_a lit/sec	Cumulative q i.e. q_c lit/sec	^{0} Est q_c lit/sec	* Estimated Average q_a lit/sec
Jan	1	0.952	0.9520	0.952	1.0850	1.0850
Feb	2	0.931	0.9415	1.883	1.8955	0.9478
Mar	3	0.902	0.9283	2.785	2.7060	0.9020
Apr	4	0.883	0.9170	3.668	3.5165	0.8791
May	5	0.732	0.8800	4.400	4.3270	0.8654
June	6	0.739	0.8565	5.139	5.1375	0.8563
July	7	0.802	0.8487	5.941	5.9480	0.8497
Aug	8	0.733	0.8343	6.674	6.7585	0.8448
Sep	9	0.766	0.8267	7.440	7.5690	0.8410
Oct	10	0.868	0.8308	8.308	8.3795	8.8380
Nov	11	0.933	0.8401	9.241	9.1900	0.8355
Dec	12	0.842	0.8403	10.083	10.0005	0.8334

+ = q_c of each row was divided by the number of months of that particular row to get q_a .

$$\therefore q_c = 0.2745 + 0.8105t$$

$$(^0R^2 = 99.9\%)$$

$$(*R^2 = 92.7\%)$$

Table A-9 Mean monthly spring yield data and its processing for spring Shilachhari-3

Month	t_m Month	q lit/sec	*Observed average q_a lit/sec	Cumulative q i.e. q_c lit/sec	^{0} Est q_c lit/sec	*Estimated average q_a lit/sec
Jan	1	10.13	10.13	10.13	14.31	14.31
Feb	2	6.69	8.41	16.82	14.45	7.23
Mar	3	9.19	8.67	26.01	20.64	6.88
Apr	4	8.15	8.54	34.16	31.87	7.97
May	5	12.86	9.40	47.02	47.15	9.43
June	6	13.15	10.03	60.17	65.46	10.91
July	7	20.30	11.50	80.47	85.79	12.26
Aug	8	22.18	12.83	102.65	107.14	13.39
Sep	9	33.90	15.17	136.55	128.49	14.28
Oct	10	16.45	15.30	153.00	148.85	14.89
Nov	11	14.66	15.18	167.66	167.20	58.20
Dec	12	11.60	14.94	179.26	182.53	15.21

+ = q_c of each row was divided by the number of months of that particular row to get observed q_a .

$$\therefore q_c = 21.23666 - 10.7918t + 4.034728t^2 - 0.16794t^3$$

$$(^0R^2 = 99.5\%)$$

$$(*R^2 = 88.5\%)$$

Table A-10 Mean monthly spring yield data and its processing for spring Kajashi

Month	t_m Month	q lit/sec	* Observed average q_a lit/sec	Cumulative q i.e. q_c lit/sec	q_c lit/sec	* Estimated average q_a lit/sec
Jan	1	15.96	15.96	15.96	19.06	19.06
Feb	2	9.65	12.81	25.61	23.27	11.64
Mar	3	9.25	11.62	34.86	31.38	10.46
Apr	4	8.34	10.80	43.20	42.68	10.67
May	5	14.24	11.48	57.44	56.48	11.30
June	6	11.71	11.53	69.15	72.08	12.01
July	7	12.52	11.67	81.67	88.78	12.68
Aug	8	24.13	13.23	105.80	105.88	13.24
Sep	9	23.02	14.31	128.82	122.70	13.63
Oct	10	12.32	14.11	141.14	138.52	13.85
Nov	11	9.93	13.73	151.07	152.65	13.88
Dec	12	12.08	13.59	163.15	164.40	13.70

+ = q_c of each row was divided by the number of months of that particular row to get observed q_a .

$$\therefore q_c = 19.43343 - 2.90296t + 0.11628t^2 - 0.11628t^3$$

$$(^oR^2 = 99.5\%)$$

$$(*R^2 = 89.7\%)$$

Table A-11 Mean monthly spring yield data and its processing for spring Belbari

Month	t_m Month	q lit/sec	*Observed Average q_a lit/sec	Cumulative q i.e. q_c lit/sec	q_c^{0Est} lit/sec	*Estimated Average q_a lit/sec
Jan	1	dry	X	X	X	X
Feb	2	dry	X	X	X	X
Mar	3	dry	X	X	X	X
Apr	4	dry	X	X	X	X
May	5	dry	X	X	X	X
June	6	0.031	0.031	0.031	0.029	0.029
July	7	0.010	0.020	0.041	0.057	0.028
Aug	8	0.056	0.032	0.097	0.088	0.029
Sep	9	0.011	0.027	0.108	0.115	0.029
Oct	10	0.007	0.023	0.115	0.131	0.026
Nov	11	0.004	0.020	0.119	0.129	0.022
Dec	12	dry	X	X	X	X

X = Spring discharge not measured as remained dry and consequently q_c and q_a data not entered during the dry period
 + = q_c of each row was divided by the number of months of that particular row to get observed q_a .

$$\therefore q_c = 0.287158 - 0.15130t + 0.024769t^2 - 0.00112t^3$$

$$(^0R^2 = 94.5\%)$$

$$(*R^2 = 69.5\%)$$