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# HYDROLOGICAL ASPECTS OF RAINWATER HARVESTING IN THE KANDI BELT OF JAMMU REGION

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# PREFACE

The Siwalik foothill region, known as Kandi belt, is spread in the north-western states of Jammu & Kashmir, Himachal Pradesh, Uttaranchal, Punjab and Haryana. Denuded hills, undulating topography, erratic distribution of rainfall in space and time, small land holdings, high soil erosion, coarse textured and infertile soil, and low crop productivity, are typical features of this region.

Agriculture in this region is generally rainfed, except little area irrigated by surface and ground water sources. Although average annual rainfall in the region is relatively high, and a number of streams and rivulets pass through the area, scarcity of water is experienced both for domestic and agricultural purposes. Inadequate storage of the available surplus water, and lack of proper water management, are considered to be responsible for the poor state of natural resources in the Kandi belt.

Water harvesting is a technique of developing surface water resources that can be used in dry regions to provide water for livestock, for domestic use, for agroforestry, and for small scale farming purposes. The purpose of water harvesting is to either augment existing water supplies or to provide water where other sources are either not available or would entail prohibitive development costs. Water harvesting offers one method of improving the livelihood of the people by reducing the uncertainty of human life in arid and semi-arid ecosystems.

The Jammu Regional Centre has carried out a study on the hydrological problems in the Kandi belt of Jammu region, as part of the work program of the Center for 1999-2000. In the present study, hydrological aspects of rainwater harvesting in the Kandi belt of Jammu region were examined, and the results of a case study are presented.

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# ABSTRACT

Although average annual rainfall, and especially rainfall during monsoon season, in the Kandi region is relatively high, scarcity of water is experienced both for domestic and agricultural purposes. Inadequate storage of the available surplus water in monsoon season, and lack of proper water management, are considered to be responsible for the poor state of natural resources in the Kandi belt.

Water harvesting is a potential source of water for arid and semiarid regions. The purpose of water harvesting is to either augment existing water supplies or to provide water where other sources are either not available or would entail prohibitive development costs. The present study discusses the hydrological aspects of rainwater harvesting in the Kandi belt of Jammu region. Also, the results of a case study on water availability in a village pond in a typical Kandi village are presented.

Detailed surveys were conducted to determine the depth, volume, and relevant morphometric characteristics of a pond in village Badhori (Tehsil Samba, district Jammu). Water inflow to the pond from rainfall, and availability of water in the pond was evaluated on monthly basis. Although the capacity of the pond is quite large, the present analysis shows that only about one-third capacity is being utilised under the prevailing climatic and soil conditions. If through suitable measures, evaporation and other losses can be reduced, more water will be available for local consumption, and the available capacity of the pond water can be successfully used for cattle and horticultural purposes.

# 1.0 INTRODUCTION

Water harvesting is a technique of developing surface water resources that can be used in dry regions to provide water for livestock, for domestic use, for agroforestry, and for small scale farming purposes. The purpose of water harvesting is to either augment existing water supplies or to provide water where other sources are either not available or would entail prohibitive development costs. The aim is to provide this water in sufficient quantity and of suitable quality for the intended use. Water harvesting offers one method of improving the livelihood of the people by reducing the uncertainty of human life in arid and semi-arid ecosystems.

Arid zones are often described as pulse-reserve systems that turn on with water, store material for the dry interval and then shut down until the next water event. The natural ecosystem has developed under these constraints but the strain on human populations is considerable, particularly on sedentary populations. The objective of water harvesting is to smooth out the peaks between want and abundance by collecting and storing water for the period of want and, in addition, to work within the arid ecosystem using a renewable resource.

Water harvesting systems may be defined as artificial methods whereby precipitation can be collected and stored until it is beneficially used. The system includes a catchment area and a storage facility for the harvested water. A water distribution scheme is also required for the systems devoted to small scale farming for irrigation during dry periods.

## 2.0 THE KANDI BELT

The Kandi belt is the foothill zone of the Siwalik of Jammu and Kashmir. This belt stretches between longitude $74^0$ 21' to $75^0$ 45' E and latitude $32^0$ 22' to $32^0$ 55' N, except in the western portion, where it lies between latitude $32^0$ 50'to $33^0$ N. The Kandi belt in J&K is extended between River Ravi in the East and Munawar Tawi on the West within the Jammu and Kathua Districts (Figure 1). The area is covered under the Survey of India toposheet nos. 43L/5, 9, 10, 11, 13, 14, 15 and 43P/2, 3, 6, 7, 11. It lies at the altitude between 300 and 490m above mean sea level. Transition zone of Kandi and Sirowal lies near Jammu Pathankot National Highway, Ranbir canal and then along the Partap canal to the line of actual control on the Munawar Tawi.

Total area of the Kandi belt is estimated to be 811 $Km^2$, of which the upper and lower Kandi belts constitute 610 $Km^2$ and 201 $Km^2$, respectively (Goyal and Rai, 1999-2000). The area under Kandi belt is covered in two districts, namely Jammu and Kathua. The Kandi belt is encompassed by only three out of the five tehsils of the Jammu district, and two out of the four tehsils of the Kathua district. The area of Kandi belt falling within each of these tehsils is Jammu (189 $Km^2$), Akhnoor (147 $Km^2$) and Samba (163 $Km^2$) in the Jammu district, and Kathua (158 $Km^2$) and Hiranagar (155 $Km^2$) in the Kathua district.

The Kandi belt can be divided into small watersheds having low denuded hills in its upper part and undulating cultivated lands in its lower parts. It is necessary to develop this area on watershed basis, and all engineering and non-engineering measures of rainwater management and soil conservation should be planned and initiated from upper to lower part of the watersheds.

There are numerous big gullies and ephemeral streams originating from low hills and flowing down into cultivated terrain. They have progressively increasing cross-sectional area toward flow direction in hilly upper portion of the catchments with very porous bed.

### 2.1 Climate

The Kandi belt experiences subtropical climate, where summers are very hot and winters are cold and dry. The summer season usually starts from April and lasts upto June. June is the hottest month (Average $39^0$C; highest $46^0$C, observed in 1995) and January is the coldest month (Average $7^0$C; lowest $<1^0$C, observed in 1993). Temperature rises rapidly after February, and drops rapidly after October. The weather is very hot during summer period, and occasional dust and thunderstorms followed by light rains offer respite from the scorching heat. The months of October and November, although generally dry, are the most pleasant part of the year. The winter season begins from December and ends upto March.

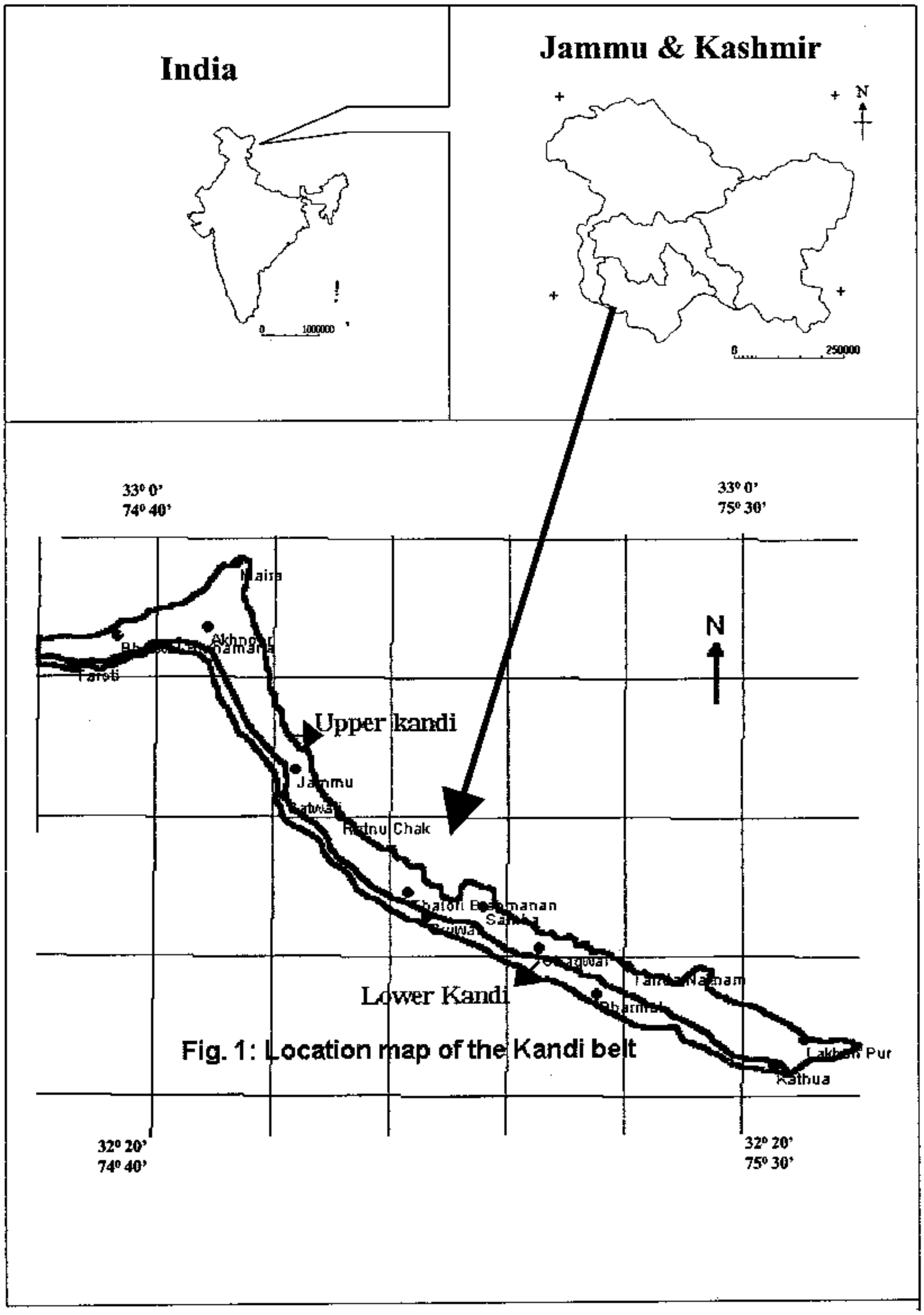



Fig. 1: Location map of the Kandi belt

The air generally remains dry except during the monsoon season, when the average RH exceeds 70%. The summer months of April to June are the driest with average RH in the morning and evening is 40 to 48% and 23 to 32%, respectively. The high RH during rainy season is very conducive for the growth of crops. Evaporation in the area is generally high. Within a year, pan evaporation typically varies between less than 1mm/day in January to about 9mm/day in June.

The average annual rainfall in the region is about 1400mm, of which about 74% is received during the monsoon period, i.e. from June to September. Distribution of monthly rainfall at three important rainfall stations in the Kandi belt, namely Akhnoor, Jammu, and Kathua is shown in Table 1. Winter rains are received during January to March due to western disturbances. Long rainless periods occur even during rainy season, causing water stress to crops. Most of the rainwater goes as surface runoff due to flashy nature of the streams.

Table 1. Average monthly rainfall at three stations in the Kandi belt

| Station | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Akhnoor | 77 | 75 | 79 | 53 | 35 | 67 | 437 | 436 | 130 | 24 | 12 | 46 | 1471 |
| Jammu | 63 | 76 | 82 | 43 | 28 | 82 | 389 | 325 | 116 | 24 | 16 | 32 | 1276 |
| Kathua | 67 | 63 | 70 | 37 | 32 | 94 | 472 | 448 | 174 | 16 | 14 | 48 | 1535 |

The rain in June is erratic and quite uncertain, resulting in delays in the sowing of *Kharif* crops and consequent reduction in crop yields. After continuous rains during July and August, the monsoon recedes by end of August or early September, leading to dry spell. Breaks in rainfall are frequently encountered in the monsoon season and sometimes it either sets in late or withdraws early, resulting in reduction in crop yield. In winter season, the rains are light and surface runoff is mild. The winter rain is received in an unpredictable manner.

**2.2 Soils**

Locally, the soils of the Kandi belt are named as (Bhan et al., 1994): *Gheo Mitti* (clay or silty clay loam in texture with presence of free $CaCO_3$ content in variable amount), *Phull Mitti* (loose in structure and sandy or loamy sand in texture), Mairall Stony and Sandy type (poor in fertility and occur in barani areas), *Gora* (lands which are manured constantly), *Parola* or *Golma* (greyish in colour, loam to clay loam), *Moongi* (brown or pink in colour with heavy texture and sometimes calcareous in nature) and *Bellas* (variable in texture).

The Soil Survey Organisation of the Department of Agriculture of the Jammu & Kashmir state has identified eleven soil series of the entire Kandi belt of Jammu region (Bhan et al., 1994). These are Jandial, Amb, Bansultan, Kotli, Aitham, Smailpur, Aitham Narka, Janakha Tara, Tara, Choha, and Punara. Bhan et al. (1994) reported that the soils in the Kandi belt are, in general, of low fertility due to deficiency in nitrogen, phosphorous, potassium and organic matter. Salient characteristics of these soils are described in the following table:

## Table 2. Characteristics of Soils in the Kandi Belt

| Soil Series | Texture | Origin | Depth | Topography | Permeability | Slope (%) | Erosion | Occurrence in Blocks | Villages | Suited to |
|---|---|---|---|---|---|---|---|---|---|---|
| Jandial | Sandy loam to loam sand | Colluvial boulders | Shallow to very shallow | Undulating | Rapid | 3-10 | Very severe | Bhalwal, Kathua | | |
| Amb | Loam to loamy sand | Sandstone | | Undulating | Rapid | 1-5 | Severe | Bhalwal | | |
| Bansultan | Silty clay loam sandy loam | | | Undulating | Moderate | 1-5 | Severe | Bhalwal | Gurupathan, Dumi, Palhetor, Dharam Khu, Martal, Assarwan, Porkhu, Barnai and Muthi | |
| | Loam to silt loam, and sandy loam | | | | | | | Parmandal | Madane, Chhatha, Gadigarh, Bandawal, Satwari, Sarore, Tarore, Belicharana, Surechak, Digiana, Bahliana, Prithiper, Tanda, Najwal, Garwal, Gidar Galian and Mahmudpur | Cultivation |
| | | | | | | | | Vijaypur | Rara, Rampur, Gajore, Khanpur, Bandral | Unirrigated |
| | | | | | | | | Marh | | |
| Kotli | Silty clay loam to silty clay | Alluviam | Very deep | Plane | Low | 0-1 | Slight | Balwal Marh | Garhi, Machhlian, Nagbani and Jangwari | Intensive cultivation |
| Aitham | | Weatered sandstone | Deep to very deep | Undulating | | 3-5 | Severe | Dhansal | | |
| | Coarse-textured with sandy loam | | | | | | | Majalta (Udh'pur) | | |
| | Loamy sand to sandy loam | | | | | | | Parmandal | Tooti-Di-Khoi, Mayeen, Raghura, Bajalta, Aitham, Keoli Purmandal, Radhan, Chergal Sandhor, Berlair | |
| | | | | | | | | Samba | | |
| | | | | | | | | Billawar | | |
| Smailpur | Sandy loam to loamy sand | | Moderately deep to very deep | Undulating | Rapid | 1-5 | Moderate | Dhansal | Dhok Wazirian, Chak Rakwalan, Nadora, Batal, Barian, Jhajjar-Kotli and Chorta | |
| | | | | | | | | Parmandal | Birpur, Bahu, Kaular, Batalo, Ratnoo Chak, Smailpur, Kotli, Chamah, Budhou, Darni and Sunjwani | |
| | | | | | | | | Vijaypur | Gura Salathian, Sungwal, Budhwal and Gupwal | |
| | | | | | | | | Samba | | |
| Aitham Narka | Loamy sand to sandy loam | Sandstone | Very shallow to shallow | Undulating | | 10-16 | Very severe | Dhansal | Bantalab, Narka, Khotrian, Galhotar, Panjawan and Sakoun | Forests, pastures and ravines |
| Janakha Tara | Silty loam to silty clay | Metamorphosed calcareous claystone | Moderately deep to deep | Undulating | | 1-5 | Severe | Dhansal | Janakha, Tara, Kanel and Puthwar | Along bank of nallahs |
| Tara | Loam to silty clay loam | Pink claystone and sandstone | Very shallow to shallow | Undulating and rolling | Rapid | 5-8 | Very severe | Dhansal | Janakha, Tara, Saleh, Bari, Dabbar, Guares and Surah | Gullies and big ravines |
| Choha | Sandy loam to clay loam | | Very deep | Undulating | Rapid | 3-5 | Moderate to severe | Majalta | Choha, Samwal, Mansar and Thalora | Cultivation Springs |
| Punara | Sandy loam to loamy sand | | Deep to very deep | Gentle sloping to undulating | | 1-5 | Severe | Dhansal Parmandal Vijaypur | | |

Gupta et al. (1990) and Sharma (1994a) studied some typical soil profiles in the Jammu Siwaliks, of which the Kandi belt is a part. Salient physico-chemical and hydrologic characteristics of the soils of the Jammu Siwaliks are shown in Table 3 and Table 4, respectively.

Table 3. Physio-chemical Characteristics of Soils of Jammu Siwaliks

| Location | Physiography | Depth (cm) | Texture | PH | Organic Carbon (%) | Cation Exchange Capacity (me/100g) | Water Holding Capacity (%) |
|---|---|---|---|---|---|---|---|
| Mahamaya | Siwalik Hills | 0-18 | Silty Loam | 7.6 | 0.3 | 6.2 | 36.3 |
| | | 18-35 | Silty Loam | 7.5 | 0.25 | 5.8 | 23.4 |
| | | 35-66 | Silty Loam | 7.4 | 0.15 | 5.1 | 21.8 |
| Bahu Fort | Kandi Belt | 0-16 | Loamy Sand | 7.8 | 0.51 | 7.8 | 36.4 |
| | | 16-36 | Sandy Loam | 7.9 | 0.38 | 8.4 | 26.4 |
| | | 36-67 | Sandy Loam | 7.4 | 0.32 | 7.1 | 25.0 |
| | | 67-78 | Sandy Loam | 7.4 | 0.22 | 6.4 | 22.2 |
| Kathua | Plain | 0-33 | Silt Loam | 6.9 | 0.6 | 6.6 | N.A. |
| | | 33-141 | Silt Loam | 7.2 | 0.55 | 6.7 | N.A. |

(Source: Gupta et al., 1990 and Sharma, 1994a) N.A.-not available

Table 4. Salient Hydrologic Characteristics of Soils of Jammu Siwaliks

| S No. | Soil Texture | Predominant Physiography | Location | Soil Moisture Content (% wt) at | | |
|---|---|---|---|---|---|---|
| | | | | PWP | FC | AWC |
| 1 | Alluvial Soil with medium sand | Upper Jammu Plain | Marh and Gajansoo | 1.7 | 6.8 | 5.1 |
| 2 | Fine Sand | Middle Jammu Plain | Kathua tehsil | 2.3 | 8.5 | 6.2 |
| 3 | Sandy Loam | Kandi Belt | Upper portion of Kathua, Hiranagar, Samba and Jammu tehsils | 3.4 | 11.3 | 7.9 |
| 4 | Fine Sandy Loam | Murree and Siwalik Hills | Part of Udhampur, Ramnagar and Billawar tehsils | 4.5 | 14.7 | 10.2 |
| 5 | Loam | Siwalik Hills and Piedmont | Mansar, Ramkot and Surinsar | 6.8 | 18.1 | 11.3 |
| 6 | Silt Loam | Middle Jammu Plain | Hiranagar tehsil | 7.9 | 19.8 | 11.9 |
| 7 | Clay Loam | Upland Dun and Siwalik Hills | Udhampur, Ramnagar and Billawar tehsils | 10.2 | 21.5 | 11.3 |
| 8 | Fine Loam | Jammu Lower Plain | Tehsils of R S Pura and Bishnah | 14.7 | 22.6 | 7.9 |

(Modified from Sharma, 1994a)

PWP-Permanent Wilting Point; FC-Field Capacity; AWC-Available Water Capacity

The decrease of cultivable land due to increasing soil loss from the upland areas, has deprived the area from fertile lands. Vegetal cover and landuse are two important factors that control the infiltration rate in the soils. Infiltration capacity is generally high in the area, varying from 12cm/h in bare land to about 19cm/h in forest and agricultural lands, and about 26cm/h in grassland (Goyal and Rai, 1999-2000). A high soil loss rate (about 10 to 45tonnes/ha/yr) is estimated in the area (Srinivasulu et al., 2001).

## 2.3 Geology

The Siwalik formations show typical and complete development in Jammu hills where they attain a thickness of about 6,000m with an outcrop width of about 40km as seen along the Chenab section in Reasi-Akhnoor sector and in Ramnagar-Samba sector (GSI, 1977). The Upper Siwaliks, locally known as the Kandi formations, consist of red earthy clays with massive beds of coarse pebbly sandstone, gritty in the lower part, overlain by about a thousand metre thick siliceous bouldary conglomerate. The coarseness of the conglomerate varies from that of a true boulder conglomerate to that of a gravelly conglomerate. The constituent boulders are 15-38cm in diameter, formed of compact siliceous rocks of a wide range of composition, embedded in a loose sandy matrix.

Based on the gradation from coarse to fine, the foothill zone can be further subdivided in two belts, one lying immediate south of Siwalik hills (Kandi belt) and the other lying further south, generally made of fine sediments (Sirowal belt). Among the Recent to Sub-recent deposits, those included are the vast alluvial tracts, flood plains, river terraces and talus and fans deposited by the major rivers and the adjoining *nallahs* in the Jammu region. The local geological setting in the area, as defined by some workers, is in the following chronological order (Pitale, 1969):

| | |
|---|---|
| Area of Sirowal | Fine sediments comprising} *Contemporeneous*<br>Gravel sand, silt and clay } *Sub-recent to Recent* |
| Area of Kandi Belt | Course sediments boulders}<br>Cobbles and pebbles }<br>} |
| Upper Siwalik<br>(Hills on the north) | Boulder bed and sand rocks} *Upper Pliestocene* |

The upper Siwaliks lying immediately north/northeast of the foothill zone comprise boulder beds and sand rocks. Boulder bed is made up of boulders, cobbles and pebbles of white quartzite, ferruginous quartzite and other material from the lower Siwalik horizon, interbedded with buff, yellowish and orange clay bands.

## 2.4 Geomorphology and Drainage

Typically, the Kandi tract runs in the northwest-southeast direction upto Akhnoor, from where it takes a northeast-southwest turn; the former part running parallel to the strike of the Siwalik formations. The tract is dissected intensely by streams of various sizes and types, gullies of various dimensions, and thus displaying a rolling appearance. The topography of the area is typical that of the piedment/alluvial deposits. The general gradient is about 10m/Km (1:100) towards south in the Kandi belt (CGWB, 1986).

The elevation in the area varies between 298m to 491m AMSL (Goyal and Rai, 1999-2000). The highest elevations are generally found in the eastern part, from Lakhanpur to Samba, on the northern edge between Jammu and Akhnoor in the central part, and west of Maira in the western part. Relatively elevated portions in the Lower Kandi belt are encountered around west of Sujwan. The lowest elevations in the area are found around Satwari.

The drainage pattern in the area is mostly controlled by the geological and geomorphological features. A number of dry, wide and flat bouldery bottomed drainage lines, locally known as *Khads*, traverse the Kandi belt and perennially drain the Sirowal belt downstream across the spring line. These rivulets display mostly the dendritic pattern with subtrellis to radial patterns at places (Figure 2).

**2.5 Village Ponds**

Ponds played a crucial role in the Kandi belt, and were the main source of drinking water till 1960s. The semi-hilly Kandi belt is generally devoid of any springs or *baolis*, which made ponds an important source of water to meet the community needs in the region. Most ponds were so designed that a part of the runoff from adjoining rivulets could be trapped. This helped in reduction of runoff, erosion and downstream floods. Also, the ponds helped in improving the level of ground water in the surrounding area. These ponds were located in forts, near temples, and along highways. Over the years, the design of ponds, stone pitching of their berms, and the role of clay in checking heavy seepage in the highly porous Kandi belt evolved.

There are three types of ponds in the Jammu region- *chhappris*, big ponds, and *pucca* tanks. *Chhapris* are small shallow ponds with hardly any masonry work. They fill up in a single shower and serve the needs of cattles and graziers, and dry up during the summers. Almost all Kandi villages have one big pond to meet the domestic needs through out the year. These big ponds were constructed with masonry work on three sides, the fourth side left open for the water to flow in. The *pucca* tanks have four-sided enclosures and are often found near temples, forts or highways. Almost all Kandi ponds had *banyan* and *peepal* trees on their banks.

The semi-hilly Kandi belt is generally devoid of any springs or *baolis*, which made ponds an important source of water to meet the community needs in the region (Agrawal and Narain, 1997). Most ponds were so designed that a part of the runoff from adjoining rivulets could be trapped. Also, the ponds helped in improving the level of ground water in the surrounding area. Although some efforts have been made to construct new ponds in the Kandi belt for irrigation purposes, yet limited success was achieved due to ignoring the importance of selection of suitable sites for this purpose. Water stored after good rainfall seeps out in just a few days.

Most of the ponds in the Kandi belt are today in a state of utter neglect and disuse. Village institutions, which organised annual desilting through voluntary labour and guarded the ponds against pollution, have since collapsed. In some cases, dirty water drains have been diverted into the ponds. High silt deposits have greatly reduced their storage capacity. With the advent of *pucca* houses, a rural women's need for pond silt to mudwash her house has lessened and, as a result, this need driven desilting of ponds is coming to an end.

Goyal and Rai (1999-2000) identified, based on the Survey of India's toposheets, 406 ponds of various sizes in the Kandi belt. A long-term solution to solve the water scarcity problem in the Kandi belt lies in the rejuvenation of these village ponds, with a total surface area of approx. 1.7 $Km^2$ which, considering an average depth of 2m, would store approx. $17x10^8$ litre of water. This water could be utilized

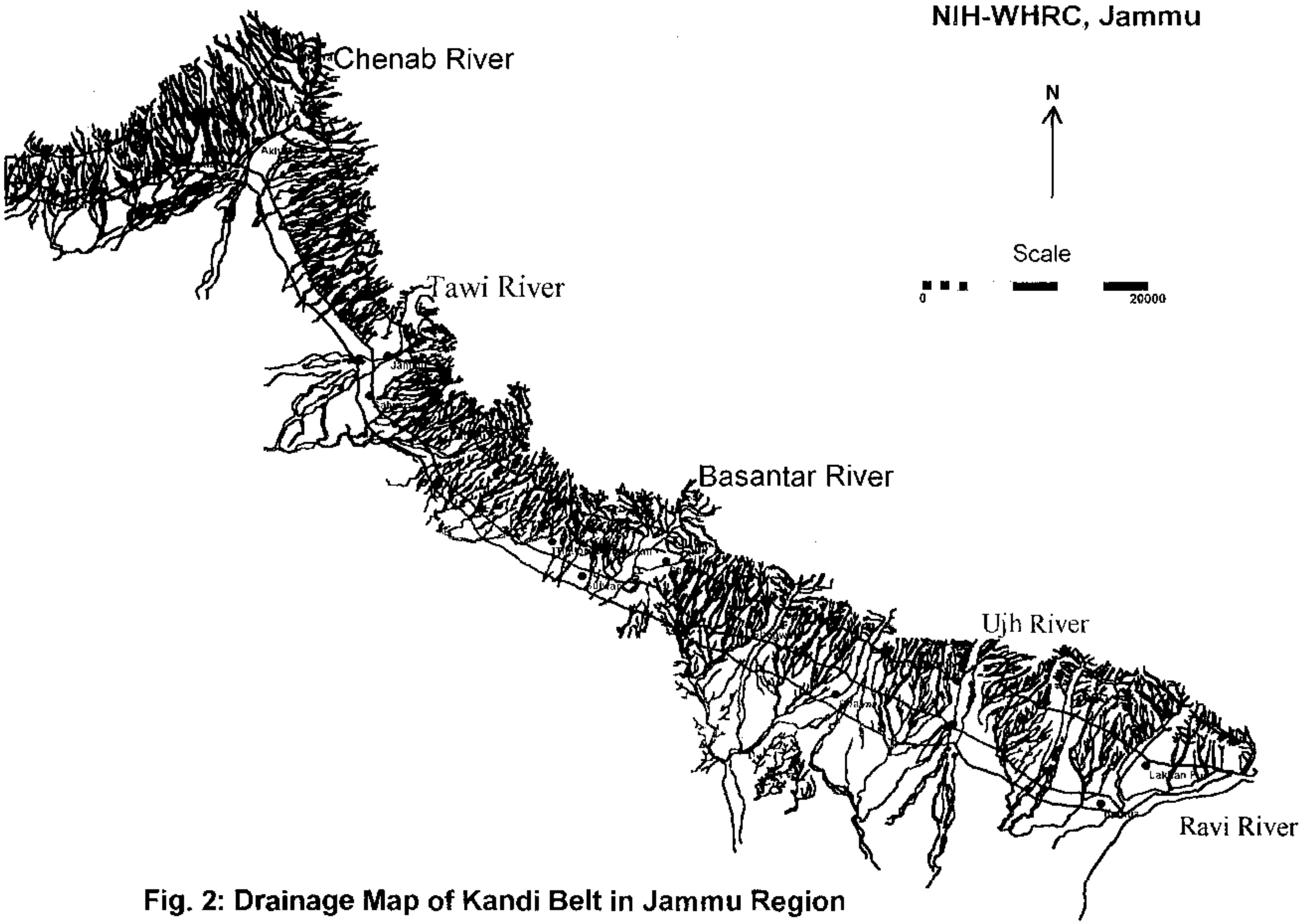



Fig. 2: Drainage Map of Kandi Belt in Jammu Region

for domestic purposes and, to a limited extent, for irrigation purposes (e.g. in horticulture, agroforestry). These ponds would also help in improving the ground water regime in the region.

A sound scheme for rejuvenation of the village ponds is required, which should use the traditional folk wisdom and the skills of the modern techniques, e.g. inputs from the hydrology, geology and geophysics, soil sciences, remote sensing and GIS for:

(1) selection of suitable sites for location of new ponds,
(2) improving inlets to the ponds, with augmentation of runoff from nearby areas,
(3) necessary desilting of ponds,
(4) deepening of ponds, if required, and improving the side walls/bunds,
(5) lining of ponds with appropriate material to control seepage from the beds,
(6) reduction of evaporation from the ponds through appropriate measures (e.g. through plantation),
(7) constructing separate sections for drinking water, bathing and washing, cattle needs,
(8) networking of ponds, wherever feasible, for domestic and irrigation purposes.

## 3.0 TYPES OF WATER HARVESTING SYSTEMS

Considering the utilization, the following three basic types of water harvesting systems are in operation:

1. Water harvesting for domestic purposes
2. Water harvesting for crop production purposes
3. Water harvesting for artificial recharge purposes

The geometric configuration of water harvesting systems is different for the above three types, and depends upon the topography, the type of catchment treatment, the intended use and logistics based on the local conditions. Broadly defined, local water harvesting systems include all measures adopted by households and communities to collect water for different purposes. The process includes tapping various sources, transporting, conveyance and storage. Two systems have been in operation: (1) locally operated, small-scale, people centered, farmer-based or managed, and easy to build and maintain, and (2) those driven by modern technologies of large-scale, engineering dominated, non-participatory and government controlled (or jointly controlled by large firms and governments). Although the sources of water to be harvested remain the same, the techniques and storage as well as delivery structures vary for the three cases.

The following table gives an overview of the cost involved in construction of some commonly used water harvesting structures (Samra et al., 1996):

Table 5. Cost of Commonly Used Water Harvesting Structures

| Structure | Storage Volume ($m^3$) | Cost per $m^3$ of Storage Volume (Rs) |
|---|---|---|
| **Rooftop Water Harvesting System** | | |
| Cement jar | 1 | 800 |
| Granary tank | 8-10 | 544-992 |
| Standing tank | 5.5-13.5 | 800-2400 |
| Masonry standing tank | 20-30 | 800-1408 |
| Ferro cement tank | 70-80 | 352-832 |
| Masonry underground tank | 21 | 381 |
| | 200 | 275 |
| | 300 | 624 |
| **Surface & Subsurface Water Harvesting Systems** | | |
| Ground tank | 17 | 611 |
| Subsurface dam | 3500 | 80-15 |
| Rock dam | 13000 | 51 |
| Small earth dam | 30000 | 61 |
| Medium earth dam | 60000 | 67 |

# 4.0 DESIGNING OF WATER HARVESTING SYSTEMS

### 4.1 Water Availability

Once the needs of an area have been established, including estimates of future requirements, the availability of water must be investigated based on hydrological analysis. From the location and the physical features of the area to be developed, the sources of water are first identified. The average annual rainfall and its average seasonal distribution are first indicators of possible water availability. Estimates of flows in perennial streams could be used to design a storage reservoir. Water from ground water sources is usually already in suitable storage, but the aquifer capacity needs to be fully investigated before a steady supply can be relied on for the design life of a development scheme.

### 4.2 Sources of Water

In the context of mountain areas, the situation is quite different than that of the lowland areas. While most mountain areas are relatively well endowed in terms of water resources, having it where and when it is required is a problem. Topography and geology of the terrain often limit the harnessing of available water from precipitation. Water from streams, springs, oozings, and snowmelt can also be harvested. Some of the important sources of water availability are discussed next.

**Rainfall:** This is the most important source of water supply in most cases. The main issue in harvesting rainfall is runoff storage and safe disposal. High variability of occurrence of rainfall in space and time needs careful designing of the water harvesting systems.

**Snowmelt:** This is the second most important source of water, especially at higher elevations. This source is available only during warm periods.

**Springs:** Springs are identified as important source of water supply in mountainous watersheds. Generally, spring water is stored in tanks, and used as and when required.

**Wells:** In valley areas of the hilly watersheds and in low elevation areas, ground water becomes and important source.

**Streams:** Small streams and rivers have been used for local water harvesting purposes. These sources are characterised by large fluctuations in water flow, being almost dry in the peak summer months. As such, these sources can be used effectively for a limited period. With proper storage structures, however, a fairly good amount of water can be harvested from these streams, to be used during lean period.

### 4.3 Selection of Storage Sites

When the most promising source region has been identified, suitable locations for the construction of a storage reservoir must be investigated. A feasibility study for evaluating a possible reservoir site includes the following operations (Cole, 1975):

i. Topographical survey to determine proposed water spread area and water volume

ii. Geological survey of the dam site
iii. Survey of proposed supply pipelines
iv. Hydrological assessments of the catchment river flows at the dam site for impounding reservoirs, or at the river site for pumping water to an off-channel storage, and of the design flood for the dam spillway
v. Appraisal of the necessary land use changes and the future amenity value of the reservoir, and
vi. Estimated cost of the scheme.

## 5.0 HYDROLOGIC ASPECTS

The design of water harvesting systems is highly location-specific and, thus, makes it difficult to design a general model, which can be used for all areas. A typical design of a water harvesting structure involves:

1. Hydrological analysis, including probability of occurrence of runoff,
2. Hydraulic design to determine physical size of the structure considering seepage and evaporation losses,
3. Policies for utilising the stored water in terms of timing, quantity, crops to be irrigated, and selection of irrigation system,
4. Economic feasibility of the scheme

In quantitative terms the hydrologic cycle can be represented by a closed equation which represents the principle of conservation of mass. This equation, known as the water balance equation, is represented in many forms, depending on the purpose of computation. In general form, this equation is represented as:

$$P + Q_{SI} + Q_{GI} - E - Q_{SO} - Q_{GO} - \Delta s - n = 0 \qquad (1)$$

where P = precipitation,

$Q_{SI}$, $Q_{GI}$ = surface and ground water inflow into the boundary from outside

E = evapotranspiration

$Q_{SO}$, $Q_{GO}$ = surface and ground water outflow from the boundary

$\Delta s$ = change of storage volume within the boundary

n = discrepancy term

Equation (1) for a tank may be expressed as:

$$P + Q_{SI} + Q_{GI} = E + Q_{SO} + Q_{GO} + \Delta s \qquad (2)$$

where, after neglecting the discrepancy term, the other terms are redefined as:

P = direct precipitation falling over the water surface,

$Q_{SI}$ = surface runoff from the catchment,

$Q_{GI}$ = interflow or subsurface flow from the catchment,

E = evaporation loss,

$Q_{SO}$ = outflow from the pond,

$Q_{GO}$ = seepage loss

$\Delta s$ = change in storage capacity

The inflow into the tank (i.e. left-hand side of the above equation) is determined from daily increase in water levels. Direct precipitation falling over the tank surface is calculated by multiplying the daily rainfall depth with water surface area as per the stage area graph of the tank. Change of water storage is calculated from the depth of water using the depth capacity curve. Outflow from the tank is computed by monitoring the discharge at the outlets.

The evaporation loss is observed from a closely located open pan evaporimeter, and by multiplying the pan evaporation value by a factor of 0.9 to obtain the equivalent tank evaporation. The volume of water lost through evaporation is obtained by multiplying the pond evaporation depth by the water surface area.

Inflow into the tank ceases after the rain stops, and water stored in the tank is lost through seepage and evaporation. Daily storage loss during this period is obtained by analysis of recession limb of the storage hydrographs. Daily seepage losses are computed by deducting the evaporation losses from storage losses.

Studies have revealed that the seepage losses after the construction of the tank become asymptotic to the time axis and stabilize after 7-8 years; the following regression equation between age of pond and seepage rate was reported by Satpathy, et. al (1997):

$$S = 0.79T^{-0.187} \tag{3}$$

where S = seepage rate in $m^3/m^2$ of wetted area/day,
T = age of the pond in years

In deep and well drained soils, interflow is that part of the rainfall which vertically infiltrates into the soil in the upslopes and, while moving down stream areas, is forced to come to the surface after reaching saturated zone which normally occurs in the lower reaches. In the upper slope reaches, soils do not get saturated even after a substantial amount of cumulative rainfall, while relatively small amounts of rain is enough to produce saturation to soil in the lower reaches. Unlike surface runoff, the amount of baseflow (including interflow) is somewhat consistent and varies with the annual rainfall. Empirical relationship of the following form has been reported by Satpathy, et. al (1997):

$$I = 0.846R^{3.85} \tag{4}$$

where I = annual baseflow (cm)
R = annual rainfall (m)

## 6.0 DESIGN PARAMETERS

Storage type small earth dams with spillways have been commonly constructed to harvest and store surface runoff for irrigation, ground water recharge, and also to moderate floods and sediment discharge in the Siwaliks. Horse-shoe type watersheds all along Siwalik hills provide a good site for constructing small water harvesting dams. Standard design procedure of small earthen dams are adopted in designing these water harvesting dams. Some of these design parameters, especially for the Siwalik region, are discussed next.

### 6.1 Water Yield

Expected average annual runoff (or water yield) from the catchment area is estimated as a function of average annual monsoon rainfall and watershed conditions.

$$\text{Average annual water yield} = \frac{A * P * R}{1000} \text{ ha-m}$$

Where, A is watershed area in ha, P is average monsoon rainfall in mm, and R is the runoff coefficient in percent. Average rainfall of at least 25-30 years period should be considered. The recommended norms for selecting runoff coefficient for water yield computations in the Siwalik region are as follows:

Watersheds with heavy soils = 30%
Watersheds with medium soils = 25%
Watersheds with light soils = 20%

A relatively higher runoff coefficient is considered for storm runoff computations in designing principal spillway.

### 6.2 Peak discharge

Peak discharge for a given design frequency (or return period) is estimated using the Rational method. Generally a return period of 25-50 years is considered. The design frequency (recurrence interval or return period), however, depends on the type of water harvesting structure, as shown below:

| SN | Type of Structure | Frequency (Years) |
|---|---|---|
| 1. | Storage & diversion dams having permanent spillways | 50-100 |
| 2. | Earthfill storage dams having natural spillways | 25-50 |
| 3. | Stock water dams | 25 |
| 4. | Small permanent masonry gully control structures | 10-15 |
| 5. | Terrace outlets & vegetated waterways | 10 |
| 6. | Field diversions | 15 |

Rainfall intensity for the duration equal to time of concentration is estimated from the intensity-duration- frequency relationship. Agnihotri et al. (1989a) developed the following relationship for Chandigarh:

$$I = \frac{61.8T^{0.1449}}{(t+0.38)^{0.8007}}$$

where, I is rainfall intensity expressed in mm/hr, T is return period in years and t storm duration in hours.

### 6.3 Storage Capacity

General practice in this region is to design water harvesting structure for total storage of average annual runoff. Live storage is provided for storing expected annual average runoff from watershed. Expected sediment yield for the designed life (usually 25 years) is estimated based upon the data available from experimental studies in the region. Unfortunately such data is rarely available at the watershed scale. The sediment yield is expected to reduce with the passage of time as a result of soil conservation measures in the watershed. It is, therefore, recommended that sediment yield should be estimated assuming time differential rates of sediment yield. The storage capacity at different heights is computed using the end area method.

However, as a rule of thumb, in the Siwalik region of Punjab, the general recommendation is to provide a dead and live storage of the order of 5% and 20% of the average monsoon rainfall, with an additional 10% of monsoon rainfall as flood storage. These small earthen dams have total storage capacity upto 62 ha-m in the Siwaliks with a variable command area (2-260 ha).

### 6.4 Dam Height

Although the general practice in this region is to design the structure to impound entire runoff from the catchment, provision for release of flood flow is always made while determining the height of the dam. Generally, the height of dams in this region varies from 6 to 16 m.

### 6.5 Spillway

Drop inlet spillway is generally recommended as the principal spillway for small earthen dams. Peak flow from design storm is adjusted for volume of temporary storage between crest of the inlet and the emergency spillway to compute required principal spillway discharge. The crest of principal spillway is recommended to be kept 1m below the crest of emergency spillway. Side channel spillway and chute spillway are also provided in some dams such as in Bunga watershed.

Some of the assumptions in tank design, adopted by Verma (1992) for the Kandi area in Punjab, are as follows:

1. Weekly estimated runoff is routed in tank in the beginning of the week and evaporation and seepage losses are computed at the end of every week. The net stored runoff is increased by next week's runoff during the collection period,
2. The silt inflow, after adopting in-situ soil and water conservation measures, will be 2 $m^3$/ha/year. It was assumed that the tank will be desilted after every 5 years regularly. Thus, the silt volume of 10 $m^3$/ha was taken for the tank design,
3. Active life of the lined tank is taken as 40 years,

4. Total area covered under the tanks is taken as 150% of the designed top water surface area of tank,
5. It is assumed that tank is located at the lowest part of the catchment and a circular strip of cultivated area is available around the tank for irrigation,
6. Cost of inlet, outlet and other structures is taken as 10% cost of the tank (excavation plus lining).

The following points emerged from the efforts made by the Irrigation Department of Punjab to construct few big earthen dams for irrigation purposes in Hoshiarpur district across big gullies (Verma, 1992):

1. Long term stream flow records are not available for this area, and there is no reliable method of runoff estimation. For designing reservoirs, runoff is taken as a percentage of annual rainfall varying from 25 to 45%, which is too high. Seasonal runoff can be estimated with available rainfall records and recharge capacity of the watershed. Frequency analysis of generated runoff records should be done and for designing reservoir, lowest assured runoff at 60 to 80% probability level should be used,
2. Normally, storage volume is designed by estimating runoff (as percentage of rainfall) on the basis of existing soil surface conditions and after few years, as a result of catchment development programmes, runoff is reduced resulting into failure of reservoir to collect the designed runoff. Therefore, as far as possible, design runoff should be estimated by simulating scenarios of different levels of catchment development over a period of time, silting, reduction in seepage losses, etc.,
3. The probability of receiving the mean estimated value of runoff is very low (between 40 to 50%). To reduce the cost of construction per unit of expected live storage capacity, the reservoir should be designed at higher probability level (between 60 to 80%) of lowest assured monsoon runoff, and a proper spillway should be provided,
4. There is no economically viable method to reduce seepage through porous bed in this area except self sealing by silting,
5. Construction of a dam reservoir in gullies for only irrigation purpose may not be economically viable, but it can serve useful purpose as soil conservation structure, percolation tank for ground water recharge, flood retention dam, and storage reservoir for supplemental irrigation to rainfed crops.

**6.6 Precipitation**

Runoff is generated by rainstorms, and its occurrence and quantity are dependent on the characteristics of the rainfall event. The amount, timing and variability of rain, which occurs during a season or year are the key factors that must be evaluated in designing a water harvesting system. Long term daily rainfall records are most desirable. In arid areas, at least 15 to 20 years of record are needed. If there are large variations between years, data from the two wettest years should be eliminated If sufficient long-term data are available, stochastic methods can be used to determine the probabilistic rainfall of extreme periods. Mean annual rainfall is not a very good indicator of available water because there will be more years with rainfall less than the mean than there will be years with rainfall greater than the mean.

To compensate for dry years, the size and efficiency of the catchment areas and storage can be increased. But regardless of the design, there will be risk involved because of the uncertainty of rainfall. The user must decide the amount of risk that can be accepted should there be insufficient rainfall during some periods.

For a water harvesting planner, the most difficult task is therefore to select the appropriate design rainfall according to which the ratio of catchment to cultivated area will be determined. Design rainfall is defined as the total amount of rain during the season at which or above which, the catchment area will provide sufficient runoff to satisfy the storage requirements of the ponds. In cropping context, this rainfall is intended to meet the crop water requirements. If the actual rainfall in the cropping season is below the design rainfall, there will be moisture stress in the plants; if the actual rainfall exceeds the design rainfall, there will be surplus runoff which may result in a damage to the structures, unless otherwise regulated.

The design rainfall is usually assigned to a certain probability of occurrence or exceedance. If, for example, the design rainfall with a 67% probability of exceedance is selected, this means that on average this value will be reached or exceeded in two years out of three and therefore the crop water requirements would also be met in two years out of three.

### 6.6.1 Probability Analysis

In a rather simple, graphical method, the first step is to obtain annual rainfall totals for the cropping season from the area of concern. In locations where rainfall records do not exist, figures from nearby stations may be used with caution. It is important to use long-term records. The next step is to rank the annual totals with m=1 for the largest and m=n (i.e. no. of records) for the lowest value and to rearrange the data accordingly. The probability of occurrence P(%) for each of the ranked observations can be calculated from the equation:

$$P(\%) = \frac{m - 0.375}{n + 0.25} x100$$

where P = probability (%) of the observation of rank m
m = rank of the observation
n = total number of observations

The above equation is recommended for n=10 to 100 (Reining et al., 1989). There are several other, but similar, equations for computation of experimental probabilities. The next step is to plot the ranked observations against the corresponding probabilities. Finally, a curve is fitted to the plotted observations in such a way that the distance of observations above or below the curve should be as close as possible to the curve. The curve may be a straight line.

From this curve it is now possible to obtain the probability of occurrence or exceedance of a rainfall value of a specific magnitude. Inversely, it is also possible to obtain the magnitude of the rain corresponding to a given probability.

The return period T (in years) can easily be derived once the exceedance probability P is known from the equations:

$$T = \frac{100}{P} (years)$$

### 6.7 Runoff

When rain falls, the first drops of water are intercepted by the leaves and stems of the vegetation. This is referred to as interception storage. As the rain continues, water reaching the ground surface infiltrates into the soil until it reaches a stage where the rate of rainfall (i.e. rainfall intensity) exceeds the infiltration capacity of the soil. Thereafter, surface puddles, ditches, and other depressions are filled (depression storage), after which runoff is generated.

The infiltration capacity of the soil depends on its texture and structure, as well as on the antecedent soil moisture content. The initial capacity of a dry soil is high but, as the storm continues, it decreases until it reaches a steady value termed as final infiltration rate.

The process of runoff generation continues as long as the rainfall intensity exceeds the actual infiltration capacity of the soil but it stops as soon as the rainfall intensity drops below the actual rate of infiltration.

#### 6.7.1 Factors affecting runoff

If all the surface depressions have been filled and the rainfall intensity exceeds the infiltration rate, then surface runoff is initiated. The soil profile near the soil surface need not be saturated for surface runoff to occur. The main components of the hydrologic cycle which are of importance in determining runoff from rainfall events include precipitation, infiltration, interception, surface storage and detention, interflow and subsurface drainage, and channel storage.

The watershed factors affecting runoff are size, topography, shape, geology, and perhaps most importantly, the soil and landuse.

**Size:** Size of a catchment has a bearing on the runoff response to a rainfall event. In general, the runoff efficiency (volume of runoff per unit of area) increases with the decreasing size of the catchment, i.e. the larger the size of the catchment the larger the time of concentration and the smaller the runoff efficiency.

**Topography:** Investigations have shown that steep slopes yield more runoff as compared to the gentler slopes, and that the quantity of runoff decreased with increasing slope length. This is mainly due to lower flow velocities and subsequently a longer time of concentration (defined as the time needed for a drop of water to reach the outlet of a catchment from the most remote location in the catchment). This means that the water is exposed for a longer duration to infiltration and evaporation before it reaches the measuring point.

**Shape:** Circular or fan-shaped watersheds have high rates of runoff as compared to other shapes because runoff from different points in the watershed are more likely to reach the outlet at similar times. High rates of runoff on small catchments of this type are short-lived. Peak flow at the outlet for long, narrow (elongated) watersheds is less than for a fan-shaped catchment but persists for a longer time, because high flows from the downstream tributaries pass the gauge before high flows from upper tributaries arrive.

**Orientation or aspect:** The aspect can be important where there is only one major slope face. On large areas, there are a multitude of aspects and the average tends to balance out to no specific direction. The aspect affects soil water content, vegetation, and is also important for soil freezing. In the northern hemisphere, north-facing slopes receive less solar energy, leading to lower soil temperatures as compared to south-facing slopes.

**Geology:** Geology is a significant factor in the historic formation of soil and physical characteristics of watersheds and the establishment of surface and subsurface flow systems of the hydrologic cycle. Geological features (e.g. type of rock formations, faults, fractures, fissures) and processes (e.g. movement of glaciers) have helped define the surface divide or ridge between watersheds, establish and control stream channel gradients, and formed the subsurface boundaries which control the movement of groundwater to surface streams. Groundwater flow boundaries do not always coincide with watershed divides and are more difficult to define.

**Soil:** Soil properties affect the runoff through infiltration. The infiltration capacity is, among others, dependent on the porosity of a soil which determines the water storage capacity and affects the resistance of water to flow into deeper layers. Porosity differs from one soil type to the other. The highest infiltration capacities are observed in loose, sandy soils while heavy clay or loamy soils have considerable low infiltration capacities.

The infiltration capacity depends also on the moisture content prevailing in a soil at the onset of the rainstorm. The initial high capacity decreases with time (provided the rain does not stop) until it reaches a constant value as the soil profile becomes saturated. This, however, is only valid when the soil surface remains undisturbed.

Due to the surface sealing phenomenon, considerable quantities of surface runoff are observed for high intensity rains even when the rainfall duration is short and the rainfall depth is comparatively small. Soils with a high clay or loam content are the most sensitive for forming a cap with subsequently lower infiltration capacities.

**Landuse:** Compared to unprotected land surface, the vegetative cover of watersheds is likely to reduce storm runoff when soil moisture is significantly less than saturation. Vegetation improves the soil structure and depletes soil moisture, thus causing more infiltration and less surface runoff. Dense vegetative cover shields the soil from the raindrop impact and reduces the sealing effect. In addition, the root system and organic matter in the soil increase the soil porosity thus allowing more water to infiltrate. Vegetation retards the surface flow, particularly on gentle slopes, giving the water more time to infiltrate and to evaporate. Trees and deep-rooted crops usually consume more soil water by ET than shallow-rooted crops, especially in dry periods, and consequently their watersheds have less runoff.

Bare soil surfaces where infiltration rates diminish rapidly have more surface runoff. This is because bare soils tend to have poor structure and are less permeable. Even in permeable soils such as sand, a common problem known as surface sealing often occurs shortly after rainfall begins. Surface sealing, which is the formation of a very thin, almost impervious layer at the surface, can be due to both physical and chemical processes.

Soil and water conservation tillage practices that maintain high rates of infiltration could reduce surface runoff and those that reduce soil water evaporation could increase subsurface runoff.

**6.7.2 Runoff Coefficients**

The design of water harvesting schemes requires the knowledge of the quantity of runoff to be produced by rainstorms in a given catchment area. It is commonly assumed that the quantity (volume) of runoff is a proportion (percentage) of the rainfall depth:

Runoff = K x Rainfall

where K is the runoff coefficient.

In rural catchments where no or only small parts of the area are impervious, the coefficient K is not a constant factor, varying with the catchment-specific factors and on the rainstorm characteristics. Therefore, the use of runoff coefficients, which have been derived for watersheds in other geographic locations should be avoided for the design of a water harvesting scheme. Also, runoff coefficients for large watersheds should not be applied to small catchment areas.

An analysis of the rainfall-runoff relationships and subsequently an assessment of relevant runoff coefficients should best be based on actual, simultaneous measurements of both rainfall and runoff in the project area. Actual measurements should be carried out until a representative range is obtained. Studies have recommended that at least 2 years should be spent to measure rainfall and runoff data before any larger construction programme starts. Such a time span would in any case be justified bearing in mind the negative demonstration effect a water harvesting project would have if the structure were seriously damaged or destroyed already during the initial rainstorms because the design was based on erroneous runoff coefficients.

A much better relationship would be obtained if in addition to rainfall depth the corresponding rainstorm intensity, the rainstorm duration and the antecedent soil moisture were also measured. This would allow rainstorm events to be grouped according to their average intensity and their antecedent soil moisture and to plot the runoff coefficients against the relevant rainfall durations separately for different intensities.

When analysing the measured data it will be noted that a certain amount of rainfall is always required before any runoff occurs. This amount, usually referred to as threshold rainfall, represents the initial losses due to interception and depression storage as well as to meet the initially high infiltration losses.

The threshold rainfall depends on the physical characteristics of the area and varies from catchment to catchment. In areas with only sparse vegetation and where the land is very regularly shaped, the threshold rainfall may be very low whereas in other catchments this value can be high, particularly where the prevailing soils have a high infiltration capacity. The fact that the threshold rainfall has first to be surpassed explains why not every rainstorm produces runoff.

In cases where annual or seasonal runoff coefficient for a catchment is required, e.g. in designing ponds for crop irrigation or domestic use purposes, it may be computed as:

$$K = \frac{\text{Yearly (or seasonal) total runoff (mm)}}{\text{Yearly (or seasonal) total rainfall (mm)}}$$

The annual (or seasonal) runoff coefficient differs from the runoff coefficients derived from individual storms as it takes into account also those rainfall events which did not produce any runoff. The annual (or seasonal) runoff coefficient is therefore always smaller than the arithmetic mean of runoff coefficients derived from individual runoff-producing storms.

The final size of the catchment area should be determined by computing a weekly or monthly water budget of collected water versus water requirement to help ensure that there are no critical periods when there will be insufficient water.

Smaller systems can be used when the periods of maximum rainfall coincide with periods of maximum use. Larger systems, with large storage capacity are necessary when the periods of greatest precipitation occur after the periods of greatest water needs when it may be necessary to store water for 6 to 9 months.

**6.7.3 Rainfall-Runoff Relationship in North Western Himalayan Region**

Wasiullah and Ram Babu (1970) developed an empirical relationship for Doon Valley:

$$Q = 0.14\, q\, A^{0.33}$$

Where Q is predicted runoff volume ($\times 10^4$ $m^3$), A is watershed area (ha) and q is peak discharge ($m^3/s$).

Ram Babu and Dhruva Narayana (1983) generalized this relationship, taking into consideration watershed characteristics, as:

$$Q_T = 2.15 + 0.172A - 4.705L + 0.799D + 0.163P - 0.025P_{30} - 0.10API$$

$$Q_P = 0.02 + 0.053A - 0.989L + 0.034D + 0.008P + 0.007P_{30} - 0.006API$$

Where, $Q_T$ is volume and $Q_P$ is peak rate of runoff, A is watershed area (ha), L is main channel length (km), D is duration of the storm (hr), P is rainfall (mm), $P_{30}$ is maximum rainfall during any interval of 30 minutes, and API is antecedent precipitation index based on seven days value.

### 6.7.4 Rainfall-Runoff Relationship in Siwalik Region

Simple and empirical rainfall-runoff relationships have been developed in different areas based on experimental data. Most of these relationships tend to relate runoff or water yield with rainfall on annual or seasonal basis for a given situation. These relationships can only be taken as a suggestive range of values. The water yield or runoff as a proportion of rainfall (i.e. runoff coefficient), under different landuses and management practices, from small and micro-watershed studies in Siwalik region is summarized in Table 6.

Table 6. Rainfall-runoff relationships for Siwalik region

| Area (ha) | Particulars of the study | Runoff as % of rainfall | Remarks |
|---|---|---|---|
| 4.60 | With bunding and terracing, mainly agriculture mixed with Eucalyptus & Subabul | 26.3 | Average of 1977-86 |
| 9.12 | Sukhomajri Dam 2, trees and grasses, steep slopes | 48.2 | Average of 1978-79 |
| 4.3 | Sukhomajri Dam 1, trees and grasses, steep slopes | 42.1 | Average of 1978-79 |
| 21.3 | Mixed forest without protection & S.C. measures | >30.5 | Estimated before 1956 |
| 21.3 | Mixed forest with protection and soil conservation measures | 9.2 | Average of 1963-90 |
| 25.0 | Nada I, bushes, grasses & scattered trees, steep hills | 29.4 | Initial period |
| 25.0 | Nada I, bushes, grasses & scattered trees | 19.9 | Average of 1984-91, 8 years after treatment |
| 4.3 | Sukhomajri Dam 1 | 14.2 | Average of 1988-91, 13 years after treatment |
| 9.12 | Sukhomajri Dam 2 | 25.2 | Average of 1988-91, 13 years after treatment |
| 59.0 | Relmajra, Steep hills, mixed forest | 17.0 | Average of 1993 & 1994, 2 years after treatment |

# 7.0 CONTROL OF WATER LOSSES

### 7.1 Seepage Control

Seepage and evaporation constitute the main storage losses from tanks, ponds, and reservoirs. To minimize these losses, storage volume should be maximized in relation to the exposed surface area. Application of suitable sealant materials becomes a necessity to reduce seepage losses. Seepage losses are generally higher in the newly constructed structures and tend to decrease with time due to deposition of finer silt particles and sealing of the pores.

Vivekanand Parvatiya Krishi Anusandhan Shala, Almora, conducted detailed studies to find a suitable and inexpensive sealant for earthen tanks in hilly areas. This study indicated Low Density Polyethylene (LDPE) film to be most effective sealant to control seepage in tanks (Srivastava, 1988). The choice of a suitable lining material, however, depends on the texture of the soil besides other factors, e.g. availability, durability and cost of the material. Table 7 shows the relative performance of the common lining materials. Some of the commonly used sealant materials and methods are:

1. Sealing by compaction
2. Clay blankets
3. Bentonite
4. Soil-cement and cement-concrete/stone or brick lining
5. Chemical additives and sealants
6. Membranes

Table 7. Relative performance of different lining materials

| Material | Weed Infestation | Dressing & Cleaning | Crack of Material | Repasting |
|---|---|---|---|---|
| Bentonite@5Kg/m$^2$ | Severe | Twice | Severe | Required |
| LDPE | NIL | Not required | Minor cracks in brick cover | Not required |
| Soil+Straw+Cowdung (10:1:1) | Moderate | Once | Minor cracks in upper portion | Required at top |
| Soil+Cement (8:1) | Moderate | Once | Minor | Required |
| Silpaulin | NIL | Not required | NIL | Not required |

(Source: Samra, J S, V N Sharda and A K Sikka, 1996. Water harvesting and recycling: Indian experiences. Central Soil & Wat Con Res & Trg Ins, Dehradun. Page 122)

### 7.2 Evaporation Control

Evaporation may account upto 50% of the water losses in open shallow reservoirs and upto 20% in deep reservoirs. Many materials have been tried to check the evaporation losses (e.g. gravel mulches, plant residues, oil sprays, silicons, polyethylene oxides, gum mixtures), but none proved to be very successful and economic. To maintain an effective layer of the retardant for sufficient period is still a major problem.

Steepening of the sides of the ponds will reduce the exposed surface area, and hence the evaporation losses. Simple vegetative fencing around these structures can be the best possible method to reduce the evaporation losses.

The following findings emerged from the research investigations carried out under the All India Coordinated Research Project on Dryland Agriculture (Verma, 1992):

1. the tanks of inverted truncated pyramid shape having square base and 1:1 side slopes and lined with polyethylene sheet of 200 micron, buried under 20cm thick soil at bottom and brick-cement (7.5cm thick) on sides are found most suitable,
2. the seepage loss from polyethylene sheet lined bottom and brick-cement lined sides of new tank is 7 to 31 litres/$m^2$/day. It further reduces to 2.87 to 12.71 litres/$m^2$/day in five years due to silting and sealing of brick pores. The polyethylene and brick-cement linings costed Rs 5.76/ $m^2$ and Rs 22.75/ $m^2$ in the bottom and sides of tank, respectively, at 1987 prices,
3. the capacity of the tank should be designed on the basis of lowest assured monsoon runoff at 50 to 80 % probability level. It should be designed to give full capacity of water at the end of monsoon considering seepage and evaporation losses during the collection period,
4. the wetted surface area, permitting water losses, per unit volume of tank reduces with increasing tank depth. However, for other practical reasons of excavation, lining, lifting water, etc., the water depth should not be more than 5m,
5. the excavation cost (C) of inverted truncated pyramid shape tanks having square base, 1:1 side slope and about 5m depth can be given as $C = 0.0043B+3.3517$, where B is the bottom width of tank in m and C is the excavation cost in Rs/$m^3$ capacity of tank,

# 8.0 WATER AVAILABILITY STUDY OF A VILLAGE POND

## 8.1 The Study Area

The selected pond is located in village Bari-Badhori, situated at a distance of about 22km east of Jammu city between $32^0$-20' and $33^0$-10'N latitude, and $74^0$-45' and $74^0$-55'E longitude (Figure 3). Inlet of the pond lies on the northeastern side and the outlet is on the north, by the side of a road. The village Badhori is located in Tehsil Samba, district Jammu. The site lies in the typical Kandi belt, having undulating topography and comprising coarse-textured soils with boulders and conglomerates.

Total area of the Badhori village is 557 hectare (ha). Landuse in the area is dominated by cultivable land (53%), followed by wasteland (36%), cultivable wasteland (9%), and forest and orchard lands (2%) (Table 8). For village Bari, the total area is 276ha, with dominated landuse as wasteland (54%), followed by cultivable land (34%), cultivable wasteland (10%), forest (2%), and only marginal orchard land. Due to the efforts of a local NGO, namely J&K Paryawaran Sanstha, watershed development activities are being carried out. Under afforestation and horticulture development programmes, a lot of new plantation has been carried out on the wasteland and cultivable wasteland. As a result, a significant change in the land use pattern has taken place in the area.

Table 8. Landuse details in Badhori and Bari villages

| Village | Total Area (ha) | Area under landuse (ha) | | | | |
|---|---|---|---|---|---|---|
| | | Cultivable land | Cultivable waste land | Waste land | Forest | Orchard |
| Bari | 276 | 94 (34%) | 27 (10%) | 148 (54%) | 6 (2%) | 1 (0.4%) |
| Badhori | 557 | 297 (53%) | 49 (9%) | 198 (36%) | 8 (1%) | 5 (1%) |

Forest in the area is mostly open scrub forest with low density. The main plant species include Sisso (Shisham), Acacia Catechu (Khair), A modesta (Phalai), Lenea grandis (Simbal), Mallotus Philipnenais (Kmela), A nilatica (Kikar), Emblica officinalis (Amla), Zizyhus (Ber), Cassia fisotula (Amaaltas), and Azadirachta indica (Neem). Some of the prominent shrubs are Carissa Spiarum (Gama), Dodonea Viscossa (Santha), Adhatoda Viscia (Brentkad), and Vitex negundo (Bana).

### 8.1.1 Infiltration Rate

Soil in the area is sandy loam to loam and silt to silt loam with stones and pebbles. Due to gravelly texture of the soil, infiltration rate is high in the area (24mm/hr). Unsaturated hydraulic conductivity test in the bed of the pond revealed a value of 8.6 cm/day, whereas in a nearby cultivated field it has a higher value of 14.2 cm/day (Goyal and Omkar, 2001).

### 8.1.2 Elevation and Slope

The pond lies at an elevation of about 410m AMSL, and the two villages (Bari and Badhori) lie between contours of 450 and 400m. General slope in the catchment is about 4.2m/100m.

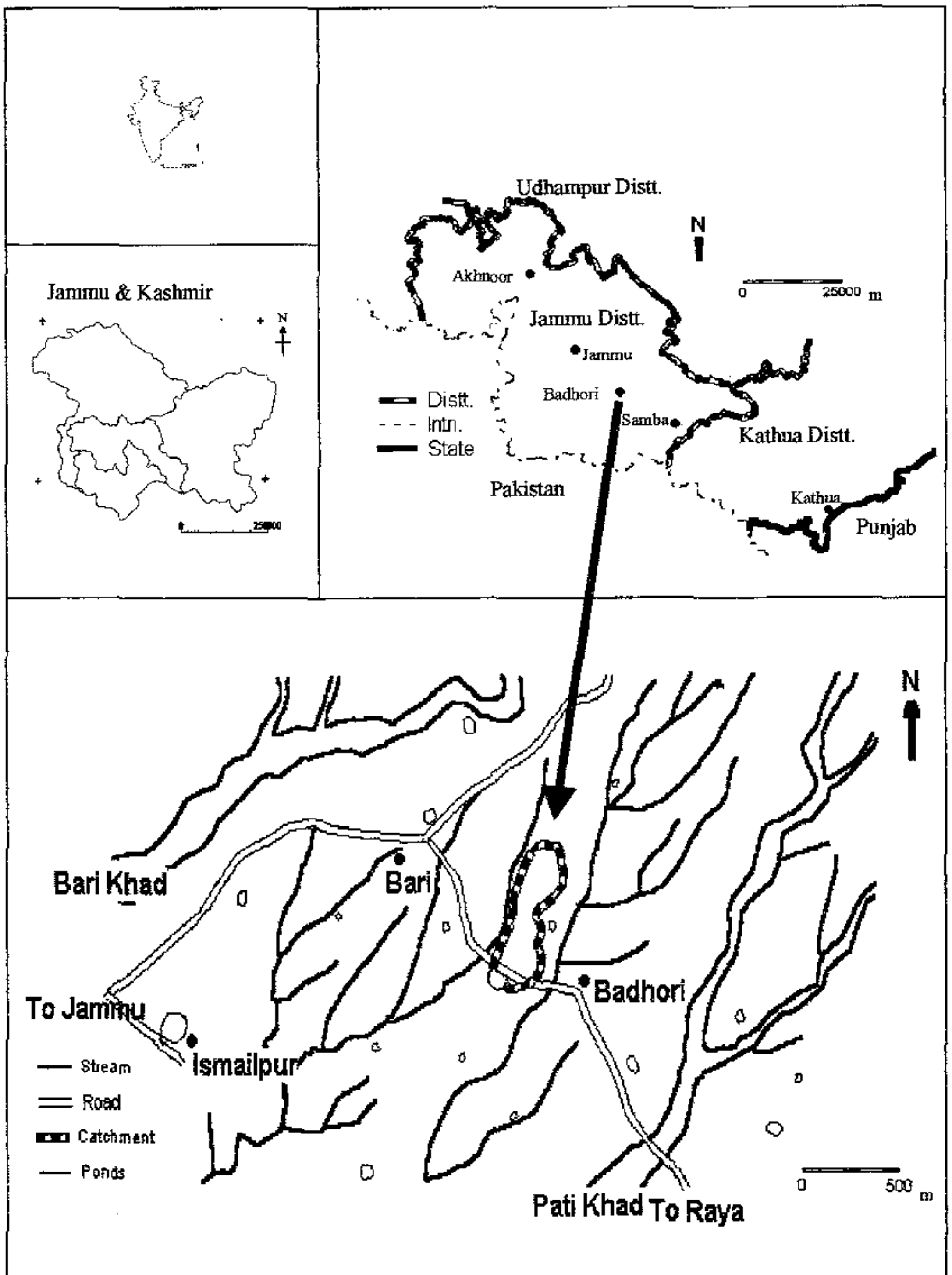



Fig. 3: Location map of Badhori Pond

### 8.1.3 Drainage and Catchment Area

The area is located between Bari khad on the west and Pati khad in the east. All the streams in the area are of ephemeral type, and have flashy flows after rain storms. Catchment area of the pond is 0.11km$^2$ (10.98ha).

### 8.1.4 Crops

The major crops in the area include wheat, sarsoon, toori, chhatala, followed by maize, bajra, tilhan, and pulses. A few farmers grow vegetables and flowers (e.g. marigold).

### 8.1.5 Water Availability

The depth of water table in the area is from 25m at Kheryian village to more than 45m in the upper catchment. A number of old village ponds are available, some of which retain water even during summer. The drinking water is supplied by the State PHE department from the tube wells at nearby villages (Patti and Ismailpur). The daily supply of drinking water by the PHED in Bari-Badhori village is 8000 Gallons.

### 8.1.6 Water Demand

***Domestic***

The total human population in Badhori village is 2582. Estimated domestic water requirement for this population, based on the standard norms of per capita requirement of 100 LPD, works out to be 258m$^3$/day. Considering water requirement of 10 litres per cattle per day, an estimated water requirement for cattle is 58 m$^3$/day. The monthly requirement of water in the two villages has been worked out (Table 9).

Table 9. Monthly domestic water demand in Badhori and Bari villages

| Village | Human Population* | Cattle Population | MHWD (m$^3$) | MCWD (m$^3$) | MTWD (m$^3$) |
|---|---|---|---|---|---|
| Bari | 1619 | 1529 | 4857 | 459 | 5316 |
| Badhori | 2582 | 5845 | 7746 | 1754 | 9500 |

*estimated figures in 1991

(MHWD, MCWD and MTWD are monthly water demand of humans, cattle and total, respectively.)

***Agriculture***

Total crop water requirement can be computed on the basis of sown area for different crops in the region. As shown in Table 10, the total crop water requirement for the important crops grown in the village is 214ha-m.

Table 10. Crop water requirement (CWR) in the study area

| Crop | Sown Area (ha) | CWR (cm) | CWR (ha-m= x10$^4$m$^3$) |
|---|---|---|---|
| Wheat | 342 | 42 | 144 |
| Maize, Bajra & other crops | 47 | 35 | 16 |
| Vegetables | 2 | 65 | 1 |
| Fruits | 82 | 65 | 53 |
| **Total** | 473 | | 214 |

### 8.2 Bathymetric Survey

A detailed bathymetry survey was conducted to determine the surface area, circumference, shape and depth of the pond. The methodology followed to conduct a bathymetric survey of the Badhori Pond is briefly discussed below.

Basically, there are two methods to carry out the bathymetric survey of lakes/reservoirs. These are the range-line survey and the contour survey. The range-line method is most widely used for medium to large lakes/reservoirs. The contour method uses essentially topographic mapping procedures. To apply this method, it is important to have a good contour map of the lake/pond when it is dry (Pemberton and Blanton, 1980). Range line method usually requires less field work and is less expensive than the contour method. In this method, number of cross sections, called ranges, are selected to survey the lake/pond. The most important is measurement of bed elevation at many known locations in the pond/lake. These measurements are almost always made by measuring the water depth beneath a boat and the exact location of the boat on the pond's surface. So, two basic types of measurements are required, (i) location measurements/Sounding tracks (ii) depth measurements.

#### 8.2.1 Location Measurement

The basic measurement required for a lake/pond survey is the location of the cross sections (range line) and points of depth measurement. It requires a base map of the pond with locations of cross section points around the pond. The location points around the pond are helpful in positioning the cross sections on a map for the bathymetric survey. To get the base map of a pond along with the location of cross section points, survey of the pond surface area is to be carried out.

In the present study, range-line method has been used to conduct the bathymetric survey of the Badhori pond. During the present survey, thirty points were identified on the map along the pond boundary. These points were used to locate 10 cross sections covering the entire pond along which survey was carried out at 147 points (Figure 4). For positioning the range-line and boat, a nylon rope was used to define the cross section lines. Marking on the rope at every 6.25m interval was made using different colour tags. Mapping of the pond surface area was carried out on a scale of 1:300, using the plane table surveying method. After completion of the plane table survey, surface area of the pond was determined using digital planimeter and a GIS (ILWIS) software.

#### 8.2.2 Depth and Volume Measurement

The simplest way of measuring the water depth is to use a sounding weight or a pole to obtain it directly. The other method is use of sonic sounding equipment. To measure the depth of Badhori pond, a sounding weight was used. A sounding weight

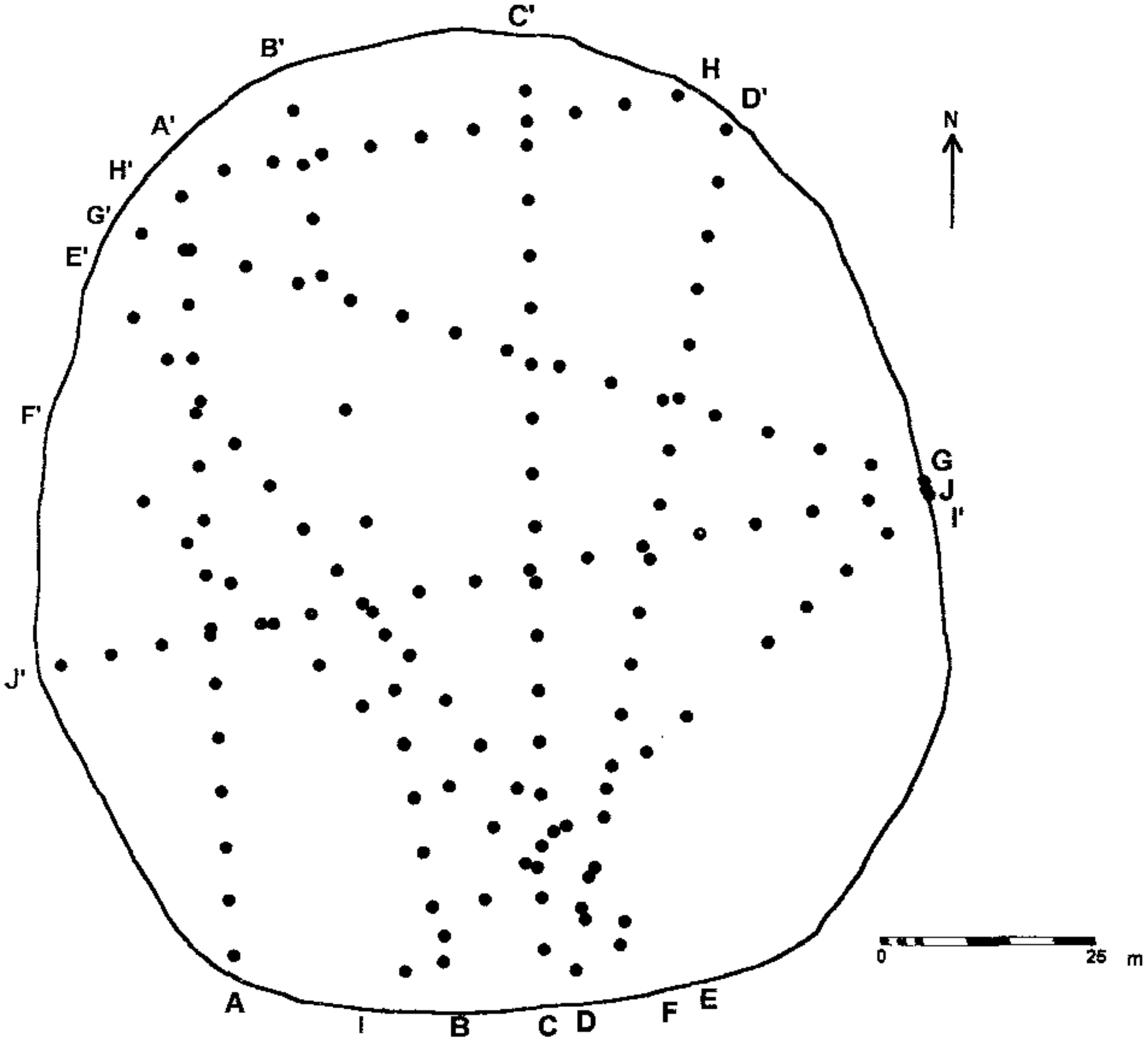



Fig. 4 : Cross Section along which bathymeric survey conducted in the pond

of mild steel angles, approximately of 10kg weight, was fabricated. The sounding weight was tied with a rope on which a measuring tape of 20m length was pasted with the help of adhesive tape.

The datum base level of soundings is the present overflow outlet near Banyan tree on the roadside. In the present study, depth measured by manual sounder is used to prepare the contour map of the Badhori pond and to determine morphometric parameters of the pond.

Volume of the lake/pond may be determined by plotting the depth area map and the area under the curve obtained may be planimetered or otherwise measured. In another method, the area enclosed by successive pairs of depth contours are averaged and multiplied by the contour interval to yield a series of volume elements which are summed (Zumberge and Ayers, 1964):

$$V_{A1A2} = \frac{h}{3}(A_1 + A_2 + \sqrt{A_1 A_2})$$

Where, $V_{A1A2}$ is volume between two adjacent depth contours, h distance apart, $A_1$ is the area enclosed by the upper and $A_2$ is area enclosed by the lower. Summation of the results of repeated successive use of the above equation will yield lake/pond volume.

**8.3 Morphometric Characteristics of the Pond**

The pond selected for this study is the "Badhori Talab", which according to the local estimates, is of 38.3m radius, 2.4m depth, and has a perimeter of 241m (Badhori Project Report).

Surface area of the pond, surveyed in the present study using the plane table method, and computed using a GIS (ILWIS) software, was found to be 8705 $m^2$. Pond is sub rounded to rounded in shape with the diameter of about 110m. Maximum depth of the pond is 5.50m. Perimeter of the outer boundary of the pond is 354m. Total catchment area of the pond is 0.11$km^2$.

The area enclosed by the successive isobaths has been determined using the GIS ILWIS software (Figure 5). The maximum area of the 0-depth contour is 2239$m^2$ and the minimum area of the 2m-depth contour is 705$m^2$. Hypsomorphic graphs show that 26% of total pond area is lying between 0 to 1m depth and 38% area between 4 to 5m and remaining 36% under different depth groups (Figure 6).

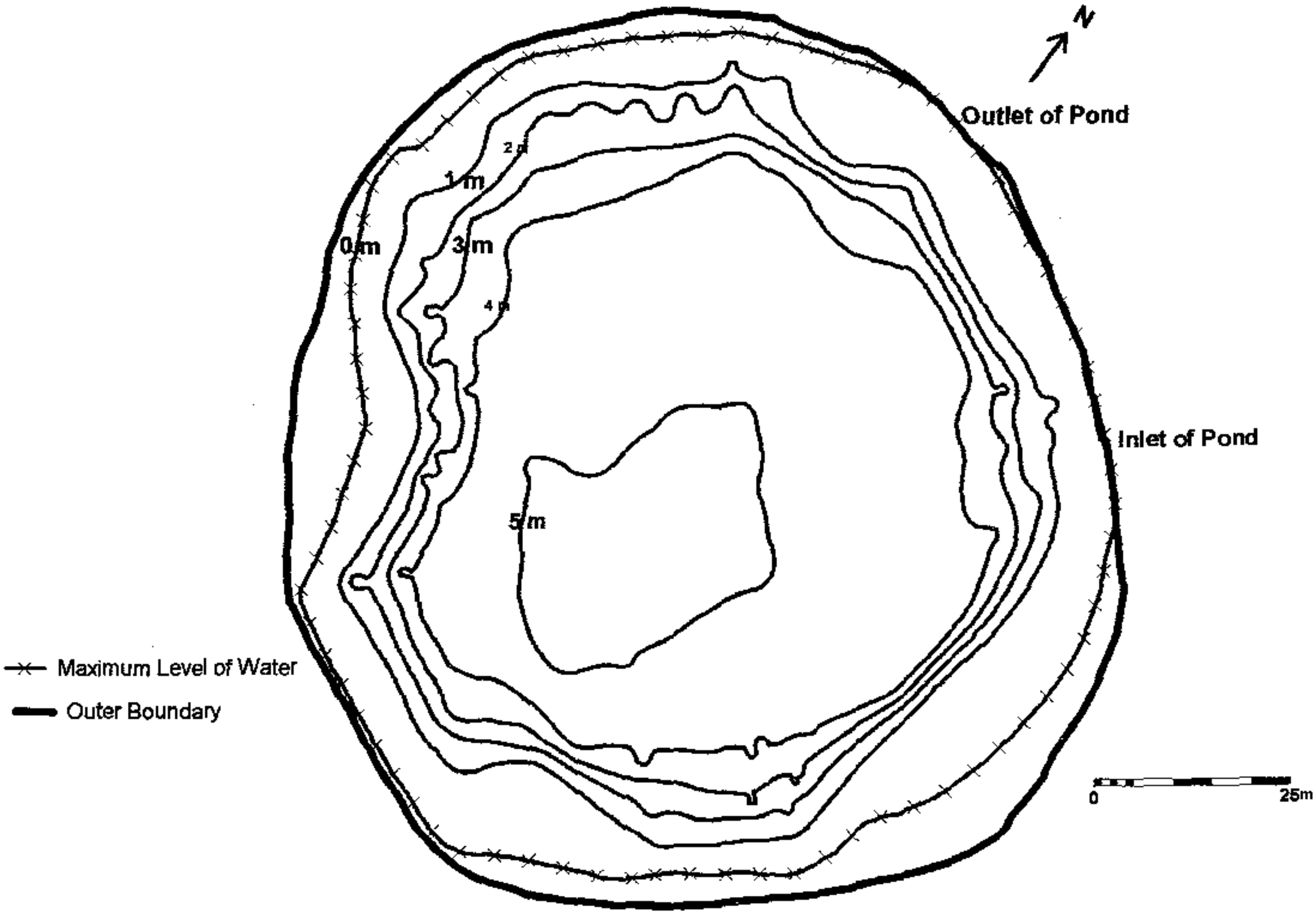



**Fig. 5: Contour map of Badhori Pond**

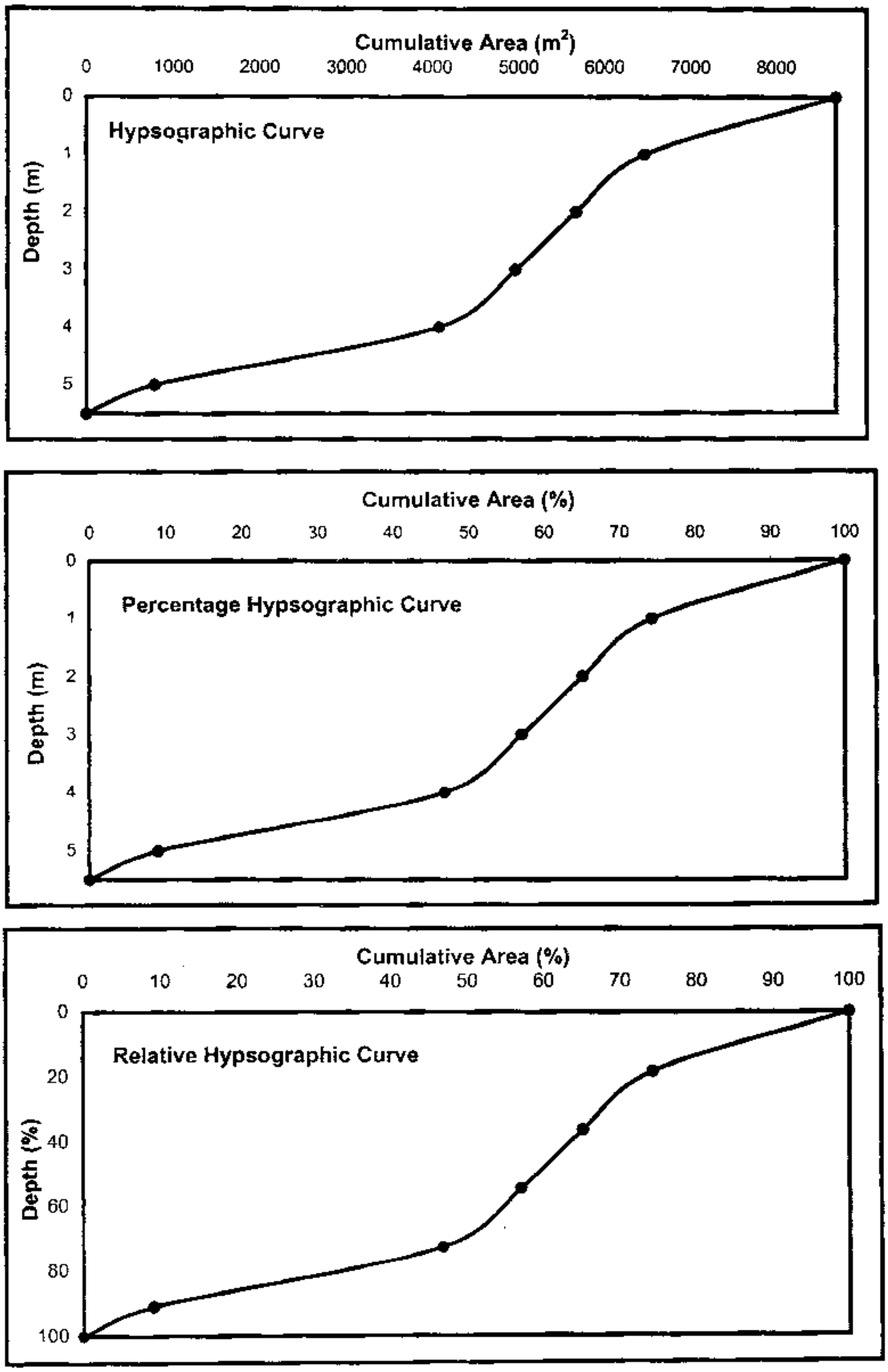



**Fig. 6: Hypsographic curve of the Badhori pond in Kandi Belt**

Slope of the pond between 0 to 1m depth is 0.73m/m, which covers 26% area of the total pond. It is maximum (2.1m/m) between 2 to 3m-depth contour interval and minimum (0.28m/m) between 4 to 5m depth (Figure 7).

Maximum capacity (volume) of the pond is 25799m$^3$, of which maximum 29% is between 0 to 1m depth, 24% lying between 1 to 2m and 21% between 2 to 3m depth. Thus, 74% of the total pond volume is up to 3m depth and remaining 26% below the 3m (Figure 8).

### 8.4 Water Balance Components

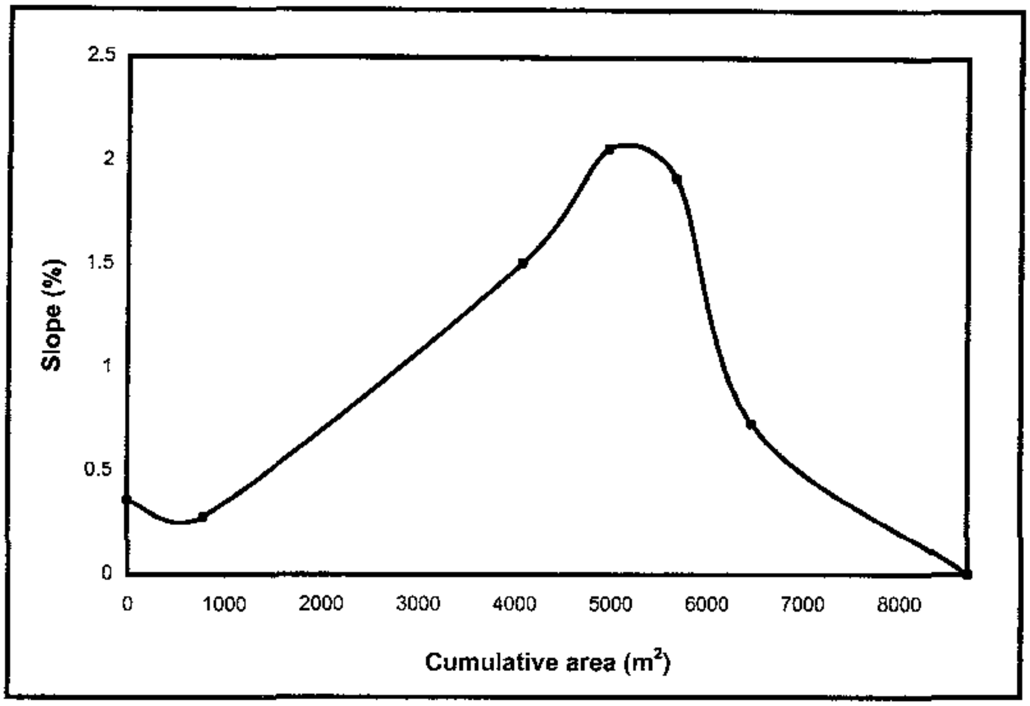
#### 8.4.1 Water Level Fluctuations

In this study, water level of the pond was measured daily using a graduated staff gauge (to a precision of 0.1 cm), during the months of May and June, 2001. The daily precipitation and evaporation data for the same period was taken from nearby stations (namely, WHRC-NIH, Satwari and Water Management Research Center, Sher-e-Kashmir University of Agricultural Sciences & Technology, Jammu).

Table 11. Water Levels in Badhori pond during May-June, 2001

| S No | Date | Water Level (cm) | Daily Change (mm) | Rain (mm) | Pan Evap. (mm) |
|---|---|---|---|---|---|
| | May 14 | 165.1 | | 1.2 | 7.4 |
| | May 15 | 164.5 | -6.0 | | 6.7 |
| | May 16 | 163.8 | -7.0 | | 7.0 |
| | May 17 | 163.2 | -6.0 | | 5.1 |
| | May 18 | 162.6 | -6.0 | | 6.0 |
| | May 19 | 161:3 | -13.0 | | 8.0 |
| | May 20 | 160.7 | -6.0 | 28.0 | 4.2 |
| | May 21 | 177.8 | 171.0 | | 5.6 |
| | May 22 | 175.3 | -25.0 | | 7.4 |
| | May 23 | 172.7 | -26.0 | | 7.0 |
| | May 24 | 170.2 | -25.0 | | 9.8 |
| | May 25 | 167.6 | -26.0 | | 10.2 |
| | May 26 | NR | | | 7.7 |
| | May 27 | NR | | | 7.6 |
| | May 28 | 165.1 | | 2.8 | 3.3 |
| | May 29 | NR | | | 4.8 |
| | May 30 | 164.5 | | | 7.0 |
| | May 31 | 163.8 | -7.0 | | 6.5 |
| | June 01 | 162.6 | -12.0 | | 8.4 |
| | June 02 | 164.5 | 19.0 | 50.4 | 4.8 |
| | June 03 | 177.8 | 133.0 | 1.2 | 4.2 |
| | June 04 | 177,2 | -6.0 | | 4.7 |
| | June 05 | 176.5 | -7.0 | | 5.6 |
| | June 06 | 175.9 | -6.0 | | 6.5 |
| | June 07 | 172.7 | -32.0 | 21.4 | 6.7 |

NR- Not recorded



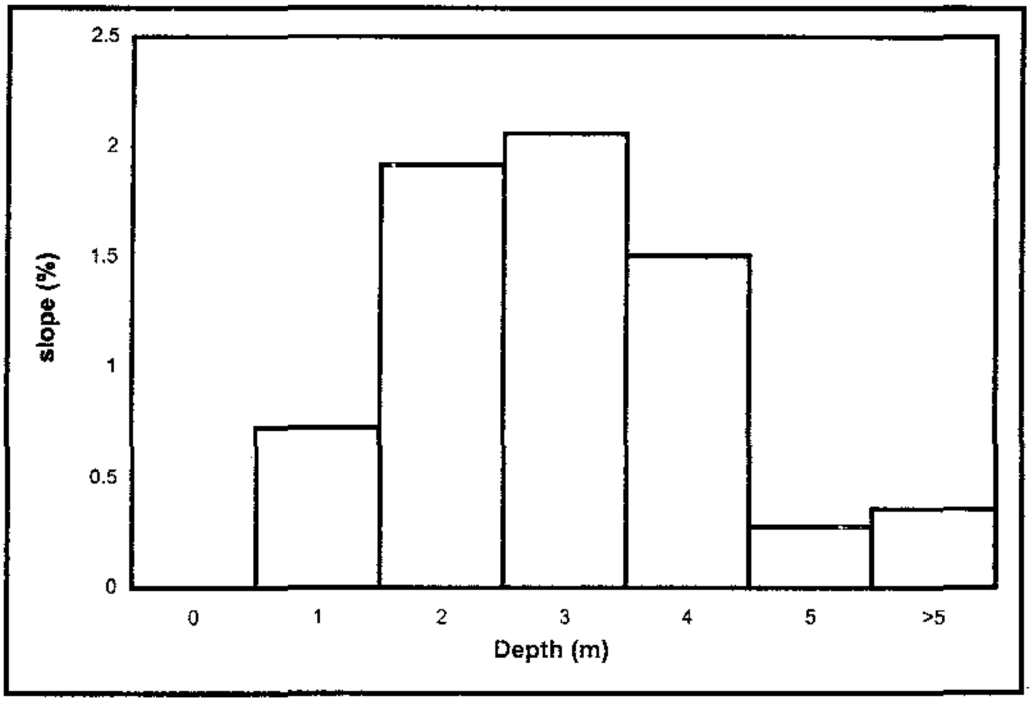




**Fig. 7: Variation of slope with area and depth in the Badhori pond**

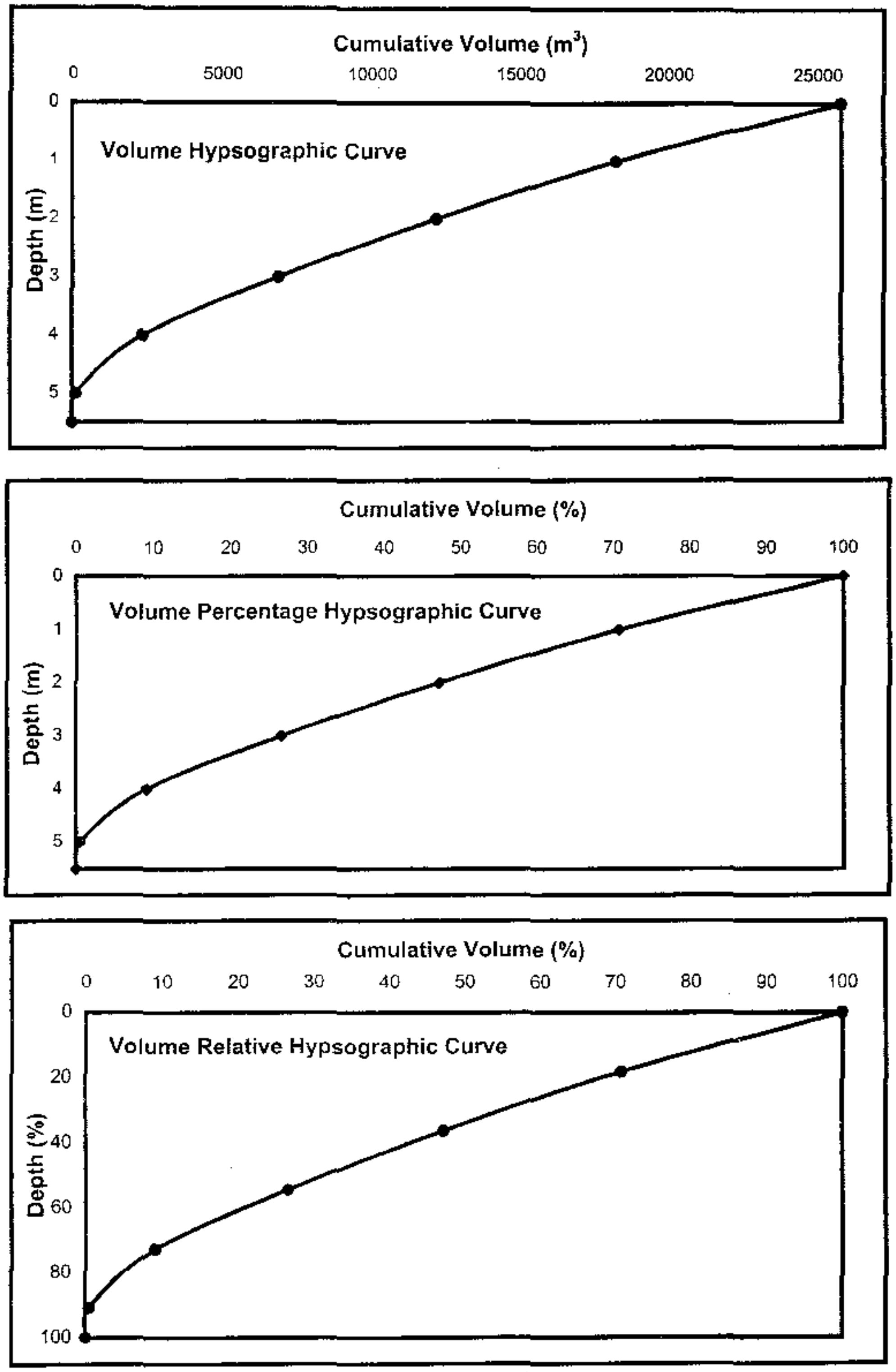



**Fig. 8: Graphs showing variation in lake volume with depth**

### 8.4.2 Rainfall

The mean annual rainfall is about 1275mm, about 65% of which occurs during July to September. Winter rainfall is received during mid-December to end of February.

Weekly rainfall at different probabilities shows large variation (Figure 9). At 50% probability, weekly rainfall of 10mm or more is expected during 28th to 39th standard weeks (i.e., July 9-15 and September 24-30, respectively). Similarly, at 30% probability, weekly rainfall of 10mm or more is expected during 2nd to 14th weeks (i.e., January 8-14 and April 2-8, respectively) in winter rains, and during 24th to 39th weeks (i.e., June 11-17 and September 24-30, respectively) in the monsoon. At 70% probability, weekly rainfall of 10mm or more is expected during 28th to 35th weeks. Total annual rainfall at 30%, 50% and 70% probability amounts to 1222mm, 575mm and 280mm, respectively (IMD, 1995).

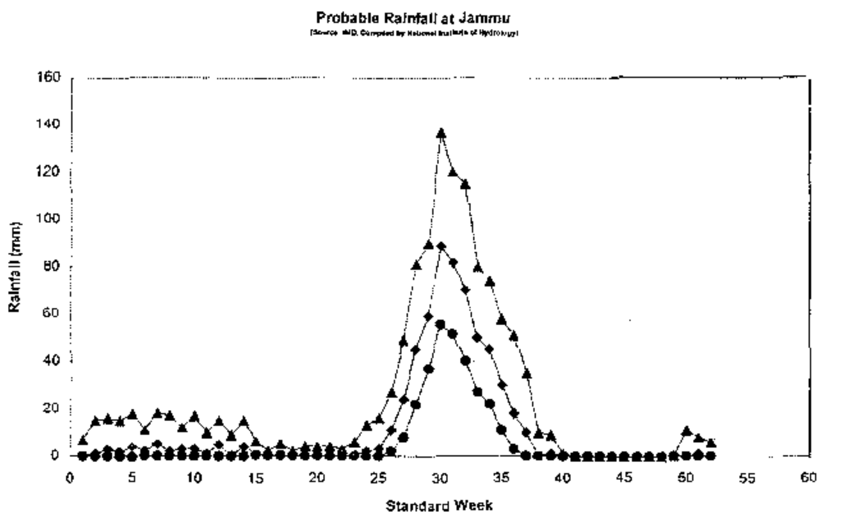



Figure 9. Weekly rainfall distribution at different probabilities

### 8.4.3 Runoff

Two seasonal *khads* pass through the study area (figure 3). The catchment area for this pond has been identified from a 1:25,000 scale SOI toposheet (No. 43L/14/5), and it worked out to be 109830m$^2$ (10.98ha). The average annual water yield from this catchment is computed from the equation:

$$Q = \frac{A * P * R}{1000} \text{ ha-m}$$

Where, A is watershed area in ha, P is average monsoon rainfall in mm, and R is the runoff coefficient in percent.

According to the recommended norms for selecting runoff coefficient for water yield computations in the Siwalik region, for small watersheds with medium soils and high slopes, a runoff coefficient of 75% can be used (Samra et al., 1996). The average annual runoff from the catchment area then works out to be 7.0ha-m which, when converted in depth units, becomes 638mm.

### 8.4.4 Evaporation

Daily/weekly long-term pan evaporation data is considered in evaluating the evaporation losses, and a pan coefficient of 0.7 is used in computing the potential evapotranspiration (PET) values. 80% of PET values were used as pond evaporation.

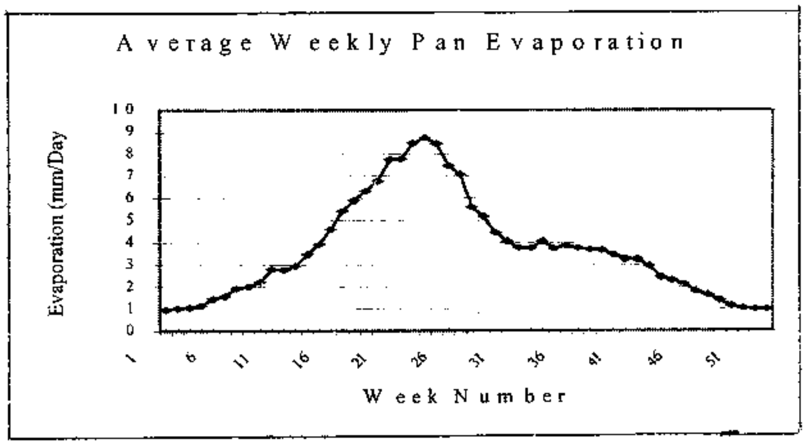



Figure 10. Weekly pan evaporation distribution

### 8.4.5 Water Balance Computations

A total of 844mm (7345m$^3$) of rainwater is collected annually in the pond from the 11ha catchment area. The ability of rainwater harvesting scheme to service the village needs is estimated as follows. It was estimated that available catchment area was 109830m$^2$ and runoff coefficient in the area was 75%, for potential storage in the 25,800m$^3$ pond (rainfall of less than 10mm/week was not considered to contribute to the runoff). In the present analysis, no account has been taken of the seepage losses from the pond.

Water available in the pond in a given month (i) is computed as follows:

Water in pond ($WP_i$) = Water input ($WI_i$) + $WP_{i-1}$

Where WI is the sum of the rain falling on the pond surface and the runoff from the pond's catchment, subject to the condition that $0 \leq WP_i \leq$ pond volume (i.e. there is no overflow).

Table 12. Water balance computations for the Badhori pond

| Month | Average Rainfall, P (mm) | Total Runoff, R (mm) | Evaporation losses, E (mm) | Quantity of Water Entering the Pond, WI (mm) | Cumulative WI (mm) | Quantity of Water in the Pond, WP ($m^3$) |
|---|---|---|---|---|---|---|
| Jan | 63 | 31.5 | 26 | 68.5 | 68.5 | 596.2 |
| Feb | 76 | 38 | 41 | 72.8 | 141.3 | 1229.7 |
| Mar | 82 | 41 | 74 | 49 | 190.3 | 1656.2 |
| Apr | 43 | 21.5 | 119 | -54.6 | 135.7 | 1181.0 |
| May | 28 | 14 | 176 | -135.5 | 0.2 | 1.74 |
| Jun | 82 | 41 | 193 | -70.3 | -70.1 | -610.1 |
| Jul | 389 | 194.5 | 120 | 464 | 393.9 | 3428.1 |
| Aug | 325 | 162.5 | 95 | 392.5 | 786.4 | 6844.0 |
| Sep | 116 | 58 | 87 | 86.8 | 873.2 | 7599.5 |
| Oct | 24 | 12 | 70 | -34.3 | 838.9 | 7301.0 |
| Nov | 16 | 8 | 42 | -17.5 | 821.4 | 7148.6 |
| Dec | 32 | 16 | 25 | 22.6 | 844.0 | 7345.3 |
| Annual | 1276 | 638 | 1068 | 844 | | |

**8.5 Summary**

Average annual rainfall in the study area is 1276mm, of which about 65% (830mm) falls during the monsoon period. The net contribution to the pond is negative during the months of April to June as a result of high evaporation losses in these months; negative net contribution in the months of October and November is due to low rainfall input. High rainfall compensates the high evaporation losses during the months of July and August. It is clear from the table that the pond water is practically not available during the months of May and June.

Although the capacity of the pond is quite large, the present analysis shows that only about one-third capacity is being utilised under the prevailing climatic and soil conditions. If through suitable measures, evaporation and other losses can be reduced, more water will be available for local consumption. The available capacity of the pond water can be successfully used locally for cattle and horticultural purposes.

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# Hydrological Aspects of Rainwater Harvesting in the Kandi Belt of Jammu Region


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