

Hydrological Characterization of Benchmark Agricultural Watersheds in India, Thailand, and Vietnam

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Executive Summary

Water is one of the most critical resource and constraint in the semi-arid tropics (SAT). To minimize land degradation and sustain crop productivity in the SAT, management and efficient utilization of rainwater is important. Watershed-based resource utilization involves the optimum use of the area's precipitation for the improvement and stabilization of agriculture on the watershed through better water, soil, and crop management. More effective utilization of water for the production of crops can be facilitated by one or more of the following means: (i) in situ conservation of moisture; (ii) proper drainage, collection, storage, and re-utilization of runoff; and (iii) groundwater recovery from wells. For the proper development, conservation, and management of land and water resources, accurate information on surface and groundwater hydrology is crucial. Under the Asian Development Bank (ADB)-supported project on integrated watershed management we studied the hydrological behavior of benchmark agricultural watersheds in India, Thailand, and Vietnam. From the five benchmark watersheds, the information on topography, rainfall, runoff, groundwater, and other relevant data were collected and analyzed.

The hydrological data from the five benchmark watersheds in India, Thailand, and Vietnam clearly show the effectiveness of improved watershed technologies in reducing runoff volume and peak runoff rate. The highest runoff volume of 433 mm (51% of seasonal rainfall) was recorded from the Tad Fa watershed in Thailand, while the lowest runoff volume of 55 mm (7% of seasonal rainfall) was recorded from the Adarsha watershed in Kothapally, India. The highest peak runoff rate of $0.235 \text{ m}^3 \text{ s}^{-1} \text{ ha}^{-1}$ was recorded from the untreated watershed at Kothapally. Between the treated and untreated watersheds the maximum difference in runoff volume was recorded at Lalatora watershed in India (290 mm in untreated compared to 55 mm in treated watershed). Among the three locations in India, the highest runoff was recorded at Lalatora watershed followed by Ringnodia and Kothapally watersheds. The groundwater observations from the three sites in India, clearly show the effectiveness of the improved watershed technologies in increasing the groundwater recharge thereby improving the availability of water for agricultural and other uses. Throughout the season the groundwater levels in the treated areas were significantly higher compared to the groundwater levels in the untreated areas.

In terms of prospects of further runoff harvesting and groundwater recharge, the Tad Fa watershed in Thailand has the highest potential followed by Lalatora watershed in India. The prospects of further runoff harvesting and groundwater recharge at Ringnodia and Adarsha watersheds in India are moderate. The region-specific hydrological data reported in this publication will be useful in the planning, design, development, and management of land and water resources in the target regions.

Introduction

The improper use of natural resources and land degradation are the major constraints to the sustainable increase in agricultural production in the rainfed regions of Asia. Optimized management of natural resources is still a major factor in agriculture in the semi-arid tropics (SAT). Inadequate water-holding capacity of tropical soils and poor temporal distribution of rainfall considerably reduce the effective use of rainwater for crop production. Uncertainty in rainfall and poor socioeconomic condition of the farmers prevent them from making heavy investments in agriculture to reduce land degradation and to make best use of natural resources to realize the full agricultural potential of the environments. To save the crops from drought and to meet the water needs of the post-rainy season crop, farmers resort to groundwater exploitation resulting in recession of groundwater levels due to lack of proper groundwater recharging facilities.

Considering the above problems of natural resource management for increasing agricultural production in Asia, the Asian Development (ADB) provided technical assistance to ICRISAT under RETA # 5812. The objectives of the project are to: (1) increase the productivity and sustainability of the medium and high water-holding capacity soils in the intermediate rainfall (800–1300 mm) ecoregion; and (2) develop environment-friendly resource management practices that will conserve soil and water resources. To implement this project ICRISAT selected five benchmark watersheds – 3 in India, 1 in Thailand, and 1 in Vietnam – to introduce improved crop production and natural resource management technologies in participation with local national agricultural research systems (NARS), non-governmental organizations (NGOs), and farmers. This work has been carried out for three years (1999–2001) at these sites and promising results have been obtained on crop productivity gains as well as efficient use and conservation of natural resources, particularly the use of rainfall. This report focuses on the impact of various watershed technologies on the surface and groundwater hydrology of watersheds in different agro-environments of India, Thailand, and Vietnam. The effect of improved and traditional technologies on runoff volume, peak runoff rate, base flow, groundwater fluctuations, and other hydrological parameters are discussed in detail.

Section 1: Adarsha Watershed, Kothapally, Andhra Pradesh, India

General description

Adarsha community watershed is located at Kothapally village (longitude 78°5' to 78°8' E and latitude 17°21' to 17°24' N) in Ranga Reddy district, Andhra Pradesh, India (Fig. 1.1). It is 40 km south of ICRISAT Center, Patancheru, Andhra Pradesh and spread over 465 ha, of which 430 ha is cultivable and 35 ha is wasteland. The watershed is characterized by undulating topography with an overall slope of about 2.5%.

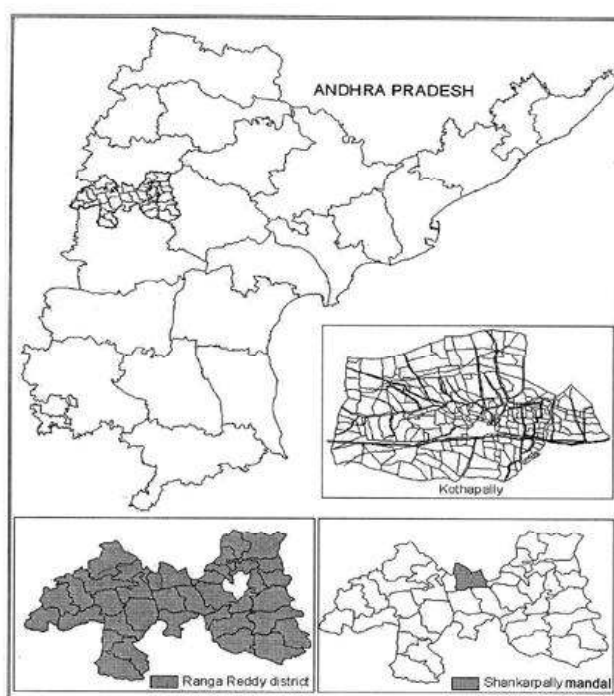


Figure 1.1. Location map of Adarsha watershed in Andhra Pradesh, India.

Soils in the watershed are predominantly Vertisols and associated Vertic soils (90%) and 10% soils are Alfisols. The soil depth ranges from 30 to 90 cm and are classified as medium to low water-holding capacity soils. Farmers diversify their cropping pattern through number of crops grown in two seasons: main rainy season (kharif) and post-rainy season (rabi). The crops grown in this area include sorghum, pigeonpea, black gram, maize, paddy, cotton, sunflower, and vegetable beans mostly under rainfed conditions, and sorghum, sunflower, and vegetables in the post-rainy season using the residual moisture and some supplementary irrigation. Turmeric, onion, and paddy are also grown in some areas using tube-well irrigation. The total population in Adarsha watershed is 1492 persons, belonging to about 270 cultivating and four non-cultivating households. The average land holding per household (for cultivating households) is about 1.72 ha and the average cultivable land per household is 1.6 ha (Shiferaw et al., in press).

Soil properties

The soil samples collected from Adarsha watershed were analyzed for texture analysis and moisture content at field capacity and wilting point (Table 1.1). The soils of medium and shallow depth were analyzed and there is significant difference in results across depths and within shallow and medium soils for coarse sand, fine sand, silt, and clay content.

The coarse sand percentage increased as soil depth increases and mean percentage of coarse sand is 30% in shallow soil (50 cm depth), and 13% in medium deep soil (90 cm depth). There is no significant difference across depths in fine sand content; it is 13% in shallow soil (50 cm depth) and 7.4% in medium deep soil (90 cm depth). Silt content also is similar across soil depth and it is 19% in shallow soil and 21% in medium deep soil. Shallow soils had 40.7% clay content whereas in medium deep soil it is 59.2% at 0–90 cm soil depth. Top 15 cm layer shallow soils contained 55.2% clay and medium depth soils contained 61.7% clay. With increasing depth up to 90 cm, clay content decreased.

At field capacity soil moisture content varied from 40 to 42% for shallow and medium deep soils. These soils are low in available phosphorus (P), zinc, boron, and sulfur content in addition to low organic carbon (C) and mineral nitrogen (N) content (Wani et al. 2001).

Table 1.1. Soil physical properties at various depths Adarsha watershed, Kothapally.

Soil	Description	0–15 ¹	15–30 ¹	30–60 ¹	60–90 ¹
Texture					
Coarse sand (%)	Shallow	13.9	22.9	41.1	43.7
	Medium	7.6	7.8	10.4	25.9
Fine sand (%)	Shallow	9.4	13.3	15.6	16.2
	Medium	5.7	5.8	6.9	11.4
Silt (%)	Shallow	21.5	17.3	18.1	19.2
	Medium	25.0	22.3	20.4	16.7
Clay (%)	Shallow	55.2	41.3	31.6	24.7
	Medium	61.7	64.4	62.3	48.2
Moisture characteristics					
Field capacity (g g ⁻¹)	Shallow	0.40	0.38	0.36	0.37
	Medium	0.42	0.44	0.45	0.42
Wilting point (g g ⁻¹)	Shallow	0.24	0.23	0.21	0.23
	Medium	0.26	0.26	0.27	0.25

1. Soil depth (cm).

Climate

An automatic weather station with a data logger was installed at Kothapally village to collect weather data such as rainfall, air and soil temperature, humidity, solar radiation, wind velocity, and wind direction. Additionally, rainfall data is collected at five other locations across the watershed to account the spatial variation in rainfall.

The mean annual rainfall at the watershed is about 800 mm received mainly in June–October (85%). The rainy season usually begins in June extends up to October; rainfed crops are grown during this

period. The postrainy winter season (October–January) is dry and cool and days are short. During this period crops can be grown in Vertisols on stored moisture in the soil profile. The hot dry summer season is from February, until rains begin in early June. The daily rainfall recorded during the past three years (1999–2001) is shown in Figure 1.2. There is a large variation in rainfall amount and distribution between years and within a season. The rainfall received in 1999 was 25% less than normal, 45% more than normal in 2000, and in 2001 it was again 23% less than normal. High intensity and large rains are common in this part of the SAT.

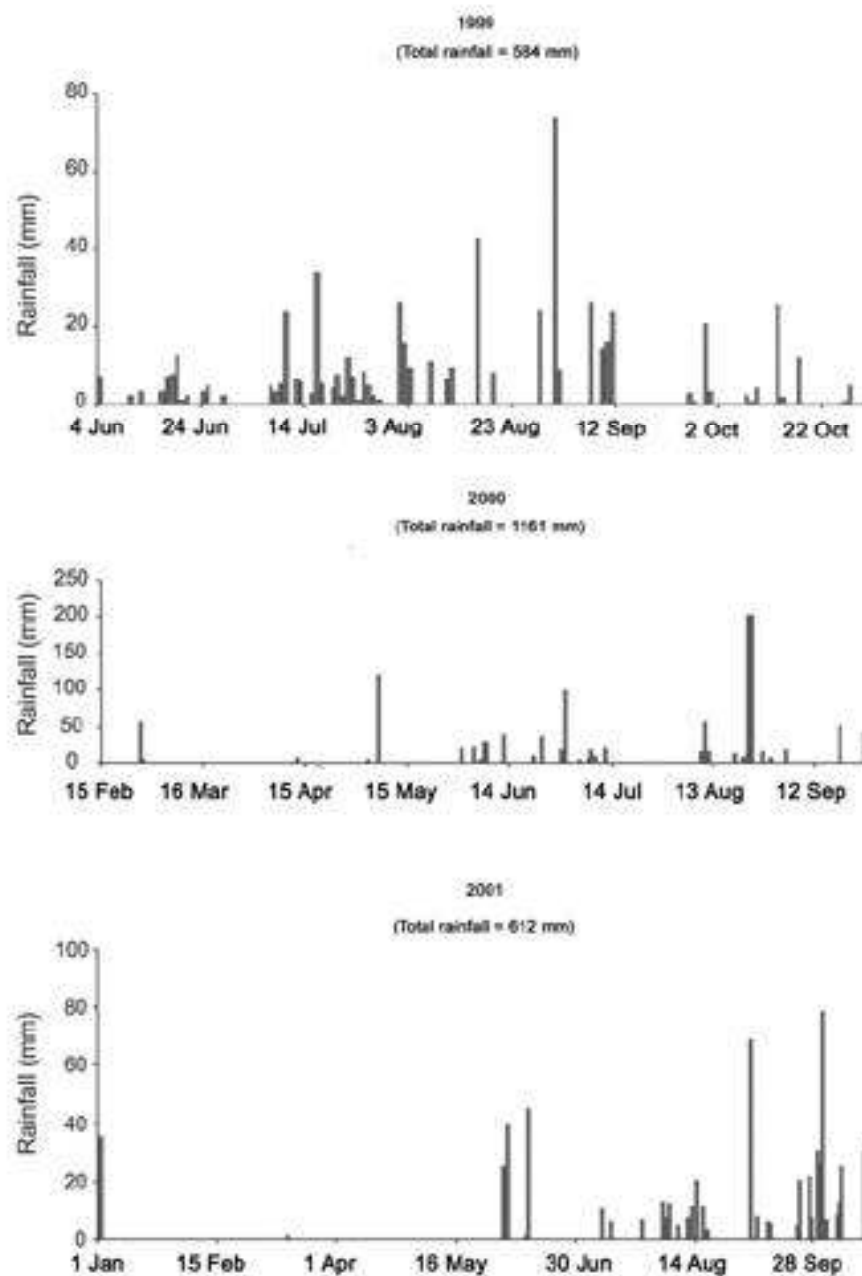


Figure 1.2. Daily rainfall at Adarsha watershed, 1999–2001.

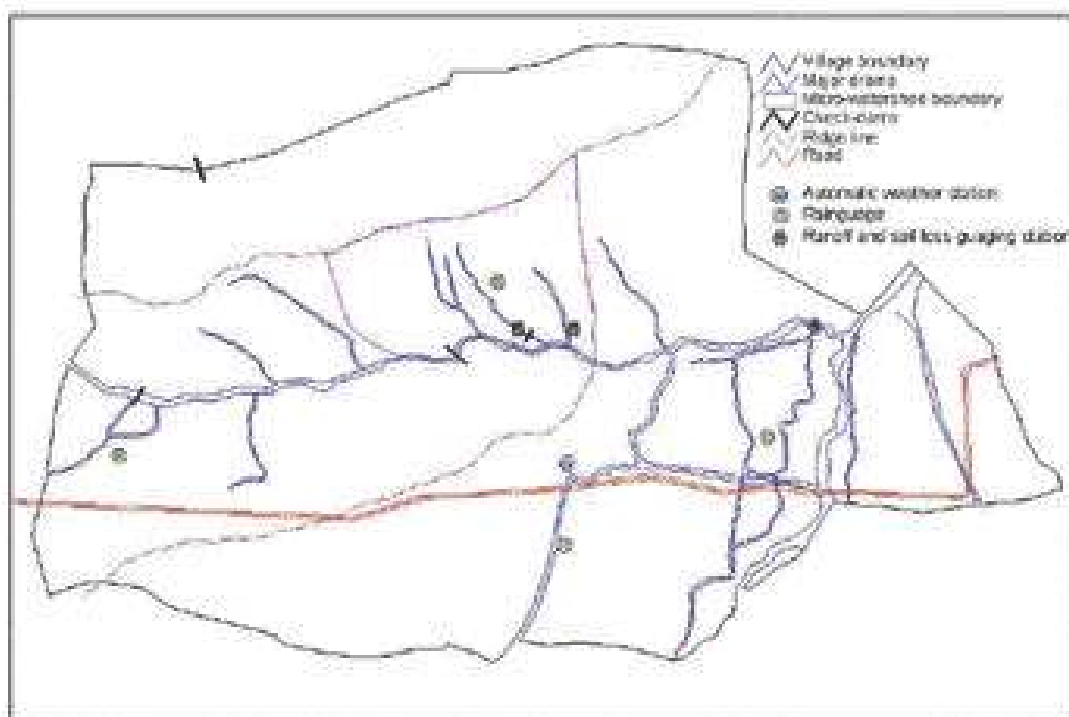


Figure 1.3. Drainage map of Adarsha watershed with rainguages and automatic weather station.

Geomorphological characteristics

The geomorphological characteristics of a watershed significantly effect the entire hydrological cycle, which includes total runoff volume, peak runoff rate, runoff duration, and other hydrological parameters. Geomorphological analysis is the systematic description of the watershed geometry and its stream channel system to measure the linear aspects of drainage network, areal aspects of drainage basin, and relief aspect of channel network (Raj Vir Singh 2000).

Using the map of Adarsha watershed (Figure 1.3), the following geomorphological characteristics were determined:

Areal aspect of watershed

1. Watershed shape

- (a) Form factor: It is the ratio of watershed area to the square of the watershed length. It gives an idea about the compactness of a watershed.

$$R_f = A/L^2$$

(where R_f = Form factor; A = Area of watershed in km^2 ; L = Watershed length in km)

$$R_f = 4.65/(3.5)^2 = 0.38$$

- (b) Area-perimeter ratio: It is the ratio of watershed area to the perimeter of the watershed.

$$R_{ap} = A/P$$

(where R_{ap} = Area-perimeter ratio; A = Area of watershed in km^2 ; P = Perimeter in km)

$$R_{ap} = 4.65/10 = 0.47$$

Linear aspect of drainage network

1. Bifurcation ratio

It represents the pronounced effect on the maximum flood discharge of the watershed. The watershed having higher bifurcation ratio (R_b) would result a lower but extended peak flow whereas low R_b produces sharp peak flow.

$$R_b = N_u / N_{u+1}$$

(where R_b = Bifurcation ratio; N_u = No. of streams of U order; N_{u+1} = No. of streams of $U+1$ order)

$$R_b = 7/3 = 2.33$$

2. Drainage density

It is the ratio of the total length of all streams of all order in the watershed to the area of watershed.

$$D_d = \Sigma L / A$$

(where D_d = Drainage density; ΣL = Total length of all streams of all order in km; A = Area of watershed in km^2)

$$D_d = 2.6/4.65 = 0.56$$

Relief aspect of drainage basin

1. Relief ratio

It is the ratio of relief (H in m) to the horizontal distance (L in m) on which relief was measured.

$$R_n = H/L$$

$$R_n = 105/3500 = 0.03$$

2. Relative relief

This form is used to measure the relief of watershed and is expressed as:

$$R_{hp} = (H/P) \times 100$$

(where R_{hp} is relative relief; H is maximum watershed relief in m; and P is watershed perimeter in m)

$$R_{hp} = (105/10000) \times 100 = 1.05$$

Surface hydrology

Two digital runoff recorders along with automatic pumping sediment samplers were installed in the watershed to monitor runoff and soil erosion from the treated and untreated areas of the watershed (Fig. 1.3). To monitor the outflow from entire Adarsha watershed, one digital runoff recorder along with sediment sampler was installed at the lowest outlet (Fig. 1.4). The treatments in the treated watershed include field bunding, gully plugging, and check-dams across the main drain along with improved soil, water, nutrient, and crop management technologies. Untreated area represents farmer's practice without any watershed development and improved technologies. There is a significant reduction in runoff from the treated area over untreated area (Table 1.2). In a high rainfall year (2000), significant reduction in runoff from treated watershed (45% less than the untreated portion) was observed. Even during sub-normal rainfall year (2001) too, significant reduction in runoff volume (29% less than the treated area) was recorded. The peak runoff rates were not very significantly different as the runoff recorder in treated sub-watershed was installed at the outlet of check-dams, which stores the runoff water behind it and discharges water only above crest level in a concentrated flow.



Figure 1.4. Hydrological monitoring of entire Adarsha watershed.

Table 1.2. Seasonal rainfall, runoff, and peak runoff rate from the sub-watersheds at Kothapally, 1999–2001¹.

Year	Rainfall (mm)	Runoff (mm)		Peak runoff rate ($\text{m}^3 \text{s}^{-1} \text{ha}^{-1}$)	
		Untreated	Treated	Untreated	Treated
1999	584	16	NR	0.013	NR
2000	1161	118	65	0.235	0.230
2001	612	31	22	0.022	0.027

1. Untreated = Control, with no development work; Treated = With improved soil, water, and crop management technologies; NR = Not recorded.

Daily runoff volumes from the treated and untreated sub-watersheds during 2000 are shown in Figure 1.5. During 2000 the first few monsoon rainfall events in June, July, and early part of August did not cause any runoff. The first runoff event was recorded on 10 August. The largest quantity of runoff was observed on August 24, which alone resulted about 70% of the total annual runoff volume. Runoff

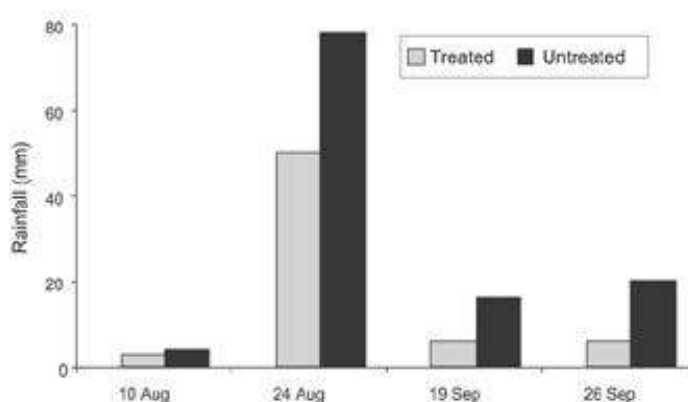


Figure 1.5. Daily runoff from the treated and untreated sub-watersheds in Adarsha watershed, 2000.

volumes from the treated sub-watershed was significantly lower during all the runoff events (small, medium, and large storms). Even for very large storms on August 24, the runoff volume from the treated sub-watershed was 40% lower than the untreated sub-watershed.

The runoff hydrographs (time vs discharge rate) from the treated and untreated sub-watersheds during 2000 and 2001 are shown in Figure 1.6. The detailed hydrological behavior of treated and

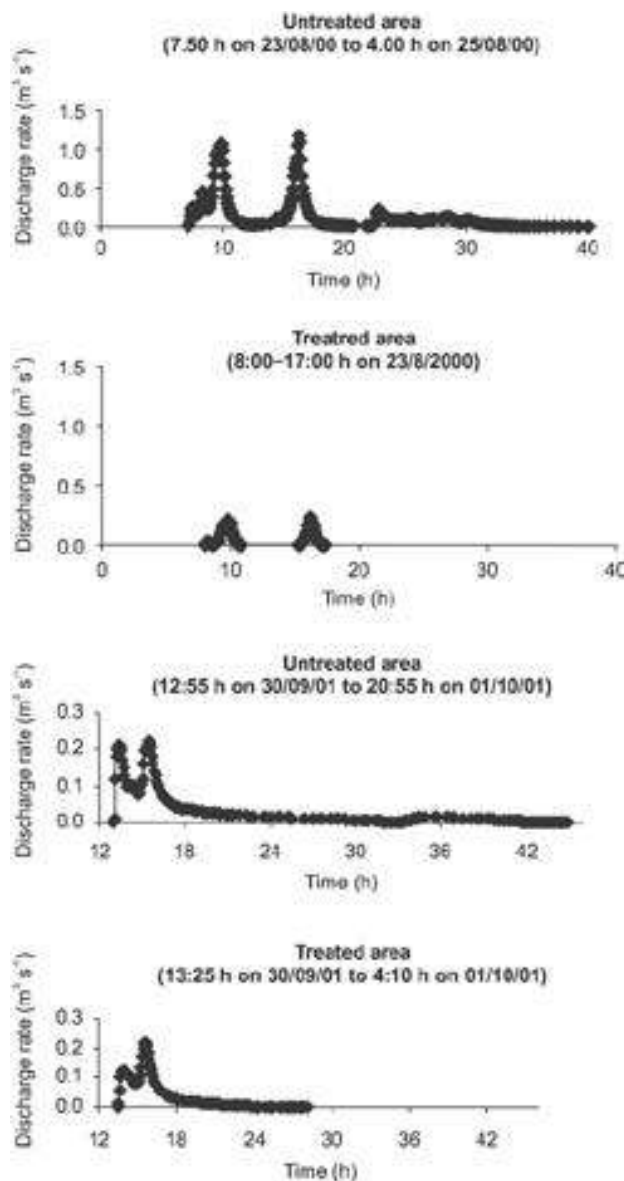


Figure 1.6. Runoff hydrographs from untreated and treated areas of Adarsha watershed, 2000–2001.

untreated sub-watersheds can be seen from these hydrographs. For the treated and untreated sub-watersheds unit hydrographs could be developed using the hydrographs shown in Figure 1.6. These unit hydrographs could become the base for future hydrological work on small watersheds.

Groundwater hydrology

There are about 62 open wells in the Adarsha watershed (Fig. 1.7). All these open wells are geo-referenced and monitored continuously for water level at fortnightly interval. In addition to open wells, there are 17 bore wells in the watershed. Most of these are located alongside the main drain (nala). Before the watershed development only 52 wells were functional with low yield at high depth and the decline in groundwater level was fast. There is significant improvement in the yield of most of these wells and another 8 wells which were completely nonfunctional also got water after the construction of check-dams and other improved soil and water conservation structures. Before the watershed project was started or implemented, water level in the wells was generally 6–12 m, and most of them were seasonal and dried up during the dry season. After the construction of check-dams and other development work, the water level and yield in the wells improved significantly particularly in those wells which are located near the check-dams (Fig. 1.8). The water level in these wells was consistently higher (around <3 m) even during below normal rainy season, whereas the water level in wells located away from the check-dams was about 6 m deep. Now the water in the wells is available even for postrainy season crops. Often runoff events during the early part of rainy season recharge the groundwater level in the wells near the check-dams. The availability of water from the well enables farmers to plant on time without reducing the growing period and also encourages them to increase the area under cultivation due to availability of additional water for irrigation.

Based on three years (1999–2001) of observations of groundwater level in the open wells, the mean annual groundwater recharge at Adarsha watershed is estimated. The average rate of groundwater outflow (outflow from the watershed + pumping of water for irrigation) during the rising part of the groundwater is estimated at 2.56 cm day^{-1} . The average groundwater outflow during the rising part of

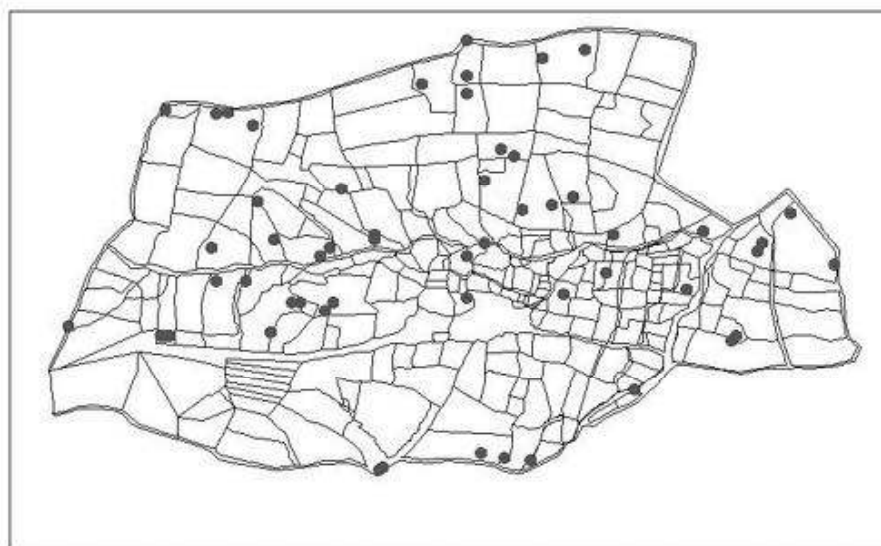


Figure 1.7. Location of open wells in Adarsha watershed.

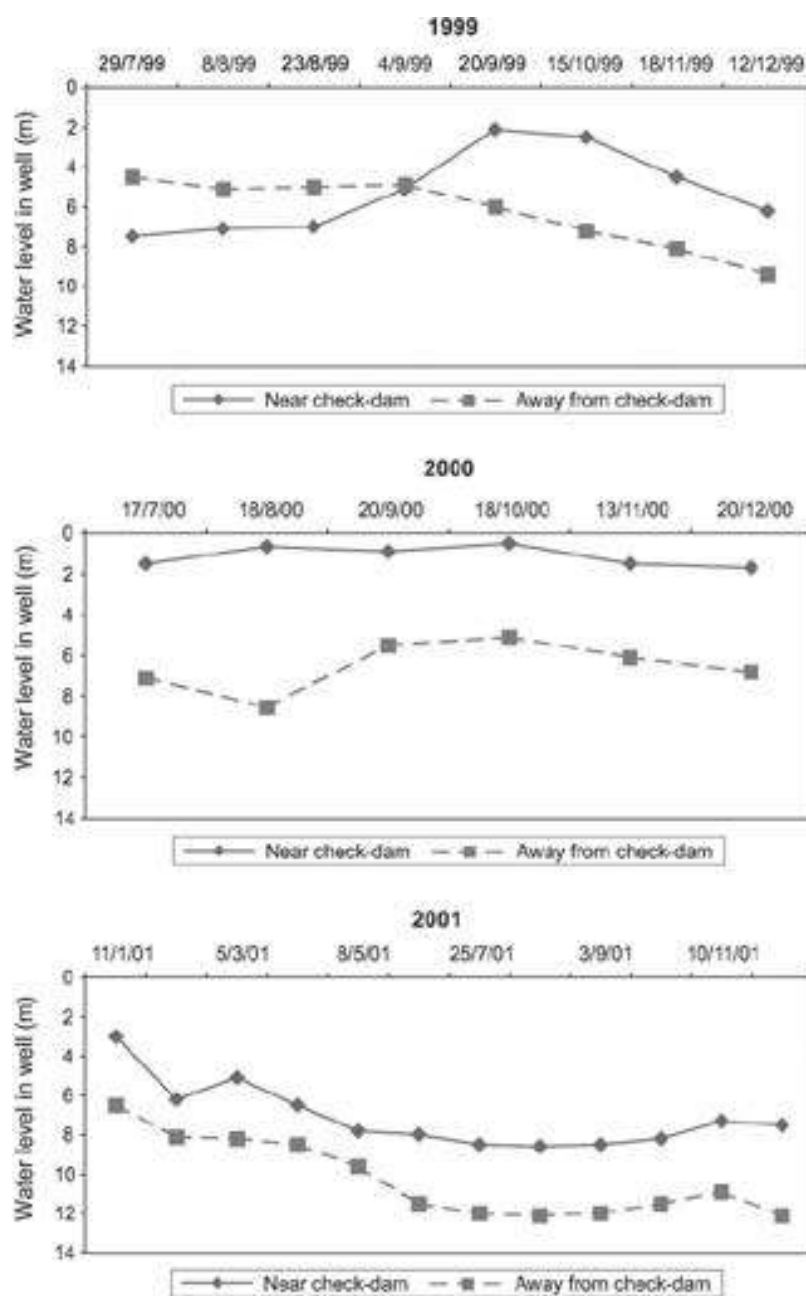


Figure 1.8. Groundwater levels in open wells at Adarsha watershed, 1999–2001.

water table is estimated at about 220 cm. The average rise of the groundwater is about 195 cm. The actual rise of the groundwater (without the outflow) should have been approximately 415 cm (220 + 195). Thus the average contribution of the seasonal rainfall to groundwater at Adarsha watershed could be estimated at 187 mm or approximately equal to 27% of seasonal rainfall (taking the specific yield of the aquifer material as 4.5%).

Simulation of runoff and soil moisture

A modified Soil Conservation Service (SCS) runoff model and a soil moisture accounting procedure (Pathak et al. 1989) was used to simulate the daily runoff and soil moisture for Adarsha watershed. In this model, important soil characteristics such as cracking and land smoothing, which have strong influence on runoff and soil moisture are represented. Therefore, it is particularly suitable for Vertisol watersheds. Using some measured hydrological data and soil physical characteristics such as moisture retention capacity and soil surface condition the model parameters were estimated. The performance of the model in predicting the runoff is shown in Figure 1.9. Using the long-term data (1986–2001) from nearby site the probability of runoff during various weeks was estimated (Fig. 1.10). The daily simulated soil moisture values at Adarsha watershed during 1999, 2000, and 2001 are shown in Figure 1.11. Considerable information on various aspects of hydrological behavior of the watershed for a 70-cm soil profile can be obtained by using this runoff model.

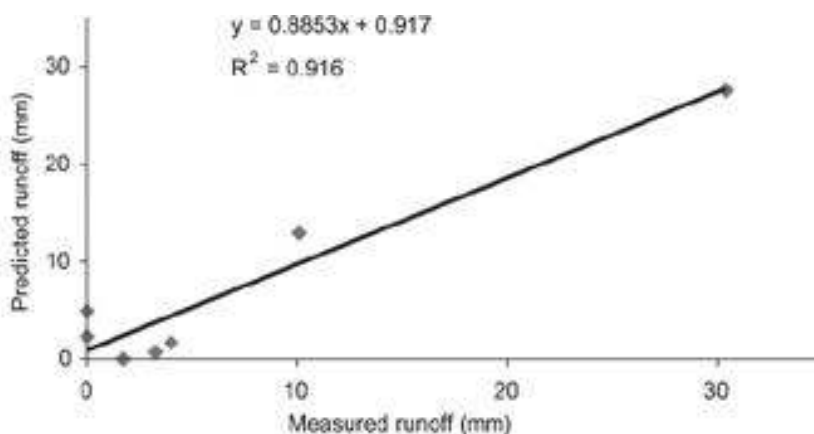


Figure 1.9. Predicted runoff vs measured runoff for Adarsha watershed, 1999–2001.

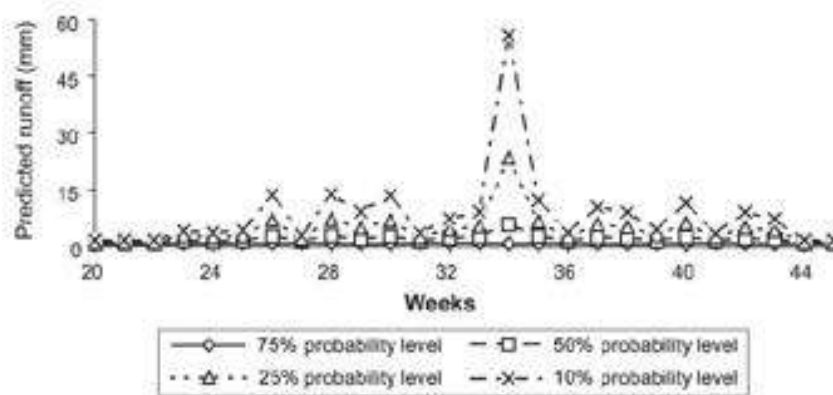


Figure 1.10. Predicted runoff at different probability levels for Adarsha watershed, 1986–2001.

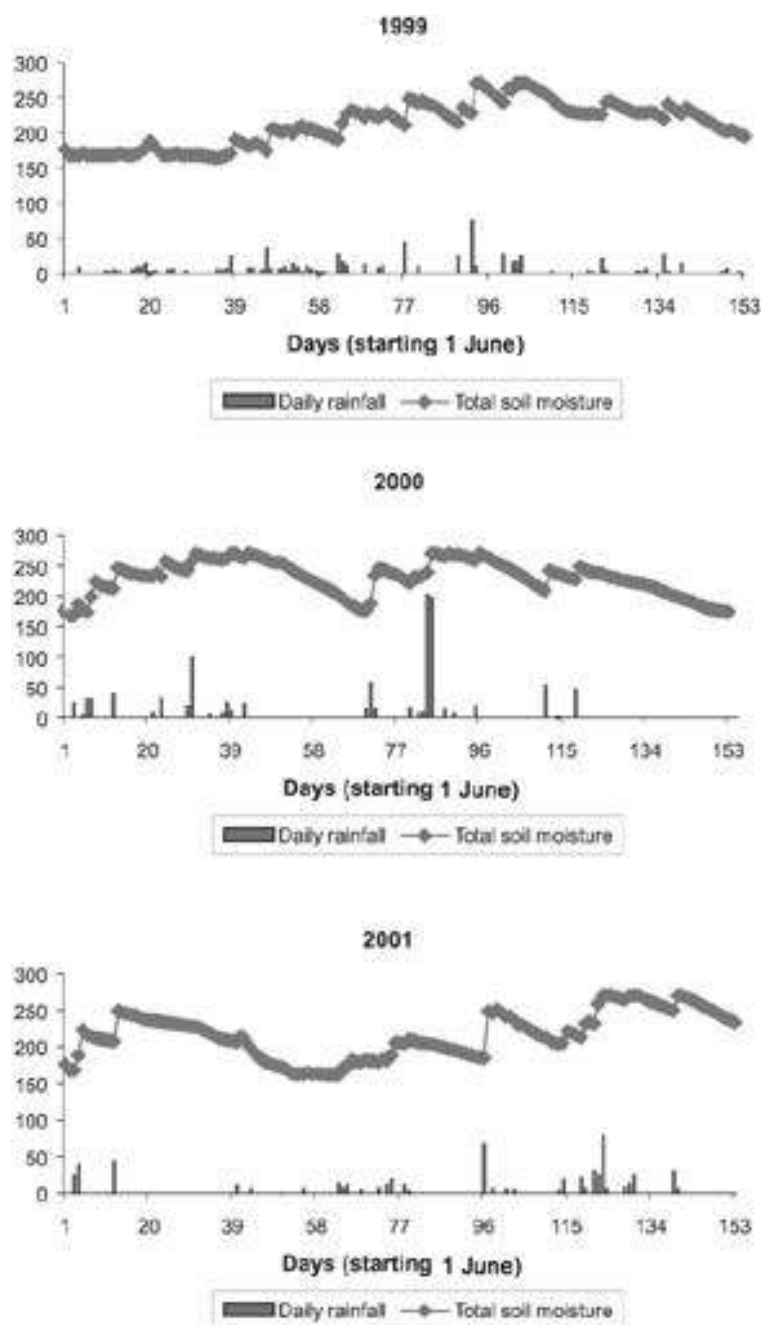


Figure 1.11. Rainfall and simulated total soil moisture for a 70-cm profile, Adarsha watershed, 1999–2001.

Summary

Adarsha watershed at Kothapally in Ranga Reddy district of Andhra Pradesh is spread over 465 ha. The mean annual rainfall in the watershed is about 800 mm. Soils in the watershed are largely (90%) Vertisols and Vertic Inceptisols with a depth of 30 to 90 cm (shallow to medium) and clay content of 41 to 59%. The physical features of the watershed include a form factor of 0.38, area-perimeter ratio

of 0.47, and drainage density of 0.56 with a relief ratio of 0.03 and relative relief of 1.05. During 1999 to 2001 hydrological measurements with annual rainfall varying from 584 to 1161 mm indicated that 5 to 10% of annual rainfall was lost as runoff. The highest peak runoff rate of $0.235 \text{ m}^3 \text{ s}^{-1} \text{ ha}^{-1}$ was recorded from the untreated watershed. The watershed under the improved technologies (improved land and water management and cropping systems) recorded 45% lower seasonal runoff compared to untreated watershed. The major impact of improved land and water management technologies was seen in improving the groundwater availability for irrigation and domestic use. On an average the groundwater level rose by 4.2 m in open wells near the check-dams compared to the open wells located far off from the check-dams.

Section 2: Lalatora Watershed, Vidisha District, Madhya Pradesh, India

General description

Lalatora watershed is located about 135 km from Bhopal in the northeastern part of Vidisha district, Madhya Pradesh, India. The watershed area is about 725 ha and is a sub-watershed of Milli watershed having total area of about 10525 ha and lying between latitude 28°8' and 24°16' N, longitude 77°30' E at an altitude of 415 m above mean sea level (Fig. 2.1).

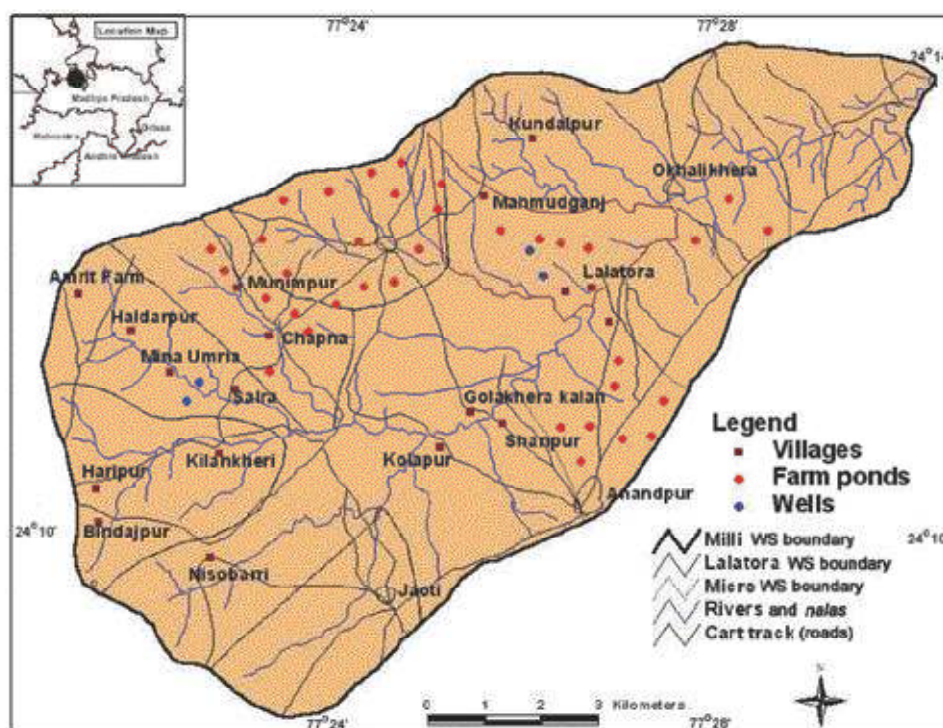


Figure 2.1. Milli watershed (WS) in Vidisha district, Madhya Pradesh, India.

Average annual rainfall in Milli watershed is about 1200 mm. The major crops grown are soybean, maize, and sorghum in the rainy season and wheat, chickpea, and lentil during the postrainy season. Some pulses, vegetables, paddy, and spices are also grown in small quantities in both the seasons. In spite of high rainfall, very large areas (more than 60%) are kept fallow during the rainy season and crops are taken only during the postrainy season on stored moisture in the soil profile (Patil et al. 2001). The households in Lalatora primarily rely on agriculture for their livelihoods. Some 97% of the households ranked agriculture as their primary occupation. The average farm size per family or household in the area is 5.04 ha. The distribution of landholding indicates that about 25% of the households had a farm size exceeding 5 ha, about 50% had less than 2 ha, while the remaining owned land between 2 and 5 ha. Farmers' landholdings include irrigated and drylands distributed across different topographic locations in the watershed (Shiferaw et al., in press).

Soil physical properties

Soil samples were collected for soil physical and chemical properties in 3 broad grids covering entire watershed up to a depth of 1.5 m. The soils are deep, clayey, black, and homogeneous. Mean clay content of top 0–15 cm is 45.4%, ranging from 32 to 52%, and increases slightly with depth, and silt content is almost similar throughout the profile (Table 2.1). Generally these soils are classified as clayey soils having poor internal drainage properties often leading to moderate/severe waterlogging. Due to high annual rainfall, cultivation practices on these soils are affected by the sticky nature and poor infiltration of the soils when wet as well as excessive hardness and difficult to work when dry. Thus, cultivation practices must coincide with the specific range of soil water contents at which the soil is trafficable and of a consistency, which allows easy preparation of the land for good soil tilth. The water retention characteristics of these soils at 0.33 bar and 15 bar were 0.30 and 0.17 g g⁻¹, respectively. The moisture retained at 15 bar increases with the increase in its clay content with depth. These soils mostly have high to medium water-holding capacity. The average field capacity of a 2-m profile is about 600 mm and the lower limit of plant-available water is 340 mm. A 2-m deep profile, therefore, can hold about 260 mm of plant-available water.

Table 2.1. Soil physical properties of Lalatora watershed.

Depth (cm)	Particle size distribution			Soil water retention capacity	
	Sand (%)	Silt (%)	Clay (%)	Field capacity (g g ⁻¹)	Wilting point (g g ⁻¹)
0–15	23.5	31.2	45.3	0.30	0.17
15–30	21.8	31.0	47.2	0.30	0.18
30–60	26.3	29.1	44.6	0.30	0.17
60–90	22.7	29.8	47.5	0.30	0.18
90–150	25.1	29.3	45.6	0.30	0.18

These soils are slightly alkaline with a pH of 8.1–8.5. Electrical conductivity of these soils is normal. Available nitrogen in the soil is greater than 500 ppm, which is in medium range whereas organic carbon and available phosphorus are low.

Climate

The climate of the area is mainly subhumid during the monsoon period. Summer is very hot, whereas winter is mild. Maximum and minimum temperatures are 31.5°C and 8.5°C, respectively. The annual rainfall is about 1200 mm of which about 90% is received during June–September. The evapotranspiration is about 1600 mm.

Daily rainfall during the last 3 years (1999–2001) recorded at Lalatora is shown in Figure 2.2. There is a large variation in amount and distribution of rainfall between years and within a season. The rainfall received in 1999 was close to normal, 25% less than normal in 2000, and in 2001 it was again 17% less than the normal. In all the 3 years very large storms were recorded. During 2000 and 2001 the rains in September and October were very small, affecting badly the rainy season crops.

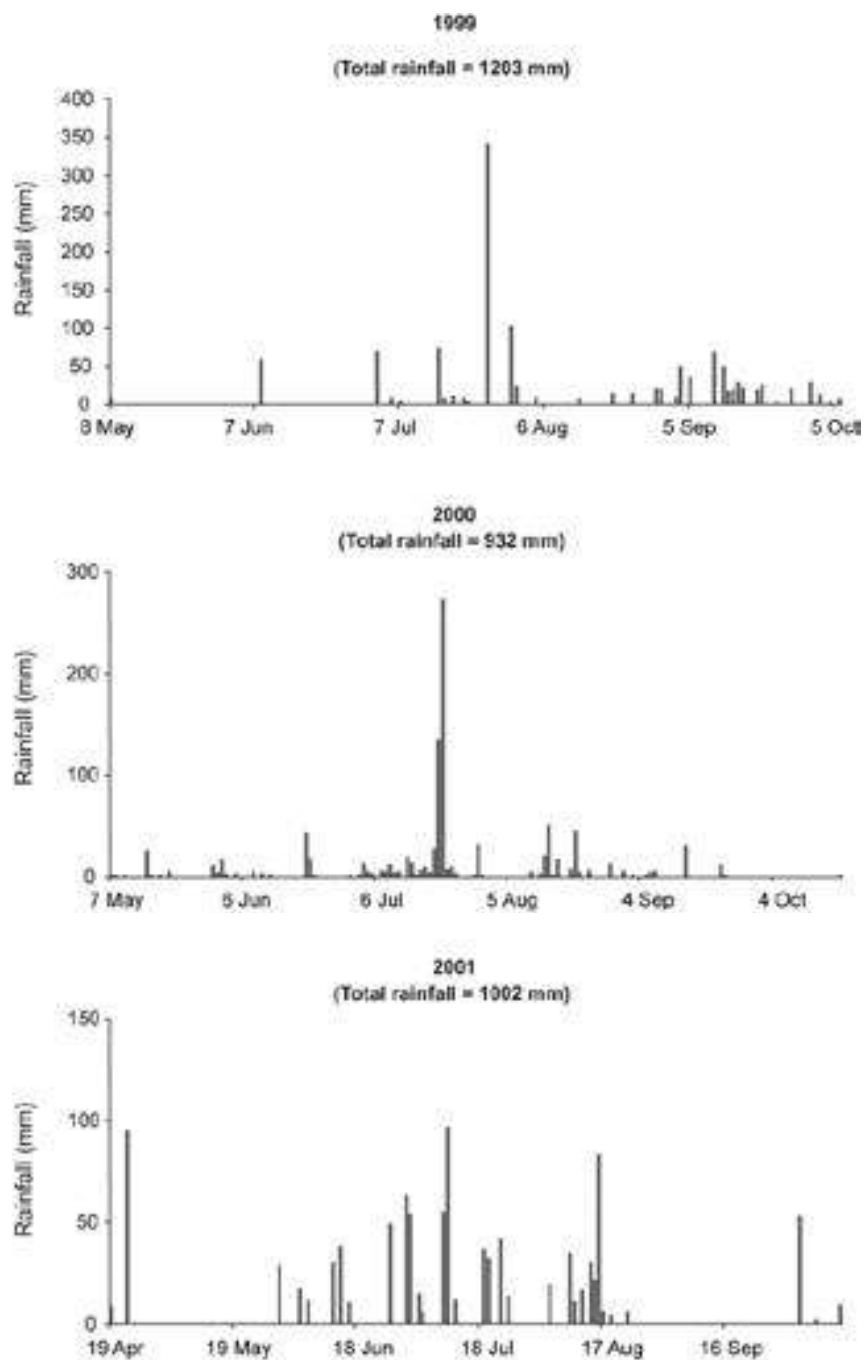


Figure 2.2. The daily rainfall at Lalatora watershed, Madhya Pradesh, 1999–2001.

Geomorphological characteristics

The Lalatora watershed map (Fig. 2.3) was used for calculations of various geomorphological characteristics of watershed.

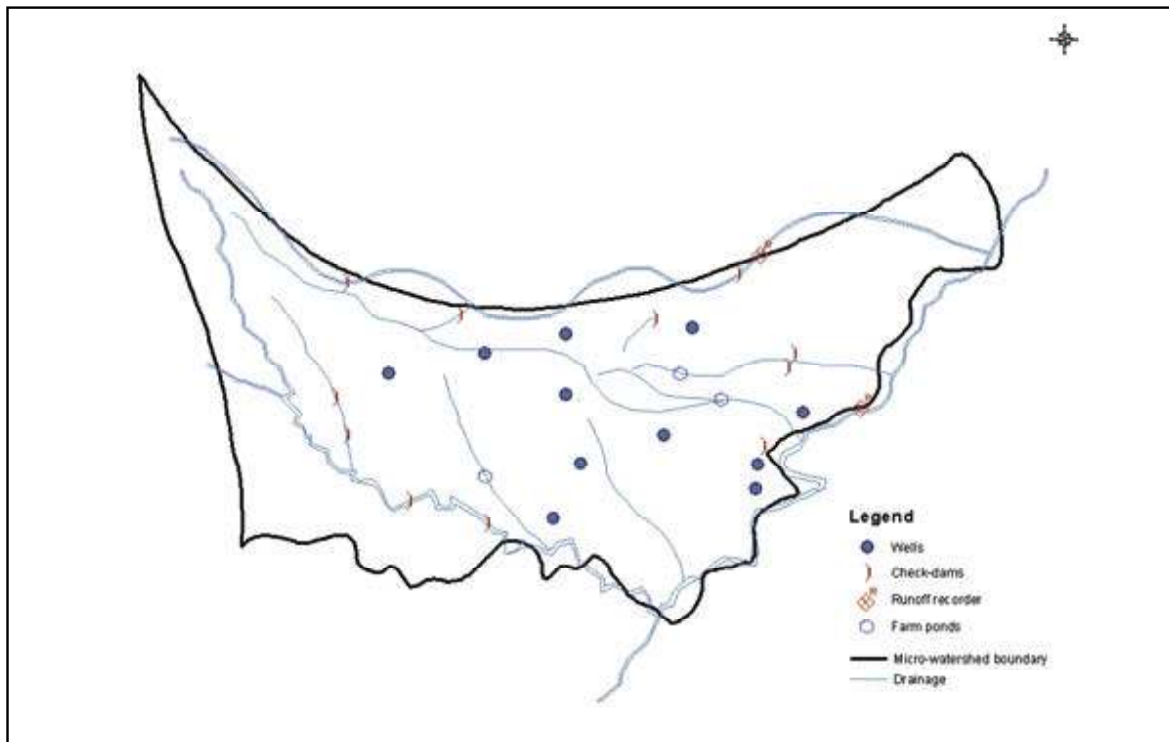


Figure 2.3. Map of Lalatora watershed with drains and other details.

Areal aspect of watershed

1. Watershed shape

(a) Form factor:

$$R_f = A/L^2$$

(where R_f = Form factor; A = Area of watershed in km^2 ; L = Watershed length in km)

$$R_f = 7.25/(4.5)^2 = 0.36$$

(b) Area-perimeter ratio:

$$R_{ap} = A/P$$

(where R_{ap} = Area-perimeter ratio; A = Area of watershed in km^2 ; P = Perimeter in km)

$$R_{ap} = 7.25/17 = 0.43$$

Linear aspect of drainage network

1. Bifurcation ratio

$$R_b = N_u / N_{u+1}$$

(where R_b = Bifurcation ratio; N_u = No. of streams of U order; N_{u+1} = No. of streams of $U+1$ order)

$$R_b = 4/2 = 2$$

2. Drainage density

$$D_d = \Sigma L / A$$

(where D_d = Drainage density; ΣL = Total length of all streams of all order in km; A = Area of watershed in km^2)

$$D_d = 2.75/7.25 = 0.38$$

Relief aspect of drainage basin

1. Relief ratio

$$R_n = H / L$$

(where H is relief in m and L is the horizontal distance on which relief was measured in m)

$$R_n = 185/4500 = 0.04$$

2. Relative relief

$$R_{hp} = (H/P) \times 100$$

(where R_{hp} is relative relief; H is maximum basin relief in m; and P is watershed perimeter in m)

$$R_{hp} = (185/17000) \times 100 = 1.09$$

Surface hydrology

Two digital runoff recorders along with automatic pumping sediment samplers were installed in the Lalatora watershed to monitor runoff and soil erosion from untreated and treated sub-watersheds. To monitor the outflow from the entire Lalatora watershed, one digital runoff recorder was installed at the major drain. The seasonal runoff and peak runoff rates from the untreated and treated sub-watersheds are shown in Table 2.2. There is a significant reduction in runoff from the treated sub-watershed compared to untreated sub-watershed. In 1999, the significant reduction in runoff from treated sub-watershed (24% less than the untreated sub-watershed) was observed. During 2001, very large reduction in runoff volume (81% less compared to untreated sub-watershed) was recorded. The difference in the runoff between the treated and untreated sub-watersheds was very large during 2001 compared to 1999. This is mainly due to the fact that starting from 1999, more areas were brought under improved technologies including check-dams and structures in the treated sub-watershed. The peak runoff rates were also significantly lower from the treated sub-watershed compared to untreated sub-watershed. During 1999, the peak runoff rate in the treated watershed was only 1/3 that of untreated watershed. During 2001, the peak runoff rate in the treated watershed was 30% lower than untreated watershed. During three years (1999–2001) the highest peak runoff rate of $0.218 \text{ m}^3 \text{ s}^{-1} \text{ ha}^{-1}$ was recorded from the untreated watershed.

During all the three years (1999–2001), few major storms contributed 50–75% of the seasonal runoff (Fig. 2.4). During 1999, one single storm on 5 September resulted more than 50% seasonal runoff from both treated and untreated sub-watersheds. Similar trend can be seen during 2000 and 2001.

The effectiveness of treated watershed in controlling runoff from small and medium storms during 2001 can be seen in Fig. 2.4. During 2001, runoff from all the small and medium storms were totally controlled in treated watershed except for one large storm on 12 July 2001. The runoff hydrographs recorded from the treated and untreated sub-watersheds are shown in Figure 2.5. Several detailed information regarding the hydrological behavior such as discharge rate, peak runoff rate, and runoff duration of these watersheds can be obtained from these hydrographs. Also, unit hydrograph for each sub-watershed can be prepared from these hydrographs and these could be used for our future runoff modeling work.

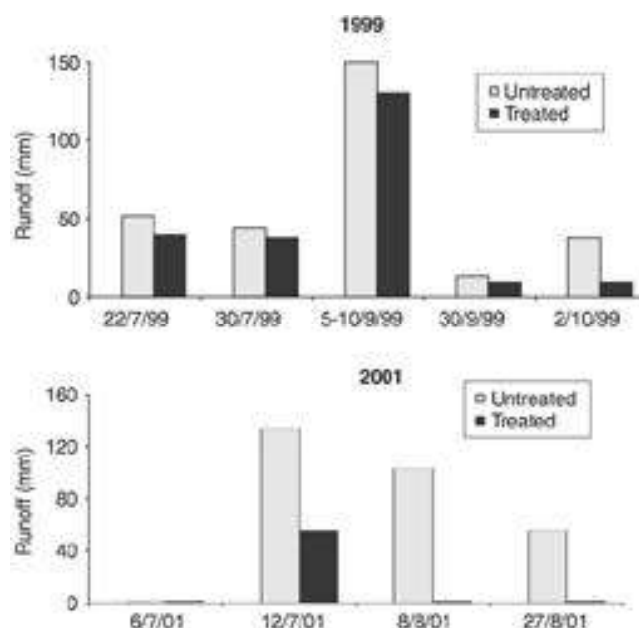


Figure 2.4. Daily runoff events from the treated and untreated sub-watersheds during 1999 and 2001 at Lalatora.

Table 2.2. Seasonal rainfall, runoff, and peak runoff rate from two sub-watersheds of Lalatora, 1999–2001.

Year	Rainfall (mm)	Runoff (mm)		Peak runoff rate ($\text{m}^3 \text{s}^{-1} \text{ha}^{-1}$)	
		Untreated ¹	Treated ²	Untreated ¹	Treated ²
1999	1203	296	224	0.218	0.065
2000	932	234	NR ³	0.019	NR ³
2001	1002	290	55	0.040	0.027

1. Large watershed with most of the areas untreated.

2. Small sub-watershed with major areas treated with improved technologies including hydrological structure.

3. NR = Not recorded.

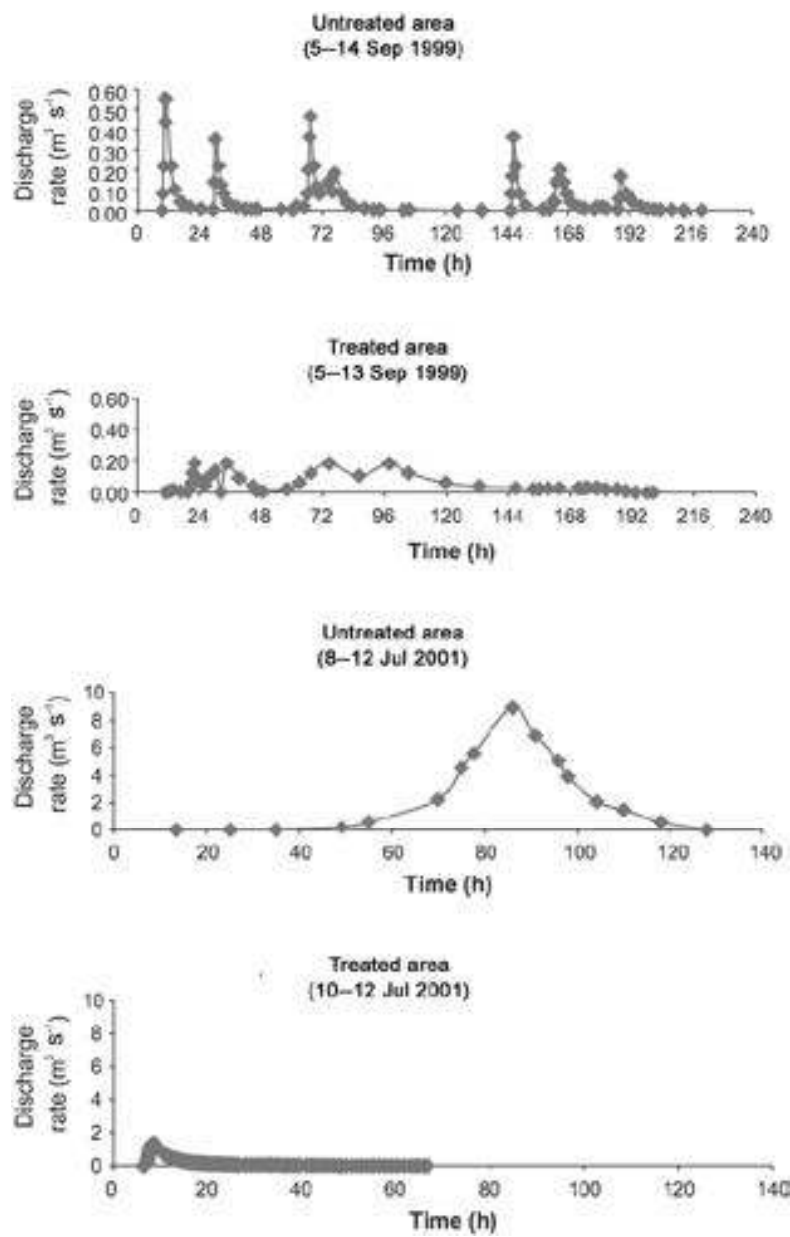


Figure 2.5. Runoff hydrographs from untreated and treated sub-watersheds at Lalatora, 1999 and 2001.

Groundwater hydrology

At Lalatora, all the 12 open wells were monitored at fortnightly interval to record the groundwater fluctuations. There are good number of tube wells around these open wells. Many of these open wells serve as recharge wells for tube wells around them. The mean water level in open wells before watershed development was about 6.5–9.5 m. The water level in open wells increased substantially in subsequent years after implementing watershed development work particularly construction of the check-dams and other water harvesting structures (Fig. 2.6). During 2000, the mean water level in the wells near check-dam was consistently around 1.5–2.0 m up to October whereas water level in the wells located away (about 1000 m) from the check-dams was about 8.5 m throughout the year. Figure 2.6 clearly shows that even during the rainy season the wells away from check-dams did not have significant increase in water level, while the water levels in the open wells near the check-dams had significant increase particularly during the rainy season.

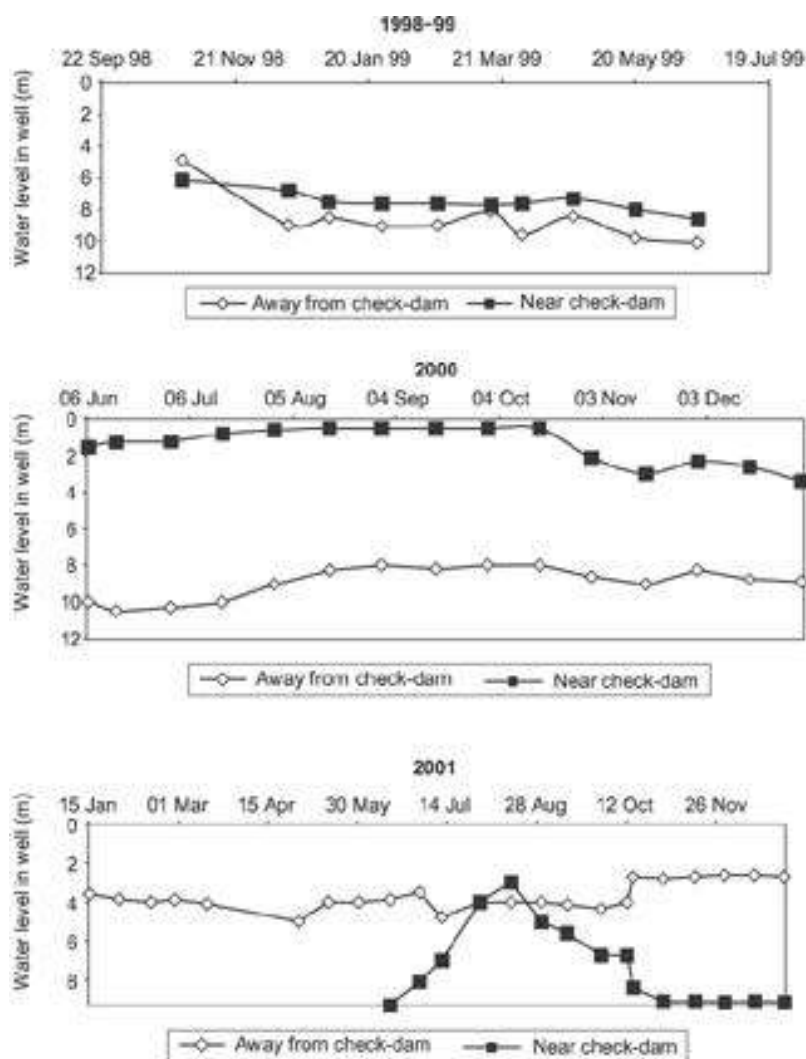


Figure 2.6. Groundwater levels in open wells at Lalatora watershed, 1999–2001.

Based on three years (1999–2001) observations of groundwater level in the open wells, the mean annual groundwater recharge at Lalatora watershed was estimated; the water levels in 1999 were used as base water levels. The average rate of groundwater outflow during the rising part of the groundwater is estimated at 1.90 cm day^{-1} . The mean total groundwater outflow during the rising part of groundwater is estimated at about 133 cm. The average rise of the groundwater level is about 456 cm. The actual rise of the groundwater (without the outflow) should have been about 589 cm ($456 + 133$). Thus the mean contribution of the seasonal rainfall to groundwater at Lalatora watershed could be estimated as 270 mm or approximately equal to 29% of seasonal rainfall (2000–2001).

Summary

Lalatora watershed is located in the northeastern part of Vidhisha district, Madhya Pradesh. The watershed area is about 725 ha with mean annual rainfall of 1200 mm. The soils in the watershed are mostly Vertisols and associated soils with poor internal drainage. The geomorphological characteristics of the watershed are a form factor of 0.36, area-perimeter ratio of 0.43, and drainage density of 0.38 with a relief ratio of 0.04 and relative relief of 1.09. During the study period of 1999–2001 the annual rainfall varied from 932 to 1203 mm with two out of three years lower than normal rainfall. Also, during the three years (1999–2001), 2 to 3 major rainfall events resulted in the major portion of seasonal runoff (50–75%). Significant reduction in runoff volume and peak runoff rate was recorded from the treated watershed compared to untreated watershed. Annual runoff in the treated watershed (140 mm) was about half compared to runoff from the untreated watershed (293 mm). During the three years (1999–2001) the highest peak runoff rate of $0.218 \text{ m}^3 \text{ s}^{-1} \text{ ha}^{-1}$ was recorded from the untreated watershed. One of the major impacts of improved watershed technologies was observed in improving the availability of groundwater for agricultural and other uses. On an average the improved land and water management technologies improved groundwater levels by 5.75 m compared to groundwater levels in untreated watershed. The average contribution of the seasonal rainfall to groundwater has been estimated at 270 mm or about 29% of the seasonal rainfall.

Section 3: Ringnodia Watershed, Indore District, Madhya Pradesh, India

General description

Ringnodia, a 390-ha watershed, is part of the National Watershed Development Program for Rainfed Areas (NWDPA), Solsinda, located at about 20 km from Indore city (22°51' N and 75°51' E) on Indore-Ujjain highway at an altitude of about 540 m from the mean sea level (Fig. 3.1). The watershed is located in the middle and lower reaches of Khan River. The topography of the Ringnodia micro-watershed can be divided into three sections: a recharge zone of 18.2 ha with a slope of 8% or more, a transition zone with a slope of 2–8%, and a cultivated area of 327 ha with a slope of 2% or less, comprising medium to deep Vertisols (Fig. 3.2) (Sharma et al. 2001).

Before the project started, very few farmers followed soil and water conservation practices and most of the runoff used to flow out of the village after eroding the valuable productive lands. The watershed had two ponds that were in dilapidated state and stored very little water due to silting and heavily breached bunds. Hence, in general, there was limited water storage from the excess rainfall during the rainy season; the land use was regardless of its capability and the farm productivity was low. Lack of water conservation and high soil erosion was a major problem in the upper reaches of the watershed, whereas waterlogging was common in the lower reaches of the watershed. A few main watercourses have developed from the several field washes that carried the runoff water towards the lower reaches, forming deep gullies. In the post-rainy season, crops were cultivated in <30% area and generally suffered from drought, especially where tube wells did not exist or dried up due to lack of enough groundwater. Soybean followed by maize are the major crops during the rainy season with <1 t ha⁻¹ yield. Wheat and chickpea are the major crops during post-rainy season. The cropping intensity in the watershed depends on the extent of cropped area in the post-rainy season, which in turn is determined by late September/October rainfall.

Landholdings are small. The Ringnodia village has a total population of 855 (466 adults and 389 children), which includes 435 males and 420 females. The village has about 40% literacy. Agriculture provides the major source of income. The landholding in the village varies from >4 ha for the large size landholders constituting about 9% of the total farmers, 2 to 4 ha from medium size landholders (26%), and <2 ha for small size landholders (65%). The large landholders have about 32% landholding under irrigation, and medium and small landholders have about 10% (Shiferaw et al. 2002). During the project (1999–2001) several soil, water, and crop management technologies were taken up in the watershed. In participatory mode several development works, viz., percolation/storage tanks, renovation of ponds, and loose and wire mesh boulder structures were implemented in the watershed. These development works had significant effect on surface and groundwater hydrology.

Soil properties

The soils of the Ringnodia micro-watershed are shallow to deep black soils. The cultivated soils are mostly clay loam in texture with medium to high moisture retention capacity (soil pH 7.5–9.3), and medium electrical conductivity (EC) (<1.00 dS m⁻¹ at 25°C for most soils). The soils in general were neutral to slightly alkaline in reaction, with low to medium in soil fertility status with respect to available nitrogen, phosphorus, and sulfur, while they were high in potassium content.



Figure 3.1. Location map of Ringnolia watershed in Madhya Pradesh, India.



Figure 3.2. A general view of Ringnolia micro-watershed from the hillock (southern) side.

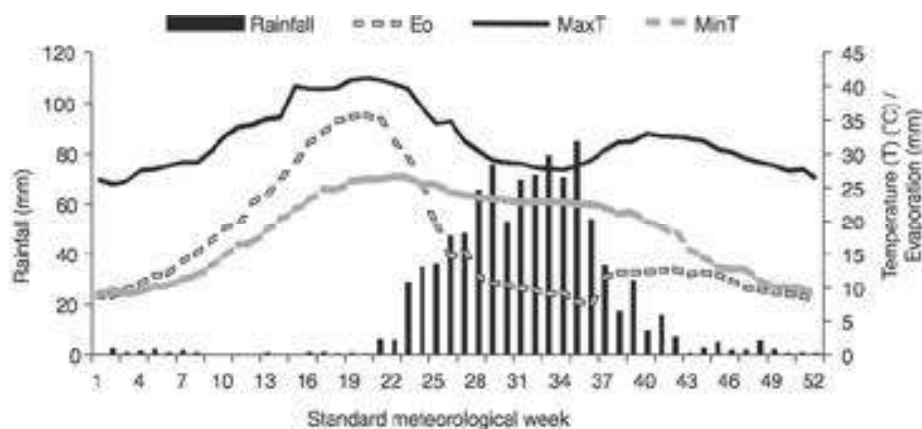


Figure 3.3. Long-term (1971–95) weather at Indore in Madhya Pradesh.

The soils of watershed are classified into six soil series: Panchdaria, Runija, Kamliakheri, Sarol, Baloda and Malikheri. The deep black soils belong to Sarol and Baloda series, which are members of fine montmorillonitic hyperthermic family of Vertic Ustochrepts and Pellusterts, respectively. The shallow soils belong to fine clayey montmorillonitic hyperthermic family of Lithic Ustochrepts (Sharma et al. 2001).

Climate

The mean annual rainfall at Indore is about 960 mm, a major portion of which is received between 15 June and 15 October (Fig. 3.3). The rate of evaporation (mm day^{-1}) increases steadily from the second week and attains a peak towards May 4th week and thereafter, shows steep decline up to July 4th week, and a gradual decline up to 15 September. The rainfall and evaporation patterns showed that the period between July end and 15 September is surplus water period. Sowing during the rainy season is usually done from 10 June (Sharma et al. 2001). The daily rainfall for 1999–2001 at Ringnodia watershed is shown in Figure 3.4.

In 1999, rainfall was near normal whereas it was 44% less in 2000 and 28% less in 2001. There were a couple of intermittent dry spells in both the seasons, which permitted intercultural operations. In 2000, the beginning of the rainy season was considerably delayed and there were very little rains after 15 August, and hence the postrainy season crops could be grown in less than 10% area. The beginning of the rainy season was at normal time in 2001. Further, about 70 mm rain in October, after the harvest of soybean, helped in sowing of the postrainy season crops. Except during 1999, major storms, which could have resulted in high runoff and soil loss were not recorded during 2000 and 2001.

Geomorphological characteristics

Ringnodia map shown in Figure 3.5 has been used for the calculations of various geomorphological characteristics of the watershed.

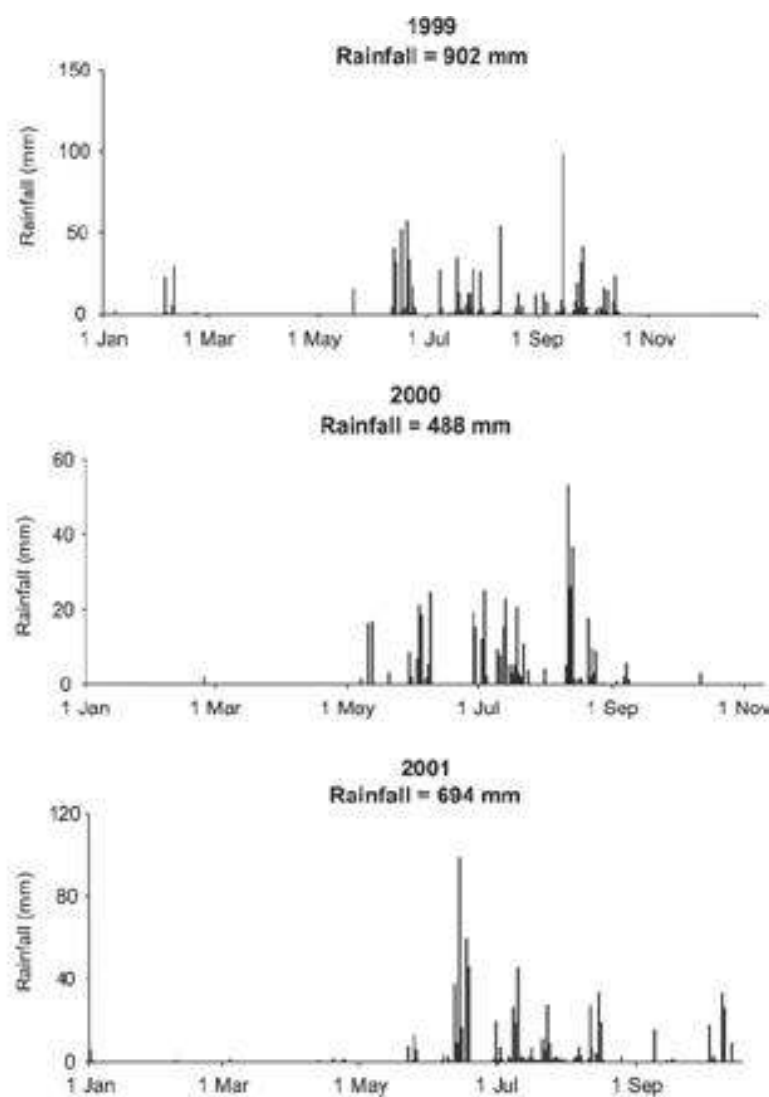


Figure 3.4. Daily rainfall at Ringnodia watershed, 1999–2001.

Areal aspect of watershed

1. Watershed shape

(a) Form factor

$$R_f = A/L^2$$

(where R_f = Form factor; A = Area of watershed in km^2 ; L = Watershed length in km)

$$R_f = 2.9/(2.1)^2 = 0.66$$

(b) Area-perimeter ratio

$$R_{ap} = A/P$$

(where R_{ap} = Area-perimeter ratio; A = Area of watershed in km^2 ; P = Perimeter in km)

$$R_{ap} = 2.9/6.2 = 0.47$$

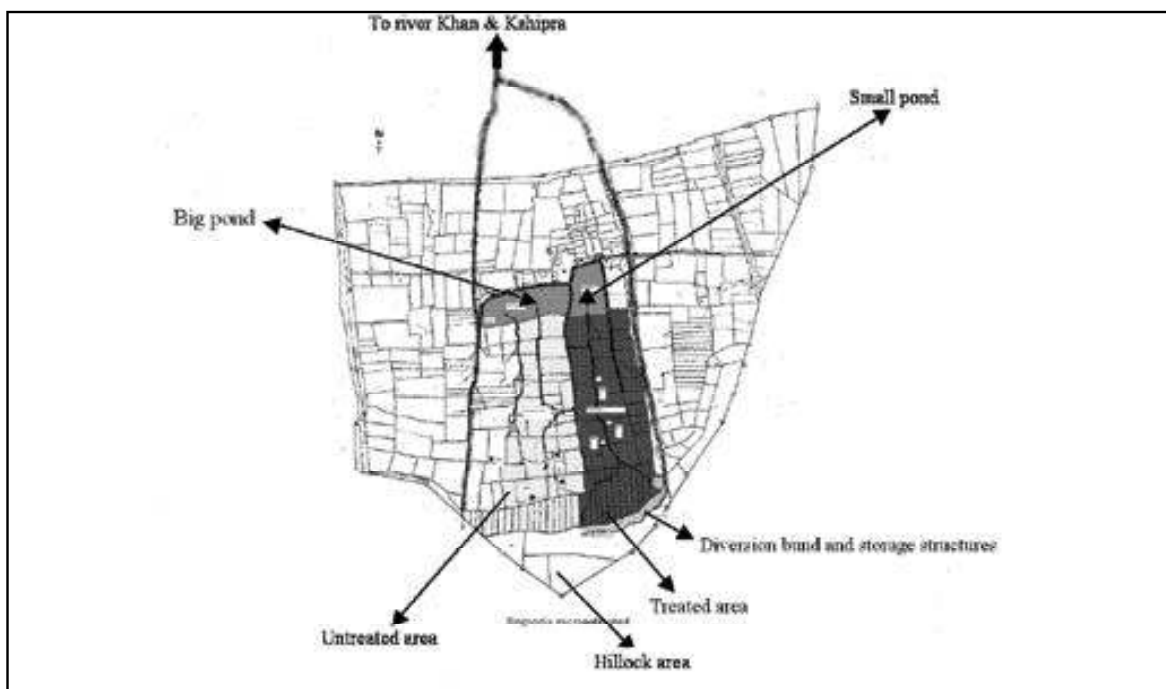


Figure 3.5. Ringnodia watershed map with drains and other details.

Linear aspect of drainage network

1. Bifurcation ratio

$$R_b = N_u / N_{u+1}$$

(where R_b = Bifurcation ratio; N_u = No. of streams of U order; N_{u+1} = No. of streams of $U+1$ order)

$$R_b = 4/3 = 1.33$$

2. Drainage density

$$D_d = \Sigma L / A$$

(where D_d = Drainage density; ΣL = Total length of all streams of all order in km;

A = Area of watershed in km^2)

$$D_d = 1.85/2.9 = 0.66$$

Relief aspect of drainage basin

1. Relief ratio

$$R_n = H / L$$

(where H is relief in m and L is the horizontal distance on which relief was measured in m)

$$R_n = 110/2100 = 0.52$$

2. Relative relief

$$R_{hp} = H / P \times 100$$

(where R_{hp} is relative relief; H is maximum basin relief in m; and P is watershed perimeter in m)

$$R_{hp} = (110/6200) \times 100 = 1.77$$

Surface hydrology

To measure runoff, digital runoff recorders were installed in two sub-watersheds (Fig. 3.6). The daily simulated runoff values from Ringnodia watershed for 1999, 2000, and 2001 are shown in Figure 3.7. The runoff for Ringnodia watershed was predicted using Pathak et al. (1989) model whose parameters have been estimated using the Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV) on-station runoff data. The highest number of runoff events occurred during 1999, followed by 2001 and least during 2000. Due to exceptionally low seasonal rainfall of 488 mm in 2000, only two very small runoff events were simulated. During 2001 most of the runoff events occurred before sowing of rainy season crops. The lowest seasonal runoff of 11 mm was estimated during 2000 (Table 3.1). The seasonal runoff was estimated at 147 mm during 1999. Due to operational problems only few runoff events were actually measured for the treated and untreated sub-watersheds. During 2001, limited data of runoff clearly indicate the effectiveness of the development works in controlling runoff and soil loss from the treated sub-watershed.



Figure 3.6. The runoff and sediment sampler used for measuring runoff and soil loss installed at Ringnodia watershed.

Table 3.1. Rainfall and simulated runoff at Ringnodia watershed, 1999–2001.

Year	Rainfall (mm)	Simulated runoff (mm)
1999	902	147
2000	488	11
2001	694	94

Groundwater hydrology

The storage structures constructed in the transition zone were useful in terms of increasing water table of the wells. To begin with, water table depth was 1 m less in a well nearest to the water conservation structures in the treated section compared to the well farthest to the water conservation structures. From 2000 onward, the water table started to increase in the well nearest to the water

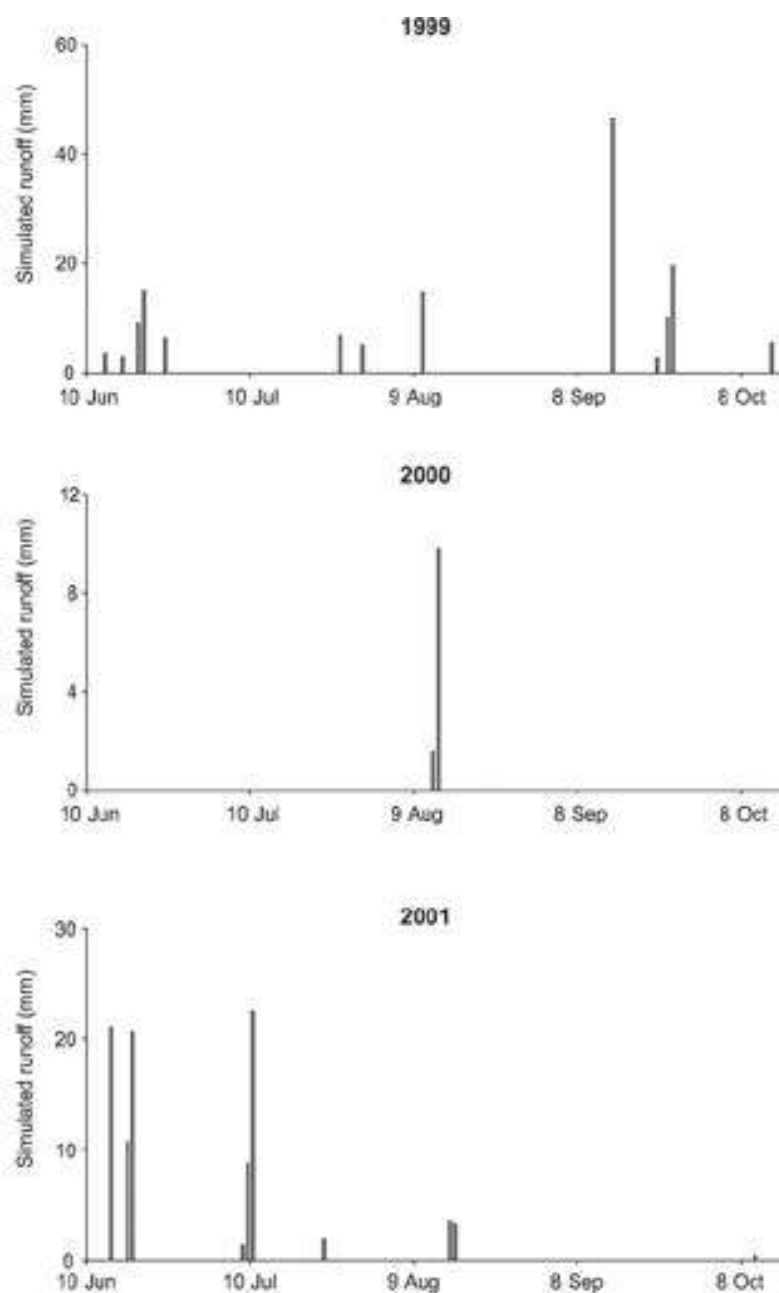


Figure 3.7. Simulated daily runoff events at Ringnodia watershed, 1999–2001.

conservation structures. At the end of the rainy season 2001 there was up to 6.9 m more water in the well nearest to conservation structures in the treated section in spite of less than normal rainfall. The groundwater fluctuations in the treated and untreated areas is shown in Figure 3.8. A somewhat similar trend emerged in the 6 other wells in the treated and untreated areas depending upon their distance from the water conservation structures. The conservation of water in different tanks has stabilized groundwater availability to a certain extent in Ringnodia micro-watershed in 2001.

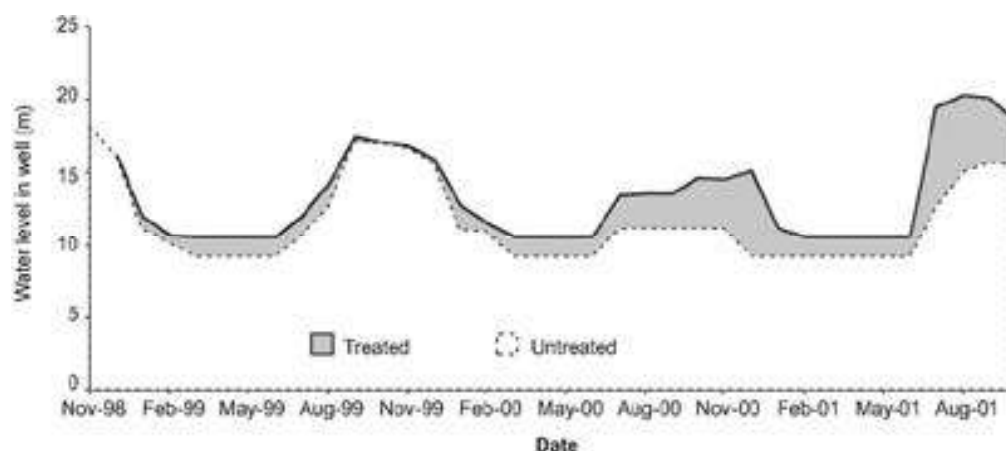


Figure 3.8. Groundwater level in open wells at Ringnodia watershed, 1999–2001.

Based on the limited groundwater level observations, the annual groundwater recharge in the treated and untreated sub-watersheds were estimated for 2001. Taking Figure 3.8 as a basis, the recharge rate of groundwater outflow during the rising part of the groundwater is estimated at 1.65 cm day^{-1} . The average groundwater outflow during the rising part of water table is estimated at 160 cm. The actual rise of the groundwater (without the outflow) should have been approximately 300 cm. Thus the average contribution of seasonal rainfall to the groundwater in the treated sub-watershed could be estimated at 120 mm or approximately equal to 17% of seasonal rainfall in 2001.

Summary

Ringnodia watershed is located about 20 km from Indore city on Indore-Ujjain highway. The watershed area is 390 ha with mean annual rainfall of 960 mm. The soils of the Ringnodia watershed are Vertic Inceptisols and associate soils. The soils are mostly clay loam in texture with medium to high moisture retention capacity and with good internal profile drainage. The watershed geomorphological characteristics are a form factor of 0.66, area-perimeter ratio of 0.47, drainage density of 0.66, and bifurcation ratio of 1.33 with a relief ratio of 0.52 and relative relief of 1.77. During the study period (1999–2001) the annual rainfall varied from 488 to 902 mm with two out of three years have much lower rainfall than normal. On an average 11% of the seasonal rainfall was lost as surface runoff. The storage structures and diversion channels constructed in the transition zone of the watershed were highly effective in improving the groundwater levels. The contribution of seasonal rainfall to the groundwater in the treated watershed was estimated at about 120 mm, which is equal to 17% of seasonal rainfall.

Section 4: Tad Fa Watershed, Khon Kaen Province, Thailand

General description

Tad Fa watershed is part of a large basin of Chi river, which is located at latitude 15°30' to 17°30' N and longitude 101°30' to 104°30' E and is about 150 km northwest of Khon Kaen (Fig. 4.1). It is a junction of three big watersheds namely Chi in east, Mae Khong in the northeast, and Pasak in the southwest. Tad Fa watershed fell in two provinces. The eastern part of the river Tad Fa comes under Khon Kaen province, which has nearly 700 ha, while the western side comes under Petchabun province. All the watershed research and development work was carried out in the eastern part of Tad Fa watershed of Khon Kaen province.

Mean annual rainfall reported at Tad Fa watershed is 1300 mm with 1900–2000 mm evaporation and in terms of temperature regime the area is tropical (26–28°C). Topographically it has sloping, upland complexes, soils are mostly Ustults and the land use is mostly comprised of forestry, agroforestry, horticulture, and field crops. Soils are highly degraded primarily due to the steep slopes and high soil erosion. The common land use practices are mainly in the form of shifting cultivation; however, farmers draw a distinction between shifting cultivation and the more common practice of “land rotation farming”. Under such a practice, land is fallowed for 3–5 years for soil fertility regeneration. Majority of the soil is silty clay loam with a very small fraction of clay loam. All the clay loam soil had

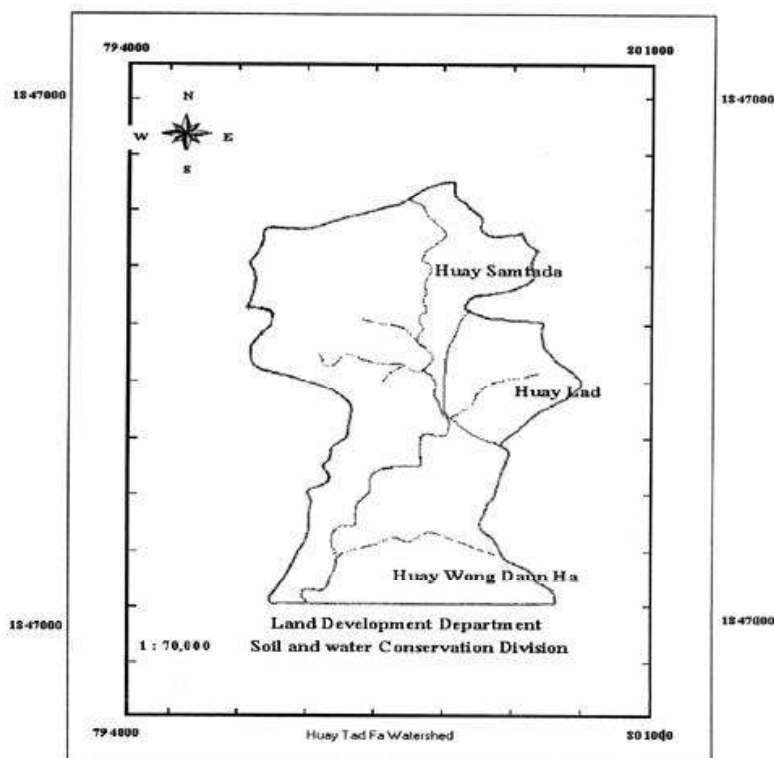


Figure 4.1. Location map of Tad Fa watershed, Thailand.

2–12% slope while a small proportion of silty clay loam had 2–5% slope and the rest had 5–12, 12–20, and even 20–35% slope (Naraongsak Senanarong et al. 2001).

The cropping systems under rainfed condition include maize as a cash crop on the high slopes and upland rice on the lower slopes. Tree crops and fruit trees are usually grown close to supplementary water resources on the lower slopes. Sometimes, legumes and cereals are rotated with upland rice and maize, according to fertility and economic returns. Cassava is another major crop.

Soil properties

Soil samples collected at various toposequence from the Tad Fa watershed were analyzed for physical, chemical, and biological properties. The textural properties of Tad Fa watershed are shown in Table 4.1. Up to 30 cm, there is gradual increase in clay content with increase in depth. Beyond 30 cm, clay content decreases with increase in depth. The high clay content of 43.1% was recorded at 20–30 cm soil layer. No specific trend was seen in silt content with depth. The highest silt content of 45.2% was recorded at 70–90 cm layer. Up to 50 cm depth, sand content was quite uniform. Beyond 50 cm the sand content increases sharply.

The soil depths in the upper, middle, and lower parts of the watershed varies considerably. Generally soil depths are very shallow on the upstream parts. Middle and lower sections of the watersheds have generally better soil depths. In most parts of the Tad Fa watershed sub-layers are generally solid rocks. This has considerable effect on surface and groundwater hydrology, and total moisture holding capacity.

Table 4.1. Soil physical properties of Tad Fa watershed.

Depth (cm)	Sand (%)	Silt (%)	Clay (%)
0–10	20.9	39.9	39.2
10–20	20.9	41.2	37.9
20–30	18.0	38.8	43.1
30–50	21.2	36.4	42.4
50–70	36.8	25.9	37.3
70–90	30.7	45.2	24.1

Climate

An automatic weather station with a data logger was installed at Tad Fa watershed to collect weather data such as rainfall, air and soil temperature, humidity, solar radiation, and wind velocity and direction. The mean annual rainfall at the Tad Fa watershed is about 1300 mm. This being hilly terrain, there is considerable variation in rainfall from location to location. The daily rainfall recorded at Tad Fa watershed during 2000 and 2001 is shown in Figure 4.2. There is a large variation in rainfall amount and distribution over year to year and within the season. The rainfall recorded in 2000 was 78% more than normal and in 2001 it was 29% less than normal. During 2000, several medium to large storms were recorded during April to September. In 2001 only one medium/large rainfall event (≥ 50 mm) was recorded.

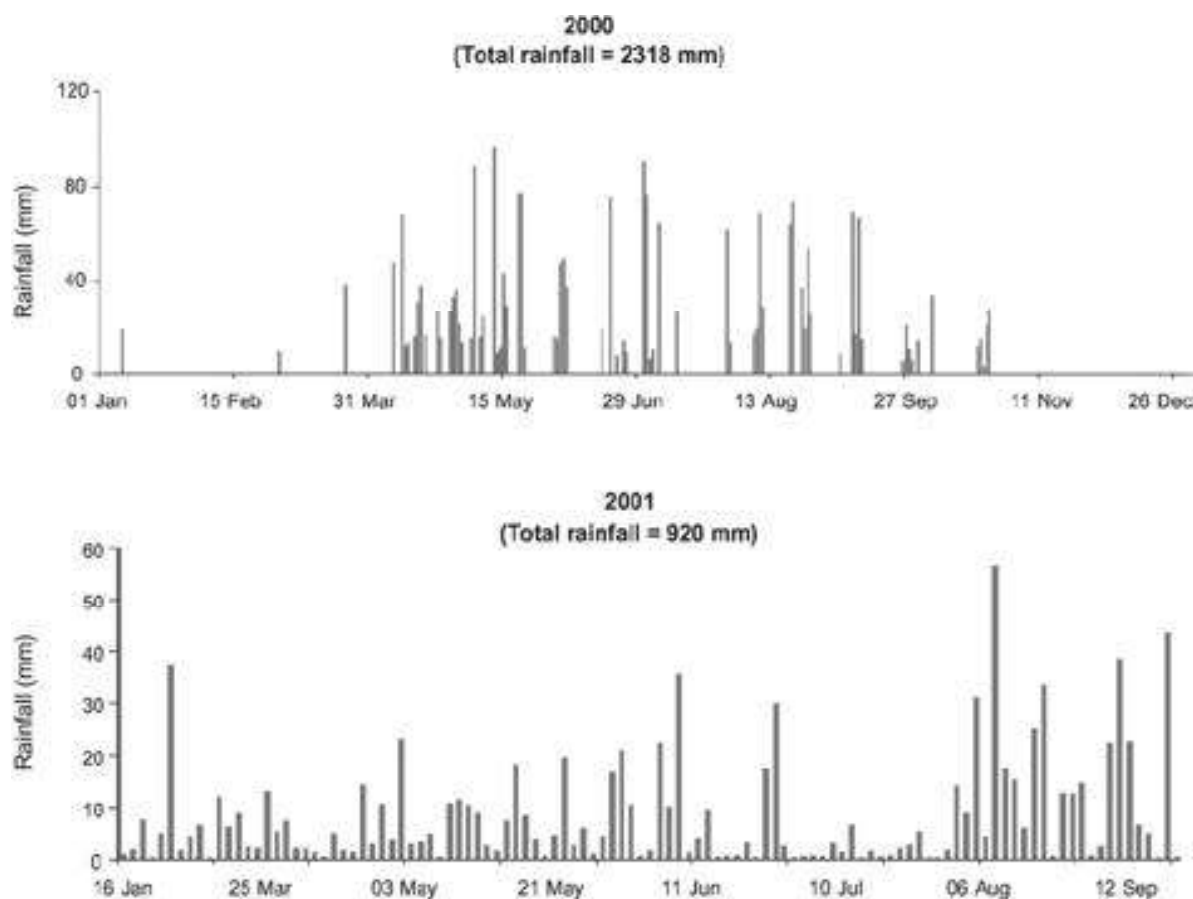


Figure 4.2. Daily rainfall at Tad Fa watershed, 2000-01.

Geomorphological characteristics

Using Figure 4.3 of Tad Fa watershed, the following geomorphological characteristics were calculated.

Areal aspect of watershed

1. Watershed shape

(a) Form factor

$$R_f = A/L^2$$

(where R_f = Form factor; A = Area of watershed in km^2 ; L = Watershed length in km)

$$R_f = 1.35/(2.5)^2 = 0.22$$

(b) Area-perimeter ratio

$$R_{ap} = A/P$$

(where R_{ap} = Area-perimeter ratio; A = Area of watershed in km^2 ; P = Perimeter in km)

$$R_{ap} = 1.35/4.2 = 0.32$$

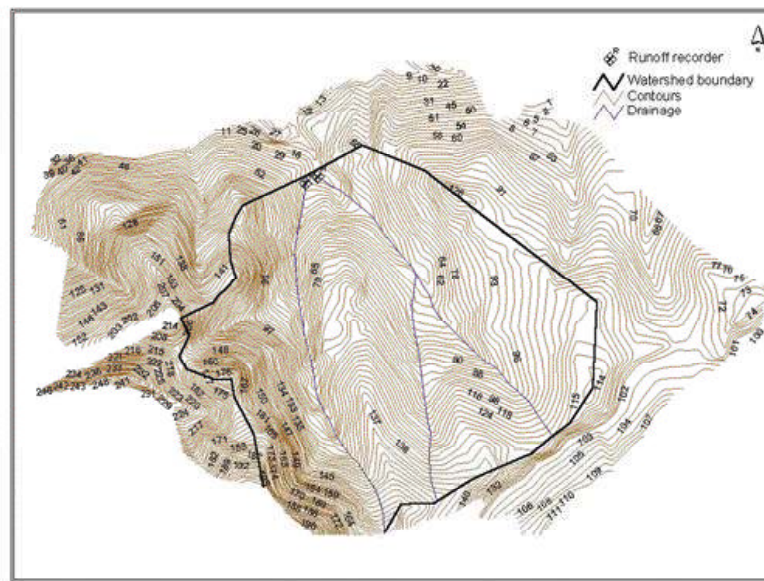


Figure 4.3. Tad Fa watershed map with drains and other details.

Linear aspect of drainage network

1. Bifurcation ratio

$$R_b = N_u / N_{u+1}$$

(where R_b = Bifurcation ratio; N_u = No. of streams of U order; N_{u+1} = No. of streams of $U+1$ order)

$$R_b = 3/2 = 1.5$$

2. Drainage density

$$D_d = \Sigma L / A$$

(where D_d = Drainage density; ΣL = Total length of all streams of all order in km; A = Area of watershed in km^2)

$$D_d = 1.85/1.35 = 1.37$$

Relief aspect of drainage basin

1. Relief ratio

$$R_n = H / L$$

(where H is relief in m and L is the horizontal distance on which relief was measured in m)

$$R_n = 140/2600 = 0.05$$

2. Relative relief

$$R_{hp} = (H/P) \times 100$$

(where R_{hp} is relative relief; H is maximum basin relief in m; and P is watershed perimeter in m)

$$R_{hp} = (140/4200) \times 100 = 3.33$$

Using above geomorphological parameters, several important aspects of hydrological behavior of Tad Fa watershed can be explained. These parameters can be used in the hydrological modeling to estimate runoff volume, runoff duration, and peak runoff rate. They are also very useful for soil loss modeling and are expected to improve the accuracy of model prediction capability.

Surface hydrology

Two digital runoff recorders along with automatic pumping type sediment samplers were installed at two sub-watersheds to monitor the runoff and soil loss from the two land use management systems (Fig. 4.4). Sub-watershed I has land under the horticultural tree-based cultivation with some areas under annual crops. Sub-watershed II has most of the areas under annual crops and cropping systems. The seasonal rainfall in the two sub-watersheds at Tad Fa during 2001 was 920 mm. There is considerable difference in the seasonal runoff between two sub-watersheds under the horticulture-based and annual crop-based land use management systems. During 2001, less than half of the seasonal runoff (194 mm) was recorded from the watershed under the horticulture-based land use system compared to watershed with annual crop-based land use system (473 mm). Similar trend in the peak runoff rate was recorded. The peak runoff rate was only $0.029 \text{ m}^3 \text{ s}^{-1} \text{ ha}^{-1}$ in the horticulture-based system and $0.048 \text{ m}^3 \text{ s}^{-1} \text{ ha}^{-1}$ in annual cropping.



Figure 4.4. Hydrological monitoring system at Tad Fa watershed.

The daily runoff from the two land use systems are shown in Figure 4.5. The daily runoff recorded from the horticulture land use system was continuously low throughout the season compared to annual crop land use system. The difference was seen even for very large runoff events. The runoff hydrographs from the horticulture and annual land use systems during 2001 are shown in Figure 4.6. Several important hydrological behaviors of two sub-watersheds can be obtained from runoff hydrographs. Using these hydrographs as basis along with geomorphological characteristics of the watershed, the unit hydrographs could be constructed. These unit hydrographs could be used as a basis for further runoff modeling work.

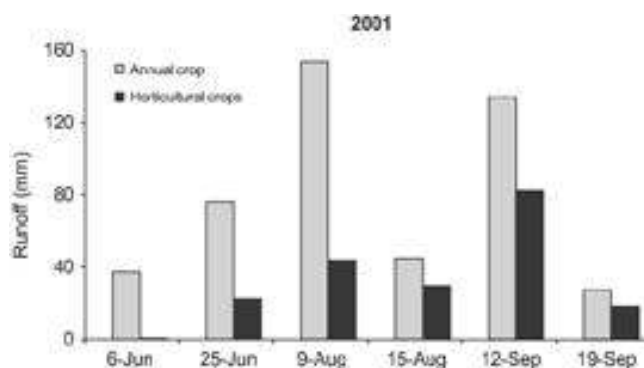


Figure 4.5. Daily runoff from annual crop-based and horticultural crop-based sub-watersheds, Tad Fa watershed, 2001.

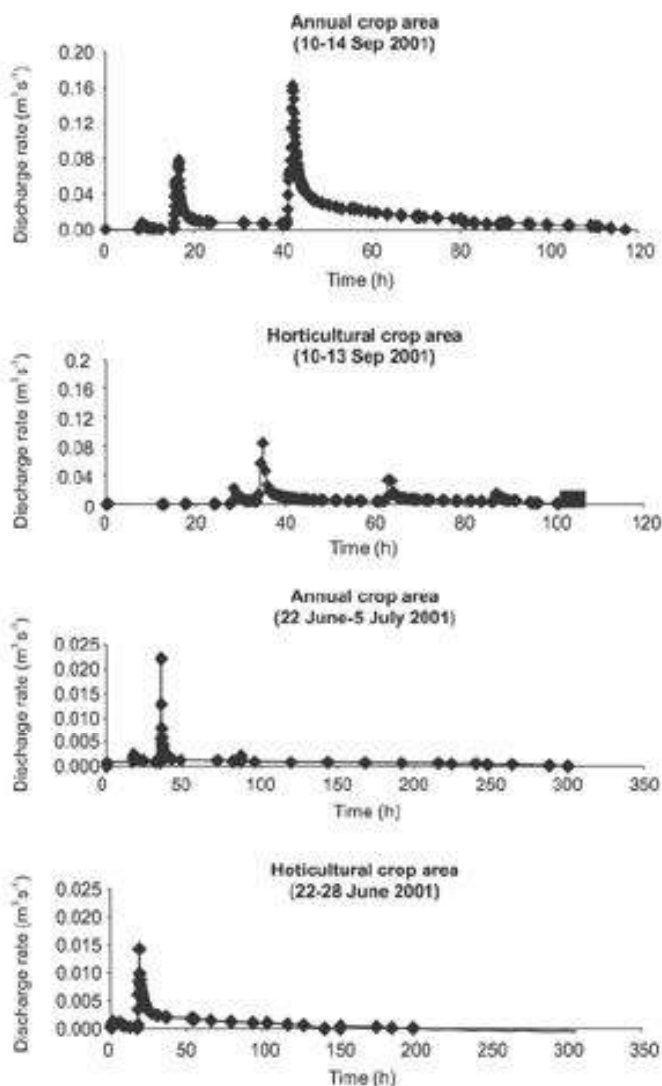


Figure 4.6. Runoff hydrographs from annual crop-based and horticultural crop-based areas of Tad Fa watershed, 2001.

Summary

Tad Fa watershed is located about 150 km northwest of Khon Kaen, Thailand. The watershed area is 700 ha with mean annual rainfall of 1300 mm. The soils in the watershed are mostly Ustults and highly degraded due to high soil erosion caused by steep slopes. The watershed geomorphological characteristics are a form factor of 0.22, area-perimeter ratio of 0.32, drainage density of 1.37, bifurcation ratio of 1.5 with a relief ratio of 0.05 and relative relief of 3.33. The high values of drainage density and relative relief indicate that the draining of excess runoff from the watershed is very fast. The other geomorphological parameters indicate presence of subsurface flow or base flow. The hydrological measurements from the watersheds clearly show the superiority of the horticulture-based system compared to annual cropping in reducing runoff losses. Less than half of the seasonal runoff (194 mm) was recorded from the watershed under the horticulture-based land use system compared to the watershed with annual cropping (473 mm). The peak runoff rate in the horticulture-based system was only $0.029 \text{ m}^3 \text{ s}^{-1} \text{ ha}^{-1}$ compared to peak runoff rate of $0.048 \text{ m}^3 \text{ s}^{-1} \text{ ha}^{-1}$ in annual cropping. These results provide the strategies for controlling runoff and soil erosion and sustaining long-term productivity in such vulnerable ecosystem.

Section 5: Thanh Ha Watershed, Hoa Binh Province, Vietnam

General description

The benchmark watershed is located in the northwest agroecological region. A landscape watershed with an area of 13.4 ha with 18 farmers was selected in Brigade # 7 of Thanh Ha State Farm, Kim Boi district, Hoa Binh province situated about 70 km southwest of Hanoi for development and evaluation of watershed-based rainfed technologies. In this area, the rainfed sloping lands vary from densely packed hills to plains with isolated knolls. Hills are rounded with level tops and convex slopes of 5–40°. Most slopes are 20–25° with elevations ranging between 15 m and 200 m above sea level. Between the hills are narrow valleys with alluvial soils used for mostly irrigated rice cultivation. The important crops are maize, sweet potato, cassava, queensland arrowroot, watermelon, medicinal plants, and seed vegetables. Crops such as cassava, maize, groundnut, mung bean, and soybean are found on the gentler upland slopes. Plantations are located on the upper and medium slopes. The general landholdings are very small. Agriculture is very intensive with moderate to high crop yields. The survey revealed that the major constraints for crop intensification are lack of water (98% respondents), non-availability of credit (92% respondents), expensive inputs such as fertilizers (84%), and lack of knowledge and information about improved management practices (80%). Farmers are currently using high doses of nitrogen fertilizers with little or no use of organic manures. Farmers are not aware of improved soil, water, and nutrient management options (Long et al. 2001).

Soil physical properties

In the watershed area, soils are complex and varied. The basic process of soil formation is ferralitic, through weathering of the parent material, leading to accumulation of rather high amounts of iron and aluminum, with leaching silica and most base cations (Long et al. 2001). The most common soil type is the red-yellow ferralitic (Plinthic or Ferric Acrisols, Humic Ferralsols). Mineralization is rapid, and organic substances quickly break down resulting in low humus content.

Soil samples were collected for soil physical and chemical properties in three broad grids covering entire watershed up to a depth of 105 cm. The soil texture at Thanh Ha watershed is shown in Table 5.1. The soils are generally clayey except at few places where it is clay loam. The soils are quite uniform at various depths. There is not much fluctuation in the clay and silt content. The highest clay

Table 5.1. Soil physical properties of Thanh Ha watershed.

Depth (cm)	Sand (%)	Silt (%)	Clay (%)
0–10	7.6	24.9	67.5
10–20	6.1	23.7	70.2
20–30	9.0	22.1	68.9
30–55	11.9	17.9	70.2
55–80	6.1	18.5	75.4
80–105	11.3	17.8	70.9

content of 75.4% was recorded at 55–80 cm soil layer while the lowest clay content of 67.5% was at the top 0–10 cm soil layer. In terms of soil moisture holding capacity the soils can be classified as medium to high water-holding capacity.

Climate

An automatic raingauge was installed at Thanh Ha watershed to record rainfall amount and intensity. Other weather parameters are collected from a nearby site, which is maintained by NARS. Long-term climatic data sets for Hoa Binh province have been collected from the local weather station. The climate is mainly monsoonal with hot, wet summer during April to August and cool, cloudy, moist winters during December to February. The average annual temperature is 25°C, with an average maximum of 35°C (in August) and an average minimum of 12°C (in January). The southwest monsoon occurs from May to October bringing high rainfall; temperature too is high. The dry season is from November to May with a period of prolonged cloudiness, high humidity, and light rain.

The daily rainfall data recorded during the last two years 2000 and 2001 are shown in Figure 5.1. There is a considerable variation in rainfall amount and distribution between two years as well as within the season. During 2000 about 21% less seasonal rainfall was recorded compared to rainfall in 2001. However, during 2000 more numbers of large storms (≥ 80 mm) were received compared to 2001. The medium size storms were more during 2001.

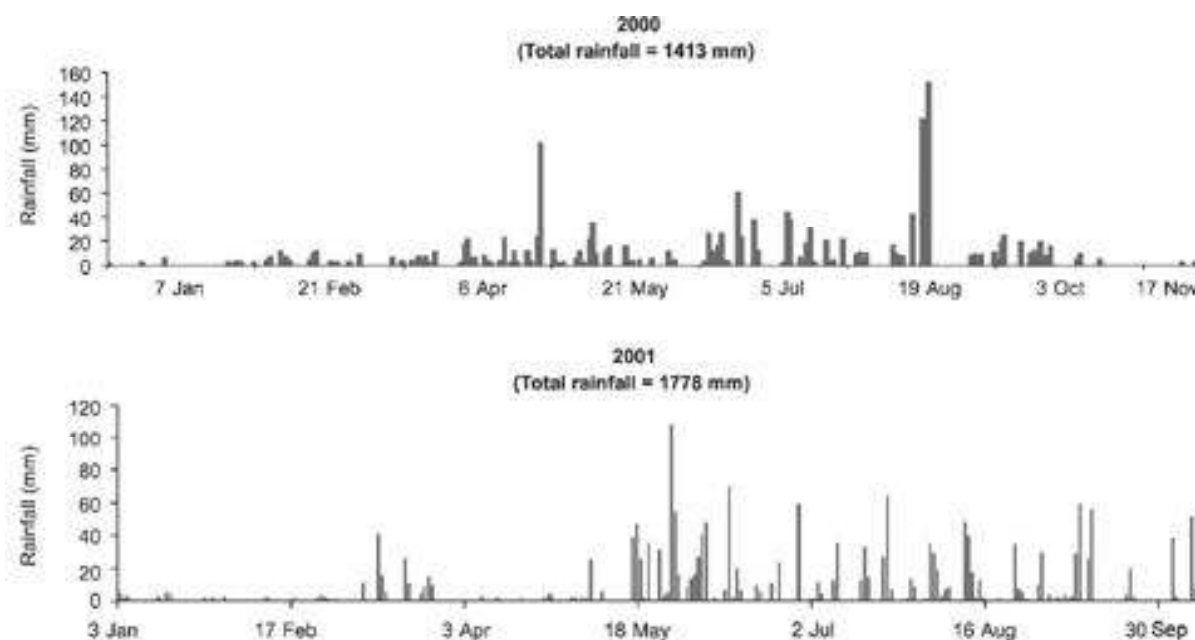


Figure 5.1. Daily rainfall at Thanh Ha watershed, Vietnam, 2000–01.

Geomorphological characteristics

Using the Thanh Ha watershed map (Fig. 5.2) the following geomorphological characteristics of the watershed were estimated.

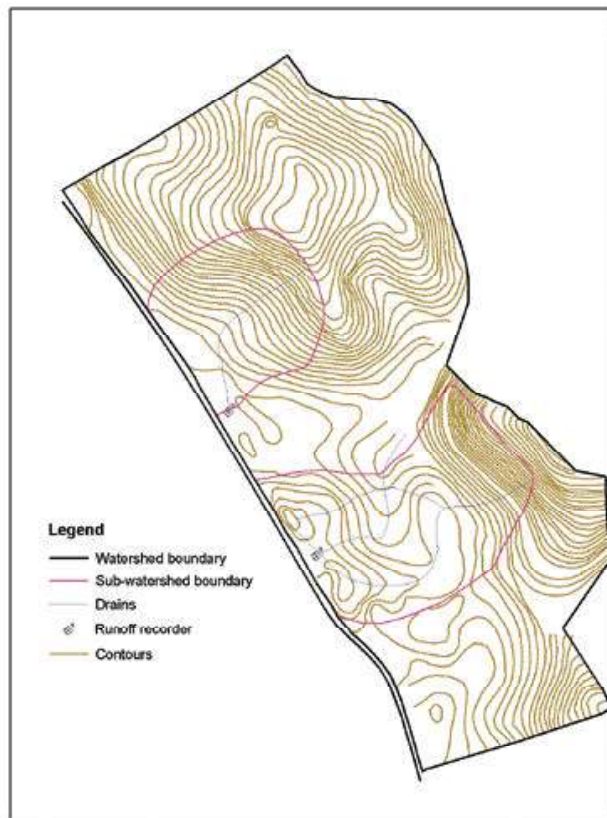


Figure 5.2. Thanh Ha watershed map with drains and other details.

Areal aspect of watershed

1. Watershed shape

(a) Form factor

$$R_f = A/L^2$$

(where R_f = Form factor; A = Area of watershed in km^2 ; L = Watershed length in km)

$$R_f = 0.7/(1.05)^2 = 0.64$$

(b) Area-perimeter ratio

$$R_{ap} = A/P$$

(where R_{ap} = Area-perimeter ratio; A = Area of watershed in km^2 ; P = Perimeter in km)

$$R_{ap} = 0.7/1.8 = 0.39$$

Linear aspect of drainage network

1. Bifurcation ratio

$$R_b = N_u / N_{u+1}$$

(where R_b = Bifurcation ratio; N_u = No. of streams of U order; N_{u+1} = No. of streams of $U+1$ order)

$$R_b = 6/4 = 1.5$$

2. Drainage density

$$D_d = \Sigma L / A$$

(where D_d = Drainage density; ΣL = Total length of all streams of all order in km;

A = Area of watershed in km^2)

$$D_d = 0.95/0.7 = 1.36$$

Relief aspect of drainage basin

1. Relief ratio

$$R_n = H / L$$

(where H is relief in m and L is the horizontal distance on which relief was measured in m)

$$R_n = 60/1005 = 0.06$$

2. Relative relief

$$R_{hp} = (H/P) \times 100$$

(where R_{hp} is relative relief; H is maximum basin relief in m; and P is watershed perimeter in m)

$$R_{hp} = (60/1800) \times 100 = 3.33$$

Surface hydrology

Digital runoff recorders along with automatic sediment samplers were installed at Thanh Ha watershed to monitor runoff and soil erosion from the two sub-watersheds. The seasonal rainfall, runoff, and peak runoff rate from the Thanh Ha watershed are shown in Table 5.2. During 2000 seasonal runoff of 129 mm was recorded compared to only 30 mm runoff during 2001. Three large rainfall events in 2000 resulted in more runoff compared to 2001 which had only one large rainfall event. The peak runoff rate in 2000 was about three times higher than 2001. The daily runoff from the Thanh Ha watershed during 2000–01 is shown in Figure 5.3. During 2001, there were total 8 runoff events, mostly very small. During 2000 one storm on 11–14 September resulted in 95% of the seasonal runoff. In spite of continuous and high seasonal rainfall during 2001, the seasonal runoff recorded was very low. This indicates the infiltration behavior of these soils in spite of having very high clay content. The runoff hydrographs from the watershed during 2000 and 2001 are shown in Figure

Table 5.2. Rainfall, runoff, and peak runoff rate in Thanh Ha watershed in Vietnam, 2000–01.

Year	Rainfall (mm)	Runoff (mm)	Runoff as % of rainfall	Peak runoff rate ($\text{m}^3 \text{s}^{-1} \text{ha}^{-1}$)
2000	1413	129	9	0.025
2001	1778	30 ¹	2	0.008

1. Up to August 2001.

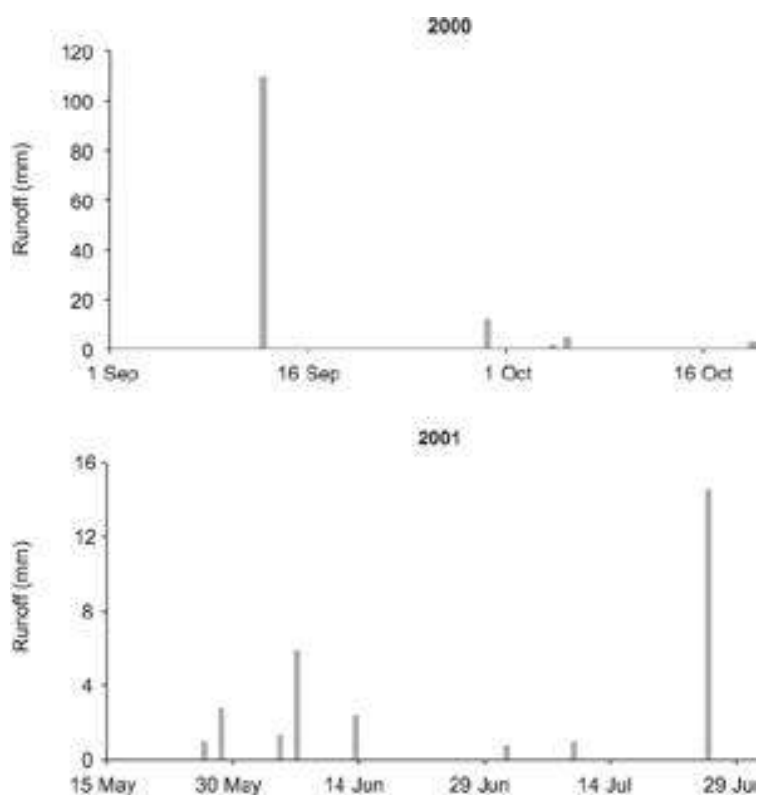


Figure 5.3. Daily runoff events from the Thanh Ha watershed, 2000–01.

5.4. Most of the runoff hydrographs show that the time of concentration to peak runoff rate is generally very low. However the total duration of runoff is exceptionally very large. These runoff hydrographs along with geomorphological characteristics of Thanh Ha watershed could provide a good basis for future runoff and water balance modeling work on this watershed.

Groundwater hydrology

Groundwater level in 10 open wells is being monitored at weekly intervals. About 1 m rise in the water level was recorded in the wells near percolation tanks in Thanh Ha watershed. Water table fluctuations in the watershed can be clearly seen in Figure 5.5.

Summary

Thanh Ha watershed is located in Kim Boi district of Hoa Binh province situated about 70 km southwest of Hanoi. The area of the watershed is 13.4 ha having mostly rainfed sloping lands which vary from densely packed hills to plains with isolated knolls. In this area agriculture is very intensive with moderate to high yields. In the watershed, soils are complex and varied. The most common soil type is the red-yellow ferralitic (Plinthic or Ferric Acrisols). The soils are generally clayey (<70% clay) except at few places where it is clay loam. The geomorphological features of the watershed are

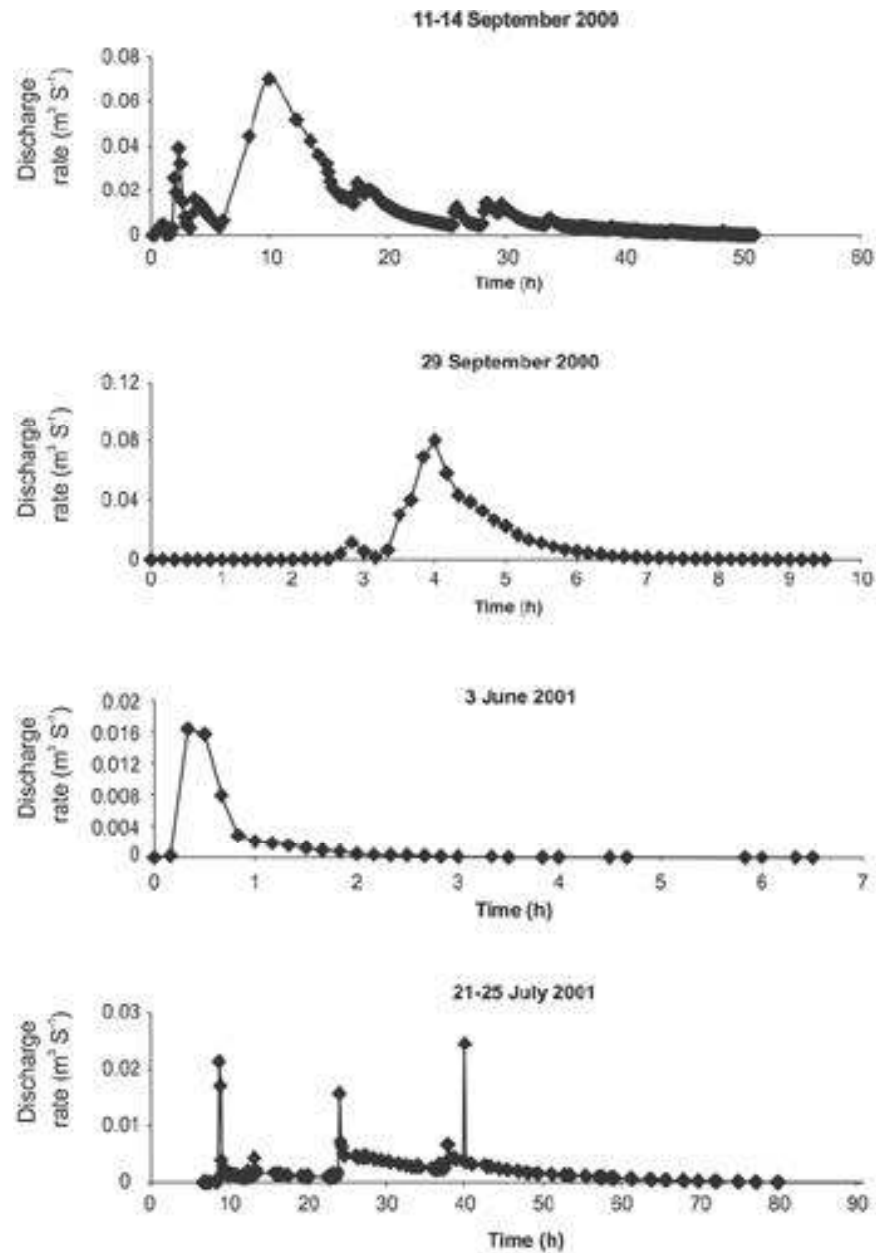


Figure 5.4. Runoff hydrographs from Thanh Ha watershed, 2000–01.

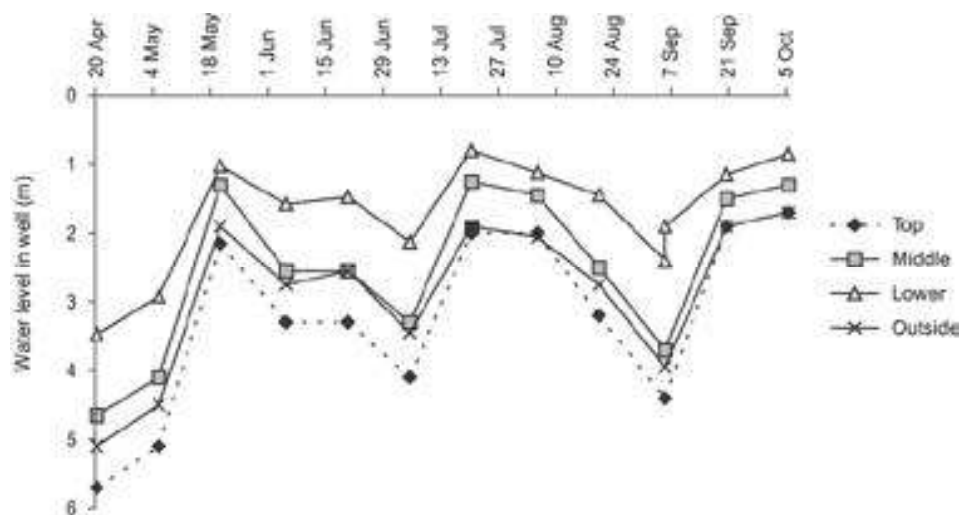


Figure 5.5. Groundwater levels in open wells at Thanh Ha watershed, 2000.

a form factor of 0.64, area-perimeter ratio of 0.39, bifurcation ratio of 1.5, and drainage density of 1.36 with relief ratio of 0.06 and relative relief of 3.33. Limited hydrological data were collected during 2000–01. On average about 9% of the seasonal rainfall is lost as surface runoff. The peak runoff rate recorded from the watershed was $0.025 \text{ m}^3 \text{ s}^{-1} \text{ ha}^{-1}$. A few more years of hydrological data will be required before worthwhile conclusions can be drawn.

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