water

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contents

water

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Tel.: (00251) 06 / 810453 Fax: (00251) 06 / 810279
Chief Editor: Degefa Ayane Assistnt Editors: Feseha G/slassie, Gossa Tessema DTP: Feseha G/slassie
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We would be very grateful should you send us names and addresses of individuals or institutions, if any, who are working in the water sector and interested in the contents of our journal. We very much like to send them free copies.

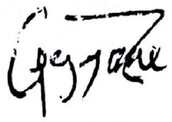
Dear readrs:

'Water', *The Ethiopian Journal of Water Science and Technology , is intended for researchers, engineers, experts, managers, etc., to publish their research findings and enlighten other researchers, the relevant authorities and the public concerning the on-going researches and developmental water works.*

The present issue of 'Water' *has papers on drainage, hydrology, irrigation, and Water quality. The work would not have been a success without the assistance and cooperation of the referees who went through the papers and gave their professional views. We are very thankful to all of them. We are also highly grateful to all the contributors for this issue.Here, the Research and Publication Coordination Service of the Institute and the Arbaminch Water Technology Institute should not be responsible for the opinions expressed in the journal,*

The second issue of this volume of 'Water' *will come out in July 1998 as a proceeding of the Symposium on Sustainable Water Resources Development.*

Finally, on behalf of the editorial board, I would like to encourage and invite all concerned experts, engineers, managers, researchers to use 'Water' *to disseminate new information and to report on the latest developments in technology, analysis and management.*



Degefa Ayane
Chief Editor

Household Treatment of Raw Water with Sand Filters

Adam Kenea, Arbaminich Water Technology Institute P.O.Box 21,Arbaminch,Ethiopia

Abstract

Installation of conventional water treatment processes in the rural and suburban areas of developing countries is, at present, impractical due to economic reasons and settlement characteristics of the population. Small scale water treatment processes seem to be suitable methods of providing relatively clean water for those who draw their water supplies from unprotected wells, ponds and streams. In this research, a sand filter has been designed that can be made from locally available materials, and that can be operated and maintained by the householder. The unit is designed to operate under declining rate taking into account the intermittent nature of collecting water in rural areas. The efficiency of the household sand filter has been checked by testing the bacteriological and physical qualities of the raw water from River Kulfo and the filtered water. Results obtained up to date show that the unit produces considerable improvement in the bacteriological and aesthetic qualities of the raw water.

Introduction

Water is a commodity without which life on earth would be impossible. Its availability alone is not sufficient to sustain life. Its quality is also of paramount importance. Of course, millions of people lose their precious lives each year due to diseases spread through consumption of contaminated water. It has been reported that about eighty percent of all infections in the world are associated with unsafe water (IRC, 1983).

In Ethiopia, more than 87% of the total population live in rural areas. Out of these only 19% get access to safe water, with the remaining 81% drawing their water supplies from unprotected sources such as streams, ponds, wells, etc. (Schotanus, 1996). Apparently, water from these sources has a large chance of being contaminated with fecal matter, with the result that about 80% of diseases prevalent among the people of the country are water-related (UNICEF, 1992). In addition, the existence of suspended solids, algae and organic matter make the water unsuitable for human consumption. The removal of these impurities from water is absolutely necessary if a reduction in the incidence of water-related diseases is envisaged. The installation of conventional water treatment plants in rural and suburban area of developing countries is, at present, impractical due to economic reasons and the settlement characteristics of the population. Small-scale water treatment processes are more justified methods in such cases.

Several methods of household water treatment have been used in different parts of the world, some of them traditional and some supported scientifically. Among the most common ones are boiling, straining (by cloth), storage to remove silt load, the use of natural coagulants such as chitosan, moringa and nirmali seeds (Schulz and Okun, 1984; Mayer et al, 1995), upflow-downflow filters (Pickford, 1991), ceramic candles and home-made sand filters (Gebre-Emanuel, 1977). Each method has a varying degree of efficiency in removing impurities from water.

Straining and storage bring about partial removal of suspended matter in the water. Coagulation with natural coagulants removes both solids and bacteria but the bacteria regenerate if the water is kept unused for a long time (usually about 24 hours). This is attributed to the organic material present in the seeds (Schulz and Okun, 1984; Mayer et al, 1995). Upflow-downflow filters produce an effluent that is hygienically safe but they need a minimum of three jars (Pickford, 1991). The home-made sand filter is effective in reducing turbidity considerably but the filtered water is not safe from bacteriological point of view.

Looking at the list of the methods mentioned above and the actual health situation in rural areas, it is doubtless to say that there is a strong need for a simple and cost-effective method of water treatment in these areas. The aim of this project is to come up with a modification of the home-made sand filter that ensures removal of solids, pathogenic organisms and organic matter in the raw water, thus remedying the defects of the home-made sand filter.

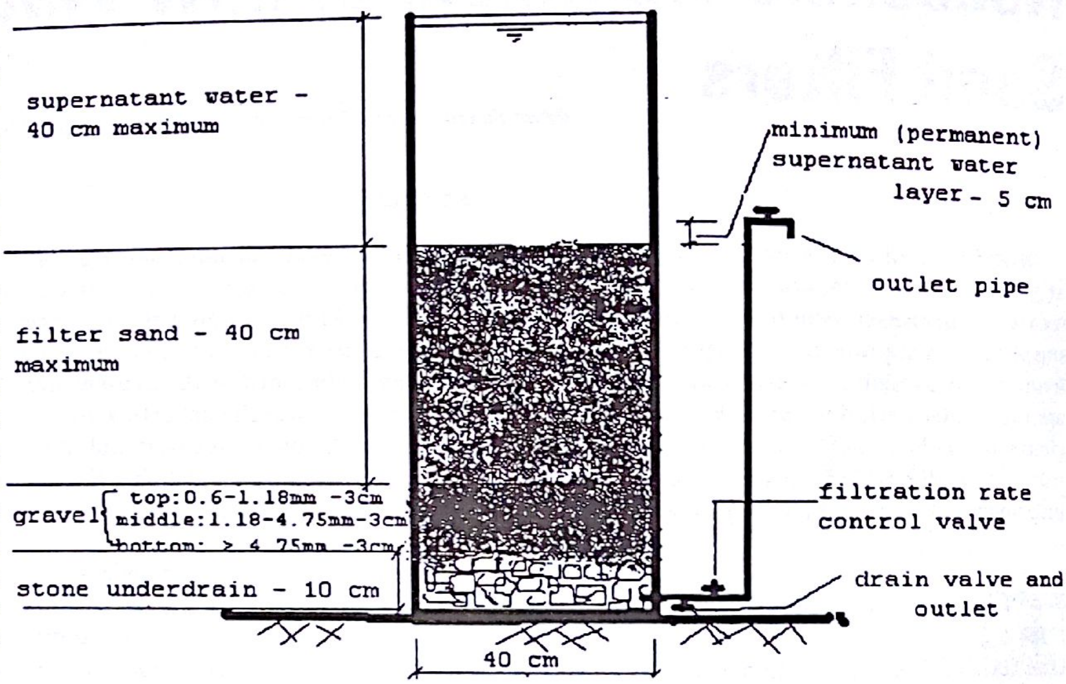
Fundamentals of Slow Sand Filtration

Removal Of Impurities

The removal of impurities in slow sand filters is brought about by a combination of different processes such as sedimentation, adsorption, straining and biological action. The biological processes that take place in the *schmuzdecke* of the filter are capable of reducing the total bacteria content by a factor of 10^3 to 10^4 and the *E. coli* content by a factor of 10^2 to 10^3 (Schulz and Okun, 1984). In a properly operated sand filter, the effluent may bacteriologically be safe for drinking, thereby avoiding the need for disinfection.

Although sand filters retain suspended matter present in the raw water, they clog easily in a short period if the raw water turbidity is greater than 50 NTU (Schulz and Okun, 1984). The suspended matter is retained within the top 0.5 to 2 cm of the filter bed. This allows the filter to be cleaned by scraping away the top 2 cm of sand after a

Figure 2 Components of Household filter (not to scale)



certain period of operation. When water of higher turbidity is encountered, some sort of pretreatment should be used to bring the turbidity down to the desired value.

Part of the organic matter present in the raw water is retained in the top layer of the filter sand but organic matter of low mass density goes deep into the sand bed, it will be adsorbed to the sand grains whereupon it is broken down by the biological film that has already been established.

Once the sand bed is matured, inorganic impurities accumulated on the filter sand grains are transformed by biochemical and bacterial activities. Thus, soluble ferrous and manganous compounds are transformed to insoluble ferric and manganic oxide hydrates that become part of the coating around the sand grains (IRC, 1983).

Materials and Methods of the Research

Materials

After making cost analysis of various locally available materials, cement mortar and bamboo matting formwork are chosen for the construction of the filter tank. The filter media was prepared from local sand, gravel and stone.

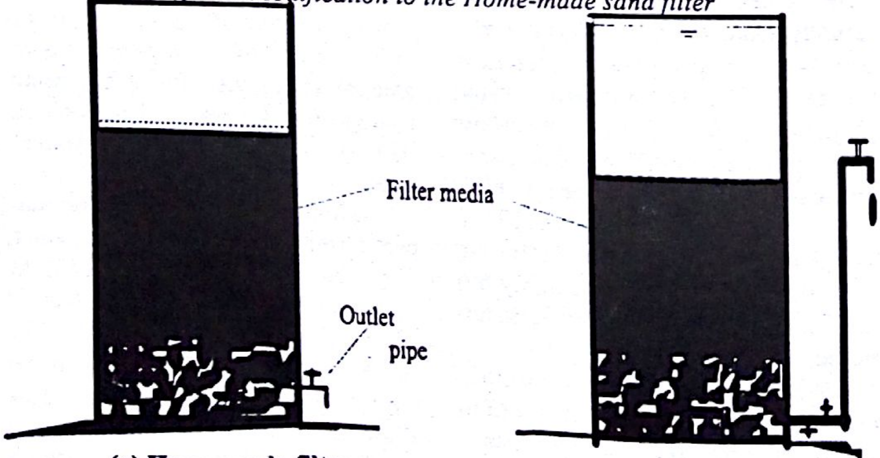
Methods

Raw water collected from River Kulfo is passed through the filter bed. The filter and raw water were analyzed for selected water quality parameters of importance to the rural areas. These include bacteriological quality and aesthetic considerations.

Modification to the Home-made Sand Filter

The home-made sand filter works under declining head, i.e. water that is added will completely drain out after a certain time and the filter bed dries out leading to the inactivation of biological organisms in the sand bed. The biological organisms are the essential components of the filtration process that play the major role in the removal of pathogenic organisms from the water. Therefore, to remedy the defects of the home-made filter, it may be essential to ensure the existence of some layer of supernatant water on top of the sand bed at all times to keep the biological film active and alive. In this research, this is realized by modifying the outlet pipe from the filter tank so that the outlet pipe rises 5 cm above the top of the filter sand. The depth of the filter sand in this experiment is limited to about 30 - 40 cm to provide a sufficient space for accommodating raw water over the sand bed. Fig 1 shows schematic diagrams of the home-made sand filter and the modified household sand filter.

Figure 1 Modification to the Home-made sand filter



(a) Home-made filter **(b) Household filter**

Design and Construction of the Household Sand Filter

Filter Capacity

The filter capacity is such that the amount of water treated per day is sufficient to sustain an average rural household. Typical water demand assessments for rural and suburban communities collecting water from surface sources show that the average per capita consumption is usually below 15 liters per day (IRC, 1983; Sinderman, 1995). In rural areas water for domestic use is collected early in the morning (before going out to work in the field) and late in the afternoon (after work). Therefore, this trend of collecting water twice a day is used in the research. Each time the tank accommodates about 50 liters, totaling to 100 liters of water per day, which is sufficient for an average family of 7 persons at the demand indicated above. Each 50 liter of filtered water is ready for use after 3 to 4 hours of operation. If water is added continuously, the unit can treat up to 300 l of raw water per day.

The essential components of the filter unit are shown in fig 2.

Characteristics of filter components

Supernatant water: maximum of 35 cm and minimum of 5 cm

Filter gravel: provided in three layers

Layer	Depth	Size(grain dia.)
Top	3-4cm	0.6mm -1.18mm
Middle	3-4cm	1.18mm-4.75mm
Bottom	3-4cm	>4.75mm

Filter sand: 30 - 40 cm deep; Effective Size (E.S) = 0.15 - 0.35mm and Uniformity Coefficient (U.C) = 1.5 - 3.0.

Tank diameter: 40 cm; total depth: 1 m.

Construction of the Filter tank

A 1 m high and 40 cm diameter tank was constructed by plastering a 1:2 cement mortar on a bamboo matting formwork layer by layer. A 1/2 inch outlet pipe with filtration rate control and drain valves and a tap was then fitted to the tank after curing is complete.

Preparation of Filter Sand and Gravel

Local sand brought from the Konso district (North Omo) was washed on a 75 m sieve and air-dried. Organic matter in the sand was then separated by floatation in a tank filled with water. The sand was air-dried again and passed through a 4.75 mm sieve to separate gravel. A sample of the sand was weighed and the grain size analysis was done to select sand satisfying the requirement. The filter gravel was prepared by passing the clean sand through 4.75 mm, 1.18 mm and 0.60 mm sieves.

Operation Principles

To keep the number of tanks required to a minimum (and hence the cost) the declining rate filtration was selected in the research. Raw water is added to the tank from the top. The experimental filter has no arrangement for filling from underneath at the beginning of the operation cycle. Therefore, to minimize the effects of air binding, a thin layer of sand is placed and water is added until it just levels with the sand. Again another layer of sand is added followed by water. This process is repeated until the required depth of sand is placed in the tank. With this method the amount of negative pressure that developed is quite small and the bed is stabilized immediately.

After the sand is filled, care is taken not to damage the bed during adding water. The energy of the falling water is dissipated by a simple arrangement. A cover of a plastic water container is placed on top of the sand bed and water is added onto this plastic, thus distributing the water slowly on to the sand bed. After the first day of filling, a minimum supernatant water layer of 5 cm is maintained on top of the sand which makes the plastic to float. Water added onto the plastic cover (of course, any floating material can be used) will lose its energy entirely when it reaches the sand bed. Therefore, it does not inflict any damage on the *schmuzdecke*, nor does it cause resuspension of settled mater.

Filtration Rate Control

Although the filter works under declining rate of filtration, it is essential to control the maximum rate of filtration to get an effluent of good quality. This is provided by fitting a gate valve on the outlet line as shown in fig 2. The maximum filtration rate at the beginning of the operation cycle is set at 0.2 m/h with the gate almost closed. The rate is adjusted to this value raising the rate slowly over several hours. As resistance to the downward flow of water increases the rate drops, coming down to less than 0.1 m/h after 2 weeks of operation at an average raw water turbidity less than 50 NTU. The head is recovered by opening the control valve by one round to raise the maximum filtration rate to 0.2 m/h again, the regulation being done slowly. This rate approximately yields 20 litres (one plastic bucket) in one hour.

Construction of filter tank

The tank was constructed by plastering a 1:2 cement mortar on a bamboo matting formwork layer by layer. A ½ inch outlet pipe with its accessories was then fitted to the tank after curing was complete.

Material Cost

The cost of materials required for a single tank as of April 1997 market prices (Arba Minch) is Birr 100 unreinforced cement mortar tank and Birr 65 for the same if a multiple of six tanks is produced.

Water Quality Analysis

Selected Water Quality Parameters

Enteric diseases are the main health hazards arising from drinking water in developing countries. Therefore, water quality standards should generally concentrate on microbiological quality. Furthermore, the removal of many chemical constituents from water requires sophisticated treatment processes that are beyond the economic capabilities of people in developing countries.

For small community and household water supplies, only a limited selection of parameters could possibly be used to survey and measure the water quality. The main emphasis given in the WHO guidelines is to the microbilogical quality, followed by aesthetic considerations such as turbidity, taste, color and odor (Schulz and Okun, 1984; WHO, 1984). Thus, this research concentrates mainly on the pathogen removal efficiency of the household sand filter and ways to improve the achievement.

Technique of Analysis

For bacteriological analysis of the raw and filtered water, the multiple tube fermentation technique is selected due to the easy availability of chemicals and due to the fact that the membrane filtration technique is not suitable for highly turbid water. Standard methods were employed for other tests.

Status of the Sample Source

The sample used in the analysis is collected from River Kulfo, 3 km from the research area. The river water has a large bacteriological load (greater than 5000 Coliforms per 100 ml of untreated water) which makes it an ideal source for the experiment.

Frequency of Analysis

Micro organisms have to multiply themselves to bring about full ripening of filter beds. The process takes time to be fully established. To see how the filter bed of the household filter progresses with time, the bacteriological quality of the raw and filtered water is analyzed weekly. Turbidity test is carried out more frequently. The other parameters are tested occasionally.

Results and discussions

The first and second cycles of experiment were carried out using a filter with the following characteristics:

Stone underdrain: 10 cm deep
Filter gravel :
bottom - 4 cm -> 4.75 mm diameter
middle-4cm-1.18-4.75mm diameter
top-4cm- 0.6 - 1.18 mm diameter
Filter sand: 30 cm deep; E.S = 0.25 mm; U.C = 2.8
Supernatant water : maximum 40 cm, minimum 5 cm.

The following results were obtained during the first sycle for three weeks.

Stone underdrain: 10 cm deep

Filter gravel :
bottom - 3 cm - >4.75 mm diameter
middle - 3cm - 1.18 - 4.75 mm diameter
top - 3 cm - 0.6 - 1.18 mm diameter
Filter sand :
35 cm deep; E.S = 0.22 mm; U.C = 3.0
Supernatant water :
maximum 38 cm, minimum 5 cm.

Table -1 Test results during the first sycle of experiment

Date	Turbidity (NTU)		MPN/100 ml Coliforms		Remark
	Raw	Filtered	Raw	Filtered	
12/6/97	37	55	1300	410	F.coli - test not complete due to power interruption
14/6/97	21	30			
16/6/97	35	20			
18/6/97	35	17			
19/6/97	27	16	5000	170	
21/6/97	24	12			
23/6/97	15	10			
24/6/97	20	9			
26/6/97	20	7	2400	40	
27/6/97	20	6			
28/6/97	240	6.4			After further regulation of filtration rate control valve
2/7/97	120	30			After heavy storm damaged the top of filter skin
3/7/97	86	26	9200	1300	

To confirm the results a second cycle of testing was done after replacing clean filter sand, gravel and stone underdrain in the tank. Table 2 shows the results of the analysis.

In Table-1 filtered water turbidity is greater than raw water turbidity for the first two samples. The samples were taken after the supernatant water was completely drained and raw water was

Table -2 Test results of the second sycle of experiment

Date	Temp °C	pH	Turbidity (NTU)		Color (ACU)		MPN / 100 ml Total Coliforms	
			Raw	Filtered	Raw	Filtered	Raw	Filtered
30/7/97	-	6.5	85	25	> 250	45	2400	2200
4/8/97	26.7	6.8	48	24	> 250	15		
6/8/97	27.3	6.78	59	19	> 250	15	5000	800
7/8/97	-	7.0	72	14	> 250	15		
10/8/97	24.7	-	30	14	40	10		
12/8/97	27.0	6.78	16	12	30	5		
13/8/97	26.8	6.7	24	10	50	5	800	800
15/8/97	26.7	6.75	7.6	6.5	25	<5		
17/8/97	27.5	6.8	8	5.4	15	< 5		
20/8/97	-	-	14	4.1	-	-	2400	22
22/8/97	27.3	6.6	7	4.1	10	< 5		

Failure of test due to fluctuation in oven temperature

A third trial is underway with the following filter characteristics:

added from the top. This has led to a negative pressure in the bed which causes cracks in the bed, leading to es-

Table - 3 The results obtained for aesthetic parameters

Date	Temp. °C	pH		Turbidity (NTU)		Color (ACU)		Remark
		Raw	Filtered	Raw	Filtered	Raw	Filtered	
9/12/97	24.8	6.5	7	43	0.55	>250	<5	after a week
22/12/97	24.5	6.5	7	126	0.84	>250	<5	a week after drying of filter bed
17/1/98	23.6	6	7	160	5.8	>250	<5	a week after resanding
22/1/98	-	-		31	15	-	-	immediately after opening control valve
23/1/98	24.3	6.5	7	28	3.9	100	<5	
25/1/98	23.7	6.5	7	28	3.4	100	<5	
27/1/98	25.3	7	7	6.1	3.4	20	<5	

caping of filter media with the treated water, thus increasing the turbidity.

From Tables 1 and 2, it can be seen that full ripening of the filter bed may take several weeks but bacteriological removal efficiencies of up to 97 % can be achieved after a week of operation if the filter is properly operated. Turbidity and color removal efficiency of the filter has been improved greatly by increasing the finer proportion of the filter sand and its depth (see Table 3). The bacteriological removal efficiency for the filter with this characteristics is currently under investigation. The treated water is free of odor during observation of all test results.

Filter operation needs care in some aspects. Scouring of the filter bed and resuspension of settled matter, due to uncontrolled addition of water, must be avoided. The filter should be covered during rain. Drying of filter bed should be prevented between filter runs. If it occurs, the filter media should be taken out completely and replaced again. If not, cracks will be formed that act as a conduit allowing short-circuiting of raw water.

Future Plan

The bacteriological removal efficiency of the filter will be analyzed for the filter media used during the third cycle (ES = 0.22 mm; UC = 3.0; depth of sand = 35 mm). Then the filter run will be determined for raw water with different turbidity ranges and tolerable turbidity limits will be set for efficient operation. Guidelines for operational control and maintenance of the filter will be set at the end.

Acknowledgment

The author extends his thanks to the Ethiopian Science and Technology Commission for sponsoring the research, and to Arba Minch Water Technology Institute for providing the necessary facilities.

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Drainage Coefficient for Surface Drainage System in Arbaminch Area

L.B.Roy, Arbaminch Water Technology Insititute P.O.Box-21, Arbaminch, Ethiopia.

Abstract

Currently available approaches for the determination of drainage coefficient for surface drainage systems have been reviewed. Thereafter the likely drainage coefficient for the Arba Minch Water Technology Institute demonstration farm (110.0 ha in area) has been determined using various approaches. These results were compared and it was found that the frequency analysis approach using 3 days tolerance period for common crops grown in the area gave the reasonable result i.e. 14 mm/day. This result may be used for agricultural watersheds in and around Arba Minch area. However, it should be preferred to measure out-flow from existing drains in the surrounding area to get the actual value of drainage coefficient.

Introduction

In several cases, natural drainage is entirely inadequate and a complex critical drainage system is required for sustained irrigated agriculture. Therefore, the provision of drainage is needed in majority of irrigation schemes. A major reason for low yields from irrigated agriculture is improper irrigation water management. Not only should water be properly used to meet the crop needs but also the timely removal of excess water is necessary. Considerable areas of fertile lands under the irrigated commands have gone out of production due to the waterlogging and salt related problems all around the world including Ethiopia. In the present study, an attempt has been made to estimate drainage coefficient for Arbaminch Water Technology Institute (AWTI) demonstration farm which is situated in North Omo zone of Gamo Gofa region of Ethiopia. Apart from this a review of the various approaches for the determination of drainage coefficient has also been made.

Project Area

AWTI demonstrations farm is situated adjacent to the Arbaminch estate farm on its northern side with an altitude of 1190.0 m, latitude of 6.08°N and longitude of 37.38°E. One of the main objectives of the farm is to integrate the irrigation and drainage systems with the pedagogic intentions of the curriculum of Irrigation Engineering Department of AWTI. The climate at Arbaminch is of bi-modal pattern with mean annual rainfall (MAR) equal to 790 mm. The average minimum and the maximum temperature in the project area are 13°C. & 29.6°C respectively. The average relative humidity is 57%. Therefore, it seems that the climate at Arba Minch is very conducive for both rainfed crops as well as irrigated crops. The Index map of the farm is shown in Figure-1.

A substantial portion of the demonstration farm is out of cultivation due to the twin problem of waterlogging and salinity. This problematic area is in the north-eastern part of the farm. There are four types of drainage situations in the demonstration farm. These situations are:

(i) Runoff from the surround in hills: At present, it is not a problem due to the construction of RR 50 standard road which intercepts these runoffs before they reach the farm area.

(ii) The internal drainage in the farm needs improvement in the form of construction of field drains, collector

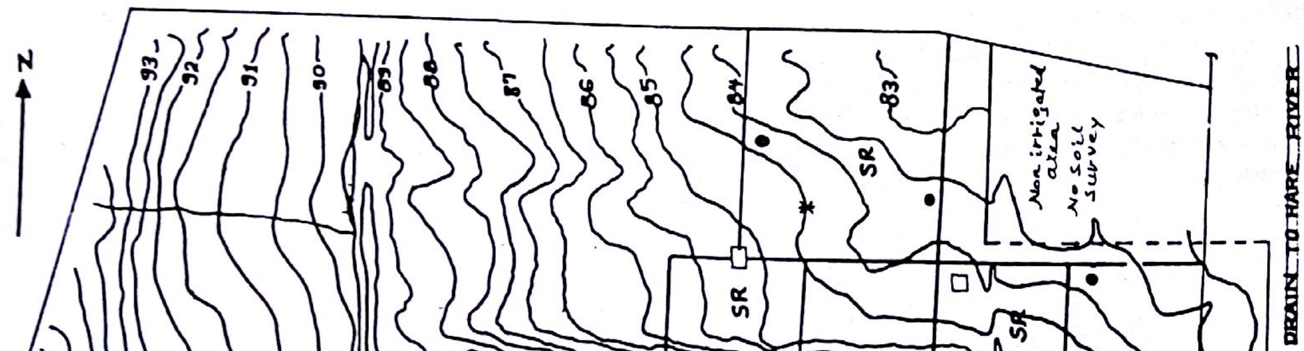

Figure-1 An Index Map of the Project area(Scale-1:8000) drains and intermediate drains to protect it from possible water table rise from excess irrigation and storm precipitation.

(iii) The high water level in the Hare river, which is the trunk drain for this farm, especially during rainy seasons, may prevent the outfall of water from irrigation waste as well as the storm precipitation from the farm. A part from this, there may be the danger of flooding of the farm itself. This point needs a detailed study.

Review of Methods for Estimating Drainage Coefficient

The drainage coefficient is the depth of water in mm which must be removed in a period of 24 hours for optimal crop production. The value of drainage coefficient depends on a number of factors e.g. intensity of rainfall, size and shape of watershed, antecedent moisture condition, hydrological soil group and the degree of protection required. In the following paragraphs various approaches for the estimation of drainage coefficient in agricultural watersheds have been briefly reviewed:

In Holland, the normal criterion states that with a drainage coefficient of 7 mm/day, the water table may not be higher than 50 cm below the soil surface for arable land and 40 cm below the surface for grass land. In France, a drainage coefficient of 9 mm/day is used when the water table is 30 cm below the ground surface (Luthin, 1973).

Luthin (1973) has reported the drainage requirement as the volume of water per unit time per unit area based on his experience for US condition as given in Table-1.

During 1960's and 1970's in Eastern England, the land drainage pumps were designed to have a capacity of 0.14 $m^3/s/Km^2$, the mean annual rainfall (MAR) for the area being 600 mm. On the other hand, in Western England, a capacity of 0.09 $m^3/s/Km^2$ was used, although the mean annual rainfall is 800 mm. The high standard of drainage reflects the high value of cash crops which can be grown in the Eastern England. On the other hand, the Western part of England grows predominantly grass land where some waterlogging will cause little damage (Smart and Harbertson, 1992).

US Soil Conservation Service (1972) has recommended the Curve number Method for the estimation of drainage coefficient for agricultural watersheds. It is a versatile and widely used method for the estimation of surface runoff. Ministry of Agriculture, Gov't of India utilized this method, for Indian condition (Water Management Manual, 1983) for the estimation of drainage coefficient The amount of surface runoff in depth unit i.e mm is estimated by following the two steps:

Step I : Estimate CN (Curve Number) with the help of tables/charts and calculate the potential maximum retention (S) by :

$$S = \frac{25400}{CN} - 254 \quad \text{in 'mm'} \qquad (1)$$

Step II : Take Ia = 0.1S or 0.2S or 0.3S as per the existing situation and calculate the surface runoff in depth unit by :

$$Q = \frac{(P - Ia)^2}{P + (S - Ia)} \quad \text{in 'mm'} \qquad (2)$$

Where P = Precipitation in mm &

Ia = Initial abstraction in mm

Based on the Curve Number method, Gupta et. al. (1971) worked out drainage coefficients for grain crops, vegetable crops and for low land rice separately for different parts of India. These values can be used for rough estimates of drainage design discharge, if no other data are available (Handbook for Drainage of Irrigated Areas in India, 1988).

Mazumdar (1983) gave Table-2 for the estimation of drainage coefficient.

Hudson (1983) gave another criteria for the estimation of drainage coefficient (Table-3).

Indian Standard IS : 8835 - 1978 has given the following criteria: The field drains should be designed for 3 days rainfall of 1 in 5 years recurrence interval. However, in special cases, requiring higher degree of protection, the drains may be designed for the recurrence interval of 1 in 10 years to 1 in 15 years. But the adoption of such a high frequency has to be justified in terms of economy.

Bhattacharya and Sarkar (1982) used 40 years rainfall data (1931-70) of Hoshangabad area in India for four monsoon months i.e. June, July, August and September to determine 1, 2, 3, 4 and 5 consecutive days rainfall of 1 in 5 years recurrence interval. They determined the above consecutive days

Table -2 Drainage Coefficient (Mazummdr, 1983)

Mean Annual Rainfall (MAR) in mm	<750	750 to 1000	1000 to 1250	1250 to 1500	>1500
Drainage Coefficient in mm/day	5 to 7.5	7.5 to 9	9 to 12	12-25	>25

Table-3 Dranage Coefficient (Hudson, 1983)

Mean Annual Rainfall (MAR) in mm	Drainage Coefficient in mm/day
≤1000	10
≥ 1000	MAR/100

Table-1 Drainage Requirement (Luthin, 1973)

Area (ha)	Drainage Requirement in litre/sec i.e. lps
0 - 16	12
greater than 16 to 32	21
greater than 32 to 360	6 litre/sec for each additional 16 ha area
400 to 1200	3 litre/sec for each additional 16 ha area

rainfall keeping in view that different crops have different tolerance periods. As per Roy (1993) drainage coefficient for an agricultural watershed may be taken as one percent of the mean annual rainfall for planning purpose in the absence of reliable data for its estimation.

Methodology

The drains are provided to carry storm runoffs, seepage from excess irrigation of fields. Since storm runoffs are usually far in excess from sub-soil seepage and the surface flow resulting from excess of the other flows, the surface drains are designed for storm runoffs only. The other small flows viz., seepage flow and the surface flow from excess irrigation will be taken care of by the drains designed to take storm runoffs.

The storm runoff can be estimated by hydrological studies of the area. It is, however, not necessary to design the drains for exceptionally intense storms because it will be quite uneconomical. Thus a judicious estimate of surface runoff should be made to obtain the design capacity of the drains. For example the drainage system on Sarda canal project in Utter Pradesh (India) was designed for a capacity of 0.109 cubic metre per Km^2 of the catchment area whereas in the Punjab (India), the drainage systems were designed for a capacity of 0.044 cumec per Km^2 of the catchment area (Modi, 1995).

Estimates of total storm runoff is needed for the hydraulic design of surface drainage channels. Gauged catchments provide the data for direct statistical analysis of stream flow, however, since few agricultural watersheds are gauged, it is more common for the stream flow to be estimated from rainfall. The design storm for drainage works is that for which the recurrence interval is acceptable. If, for example, an interval of 10 years is chosen, it can be expected that, on average over many years, the drainage system will run at capacity or over flow once in ten years. For this, the critical duration of rainfall is taken as the time of concentration of the catchment. A frequency curve is plotted for the intensity of rainfall of that duration. The records are examined and the annual maximum intencities for the given duration are listed in decreasing order and ranked, the greatest being given rank 1. The percentage of the total number of years recorded in which that rainfall is equaled or exceeded is calculated by the following formula:

$$\text{Percentage} = \frac{m}{N+1} * 100 \quad (3)$$

Where m = rank & N= total number of years of record.

For the present study the following approaches have been used for the estimation of drainage coefficient:

(i) 1 % of MAR approach (Roy, 1993)
(ii) Hudson's approach (1983)
(iii) Mazumdar's approach (1993)
(iii) Frequency Analysis approach (Bhattacharya and Sarkar, 1982 and Roy, 1993)
(iv) Curve Number method (Water Management Manual, 1983).

The rainfall data for 9 years were collected from AWTI meteorological station and the mean annual rainfall was calculated for the 23 years data by combining the rainfall records from Arbaminch estate farm and AWTI campus rain gauge station. Apart from this by measurement and visual observations, the hydrological soil cover, basic infiltration rate, slope of the farm and land use pattern were determined. Finally the results from above methods are compared and based on this some useful conclusions are drawn.

Table 4- Processed 9-Years Rainfall Data for the Project Area (1987-95)

Year	1-day max. rainfall (mm)	2-days max. rainfall (mm)	3-days max. rain - fall (mm)	4-days max. rainfall (mm)	5-days max. rainfall (mm)	6-days max. rain - fall (mm)	7-days max. rain - fall (mm)
1987	39.0	49.5	54.5	66.1	67.1	71.2	71.2
1988	46.9	55.7	67.1	70.1	70.8	85.2	103.0
1989	72.1	75.8	78.3	78.3	78.3	78.3	102.1
1990	39.3	60.4	64.8	67.0	67.3	68.3	78.5
1991	54.0	57.1	57.1	57.1	57.1	57.1	57.1
1992	71.2	73.0	96.5	110.2	123.9	126.4	126.4
1993	70.0	70.8	70.8	74.1	74.1	74.1	74.1
1994	38.0	42.7	62.3	62.3	63.6	83.0	84.8
1995	40.7	73.1	85.8	102.0	110.7	122.0	124.2

Table-5 1 in 5 Years 1 day,2 days..7days rainfall for the Project Area (1987- 95)

Duration	1 day	2 days	3 days	4 days	5 days	6 days	7 days
Rainfall in (mm)	71.2	73.1	85.8	102.0	110.7	122.0	124.2

Results and Discussion

The processed rainfall data for 9 years (1987 - 95) from the meteorological station situated inside AWTI campus are as given in Table-4 . After frequency analysis, the 1- day, 2-days, . . 7- days rainfall values are as given in Table-5. However, the mean annual rainfall was calculated for 23 years (1973 -95) data which included the data from both Arbaminch estate farm rain gauge station (1973 - 86) and AWTI campus rain gauge station (1987 - 95) . The value of mean annual rainfall was 790 mm. The land use pattern, the hydrological soil group and the condition of vegetation cover for the demonstration farm are as given in Table - 6. The results from the methods used for the estimation of drainage coefficient for the study area, based on the above data are as given in table 7, 8 and 9.

Thus, it is observed that 1 % of MAR approach and Mazumder's approach give almost the same result.

Table-6 Relevant Data for the study area

SL No.	Land Use	Area in ha (%)	Basic infiltration rate in mm/hr	Soil Cover condition	Hydrological soil group
1	Fallow	57.0 (52)	10	Poor	C
2	Straight Row Crops:				
	(i) Banana	12.0 (11)	10	Poor	C
	(ii) Maize	41.0 (37)	10		C
	Sub Total :	53 ·0 (48)			
	Total :	**100(100)**			

Table -7 Drainage Cofficient for the Study Area (MAR = 790mm)

SL No	Name of Method	Drainage Coefficient (D. C.) in (mm/days)	Remarks
1	1% or MAR	8	.01 x 790 = 7.9 ≈ 8 mm/day
2	Hudson (1983)	10	Since MAR < 1000 mm ∴ D. C. = 10 mm/day
3	Mazumdar (1983)	8	Refer Table - 2

However, this value of drainage coefficient is the lowest among all the methods used in this study i.e 8 mm/day. Hudson's approach gives a slightly higher value of drainage coefficient i.e. 10 mm/day. However, all the above three methods are purely empirical, therefore, these values of drainage coefficient should be used with caution.

The frequency analysis approach and the curve number method give higher values of drainage coefficient i.e. 36 mm/day and 30 mm/day for one day rainfall of 1 in 5 years recurrence interval, respectively (Table-8 & 9). However the common field crops can tolerate waterlogging for 3 days period without reduction in their yields. Since the above values of drainage coefficient are for 1 day rainfall, hence their values are high. Therefore, it is reasonable to use the drainage coefficient for 3 days rainfall of 1 in 5 years recurrence interval as per frequency analysis approach i.e 14 mm/day (Table-8) by assuming the tolerance period of crop as 3 days.

The period of rainfall data for frequency analysis as well as curve number method was very short i.e 9 years only. The preferable rainfall period for such an analysis is 15 - 30 years. Therefore, for above two methods, it is better to use the data for a minimum period of 15 years. But it is always preferable to get accurate value of drainage coeffi-

Table-8 Drainage Coefficient for the study Area Based on Frequency Analysis Approach

Tolerance period of the crop	1-day	2-days	3-days	4-days	5-days	6-days	7-days
Drainage Coefficient in (mm/day)	36	18	14*	13	11	10	9

* The sample calculation for the frequently Analysis approach is as given below:

Soil texture of the area under study : Silt loam

Tolerance Period of the Crop : 3 days

Slope of the area under study : flat (<0.5%)

Surface runoff Coefficient : 0.5 (assumed)

1 in 5 years rainfall of 3 days duration : 85.8 mm (Table 5)

$$\therefore \text{ Drainage coefficient} = \frac{0.5 \times 85.8}{3} = 14.3 \approx 14 \text{ mm/day}$$

Table-9 Drainage Coefficient as per Curve Number Method

Area (ha)	Land use	Soil cover condition	Curve number CN for Hydrologic soil group - C, AMC - II and Ia = 0.3S	CN for AMC - III	Multiplication of column(4) & column (5)
(1)	(2)	(3)	(4)	(5)	(6)
57.0	Fallow	Poor	91*	96*	5472
53.0	Straight: row crops	Poor	88*	95*	5035
				Total :	10,507

* Curve numbers (CN) has been determined as per Water Management Manual, 1983.

∴ Weighted Average CN = 10,507/110 = 95.5

1 in 5 years rainfall for 24 hours duration = 71.2 mm (Table - 5)

∴ Estimated 6 hr rainfall = 0.6 x 71.2 = 42.72 mm

$$\therefore \quad S = \left(\frac{25400}{95.5} - 254\right) = 11.97\ mm \qquad \text{from eq}^n \ \text{-----}(1)$$

$$\therefore \quad Q = \frac{(42.72 - 0.3 * 11.97)^2}{42.72 + 0.7 * 11.97} = 29.96\ mm \qquad \text{from eq}^n \ \text{-----}(2)$$

∴ Drainage Coefficient = 29.96 mm/days
≈ 30 mm/day.

cient by the measurement of out-flow from the existing drains in the surrounding areas.

Conclusions

Based on the above results and discussion, the following conclusions may be drawn:

(i) The drainage coefficient is of paramount importance in the design of any drainage system. Therefore, every possible effort should be made to determine it as accurately as possible.

(ii) In Arbaminch area, the drainage coefficient of 14 mm/day may be taken for the design of surface drainage system. This result is obtained from frequency analysis approach assuming the crop tolerance period equal to 3 days. However, it is better to process 15-30 years rainfall data to get more reliable result for drainage coefficient.

(iii) 1% of MAR approach, Hudson's approach and Mazamdar's approach are purely thumb-rules based on experience. Therefore, any of these methods should be used in the absence of adequate data and for planning purposes only.

(iv) The curve number method has given the highest value of runoff i.e 30 mm/day. It may be attributed to two reasons: first reason is the very short period of processed rainfall data i.e. 9 years only and second one is the non consideration for the tolerance period of crops.

(v) It should be always preferred to get the drainage coefficient by the actual measurement of outflow from the existing drains in the surrounding areas.

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Estimation of Usable Storage for an Ungauged Watershed

Taffa Tulu, *Ambo College of Agriculture, P.O.Box 19, Ambo, Ethiopia*

Abstract

A method of determining usable storge for ungauged watershed was developed. Four watersheds having measurements of streamflows and the necessary meteorological variables were used to determine useful parameters by using a deterministic physically based conceptual hydrologic model. The derived parameters were used for the simulation of hydrologic events of ungauged watershed. The simulated streamflows were applied to the determination of usable storage from the storage balance of a reservoir used for agricultural purpose. The procedure is useful for the estimation of usable storage in an ungauged watershed or for regions in shortage of observed hydrological data.

Introduction

The basic problem of water distribution of the world is the temporal and spatial differences in the supply and demand of water. The general solution of this problem lies in the adjusting water supply and demand so that the demand will be always smaller than or equal to the supply. The storage of water is one of the most useful methods for changing the amplitude and phase of the water supply. Such storage of water can be done only through the knowledge of the water resources of the region being considered.

A deterministic hydrologic model called HYBSCH, which was developed in the Technical University of Dresden in Germany (Miegel, 1988) and modified by Taffa Tulu (1989 and 1991) for the central highlands of Ethiopia, was used in the determination of useful parameters (Table 1) on the bases of four gauged watersheds in western Shewa. These parameters were determined through the process of calibration against observed data of streamflow. The period of comparison was 19 years for Indris, Bite and Guder watersheds and 14 years for Belo watersheds. The derived parameters were used in the simulation of streamflow for ungauged watershed. The simulated streamflows were applied for the determination of storage balance and usable storage which are essential for the design of a reservoir.

The mass curve method, the sequent peak algorithm method and the Monte-Carlo-Method (Dyck, 1980; Linsley, et al., 1985; Gurtz, et al., 1987) were compared with each other for the estimation of usable storage in the central highlands of Ethiopia (Taffa Tulu, 1989). The comparison showed that the Monte-Carlo-Method balances the results more accurately than the other methods being considered.

Frequently used abbreviations

- Q = discharge reaching a reservoir
- Qin = inflow to a reservoir
- Ac = catchment area
- Ve = total volume of evaporation in a month
- Ass = surface area of storage
- Ew = evaporation from free water surface
- RET = real evapotranspiration
- Qmin = minimum outflow
- Qir = amount of water for irrigation requirement
- Sb = filling of storage at the beginning
- Se = filling of storage at the end
- Sh = auxiliary quantity for balancing
- O = overflow
- B = balanced storage
- Ta = air temperature
- Dsa = actual duration of sunshine
- Rh = relative humidity
- Ws = wind speed

Materials and Methods

The considered ungauged watershed is that of the Teltele River which is a tributary of the Guder River. The geological and morphological conditions as well as the vegetation cover of the Teltele watershed is similar to that of the Guder watershed. These enable the application of the necessary parameters of the Guder watershed (Table 1) to the Teltele watershed. The simulation of the mean monthly streamflows for the Teltele River using HYBSCH model was carried out for a period of 1966 - 1984 (Table 2) in which these values of streamflows were used for the storage balance determination of the suggested Farise Reservoir on Teltele River.

The required amount of water for irrigating the vegetable farm of Ambo College was estimated (Table 3) depending on the works of Taffa Tulu (1987 and 1989) in which irrigation schedule of onion farm was taken as an example (Table 4). The evaporation from open water surface of a reservoir was computed after Penman (1948) and Richter (1977) (Table 5). Input data were the air temperature in °C, actual duration of sunshine in hours per day (h/d), relative humidity in % and wind speed in m/s. In most of the watersheds in Ethiopia, data for wind speed at the site of reservoirs are not available. The method after Richter (1977) was chosen for this work for it doesn't require wind speed as input data (Taffa Tulu, 1994).

The usable storage was determined after Monte-Carlo-Method. The input data for the method are inflow, evaporation from open water surface, minimum outflow, infiltration loss and the needed amount of irrigation water (Gurtz, et al., 1987). The discharge, Q, was converted to inflow to a reservoir (Qin per month) by means of the catchment area up to the dam location (Ac in

Table-1 Soil parameters for the Guder Watersed in Western Shewa
***Note: QG** = grounwater*

Soil Parameters	Indris	Bite	Belo	Guder
Total soil depth in mm	950.0	1800.0	870.0	1000.0
Intial storage for QG1in mm	15.0	10.0	15.0	15.0
Intial storage for QG2 in mm	55.0	40.0	55.0	55.0
Storage constant for QG1 in month	1.0	0.7	1.0	1.0
Storage constant for QG2 in month	14.0	12.0	14.0	14.0

km²), which is 17 km² for the Farise Reservoir.

$$Qin = 0.001Ac*Q \quad (1)$$

The total evaporation volume (Ve) of a month is given as follows (Gurtz, et al., 1987):

$$Ve = 0.001Ass*(Ew - RET) \quad (2)$$

Where Ass is surface area of storage in km² (for Farise Reservoir Ass = 0.0345 km²), Ew is evaporation from free water surface of the reservoir and RET is real evapotranspiration from land surface which is computed using HYBSCH model. The minimum outflow was determined by means of the sequent peak algorithm to be 0.5 hm³ (500000 m³) per month. Depending on Tables 3 and 4, the monthly irrigation water requirements (Qir) were given (in 10^6 m³ or hm³) as 0.120 hm³ for January, 0.096 hm³ for February, 0.080 hm³ for March, 0.064 hm³ for April, 0 hm³ for May to October, 0.080 hm³ for November and 0.080 hm³ for December.

The storage balance was carried out after Gurtz, et al. (1987) based on a critical period of 1972/1973, which is the driest period from the historic record of 1966 to 1984. The balancing was done in a simplified form as follows:

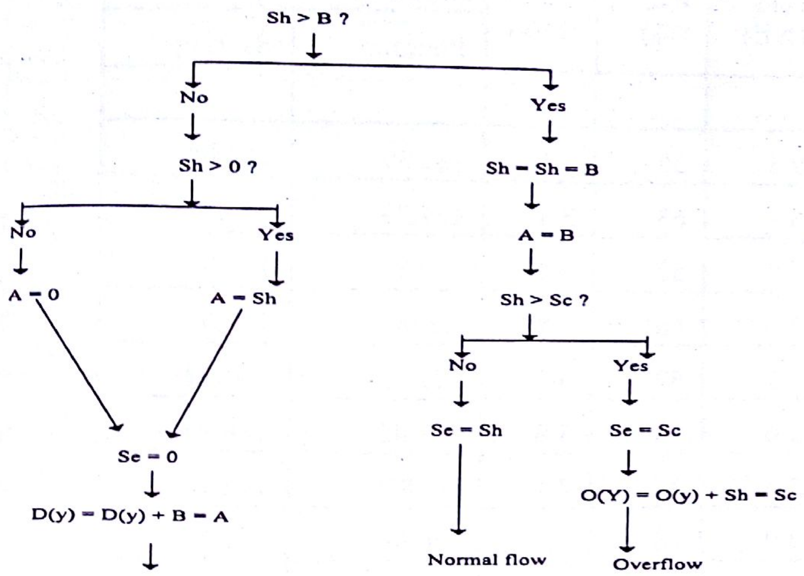
$$Sh = Sb + Qin - Ve - Qmin \quad (3)$$

$$B = Qmin + Qir \quad (4)$$

Table - 2 Simulated monthly Stream flows in mm for the Teltele Watershed

Year	Jan	Fe	Ma	Ap	May	June	July	Aug	Sept	Oct	Nov	De
1966	13	7.0	4.6	3.5	3.0	4.0	142.4	160.2	188.7	13.0	7.1	4.8
1967	3.8	3.3	3.0	2.7	4.3	17.1	215.8	206.1	138.2	124	10.2	6.2
1968	4.6	3.8	3.4	3.1	2.8	66.0	161.4	139.0	150.9	12.0	6.8	4.7
1969	3.8	3.3	3.0	6.2	7.0	121.2	163.3	165.9	117.3	11.5	6.6	4.6
1970	3.8	3.3	3.9	3.6	2.9	39.7	231.0	239.3	94.1	11.2	6.6	4.7
1971	3.8	3.4	3.1	2.8	4.5	94.6	136.7	196.1	125.1	12.3	6.9	4.8
1972	3.8	3.3	3.0	2.8	2.6	2.4	80.5	126.4	88.8	8.7	5.0	3.5
1973	2.8	2.5	2.3	2.1	10.2	60.6	151.6	141.5	66.3	8.1	4.7	3.4
1974	2.7	2.4	2.2	2.0	1.9	69.3	159.9	190.1	186.8	13.4	7.2	4.7
1975	3.6	3.1	2.8	2.6	2.5	91.2	237.0	259.7	142.5	14.4	8.0	5.4
1976	4.3	3.8	3.4	3.1	40.6	95.3	159.8	172.1	83.3	10.5	6.3	4.6
1977	3.8	3.4	3.1	2.8	2.6	77.1	192.4	207.9	164.5	113	11.7	7.0
1978	5.0	4.1	3.7	3.3	4.2	33.9	162.7	187.8	157.4	13.4	7.5	5.2
1979	4.1	3.6	3.3	3.0	35.3	42.4	117.6	224.6	167.2	29.9	8.1	5.3
1980	4.1	3.5	3.1	3.4	20.3	178.3	209.1	225.2	139.5	13.4	7.7	5.4
1981	4.4	3.9	3.5	3.2	3.2	106.2	214.8	225.3	154.2	17.4	8.4	5.7
1982	4.5	3.9	3.5	3.3	3.2	63.4	97.7	149.9	132.7	86.5	20.3	6.7
1983	4.6	3.6	3.2	2.9	125.4	38.3	150.4	215.9	172.4	51.6	9.4	6.0
1984	4.5	3.8	3.4	3.1	2.9	32.2	232.6	131.5	74.4	9.4	5.7	4.1
Mea-n	4.5	3.6	3.2	3.1	14.7	64.9	169.3	187.6	133.9	30.2	8.1	5.1

where y is an index representing a given month; Sb and Se are filling of storage at the beginning and at the end of a month respectively; Sh is auxiliary quantity for balancing; Sc is assumed



storage capacity; A is possible storage output; B is balanced storage output; D(y) is auxiliary quantity for calculating average monthly deficits; and O(y) is auxiliary quantity for calculating average monthly overflow.

For the computation, the simulated streamflows of 1972 and 1973 (Table 2), the evaporation from open water surface after Richter (Table 5) and the real evapotranspiration calculated with the help of HYBSCH model were used.

Results and Discussion

Table - 3 Irrigation application and intervals for vegetable farm in Abmo College
Note: Dtz =depth of root zone in m; Da = depth of application in mm; Daa = actual depth of application in mm

Crop	Drz (m)	Da (mm)	Daa (mm)	Irrigation interval (T) in days					
				N	D	J	F	M	A
Cabbage	0.5	100	50	12	9	9	12	13	10
Carrot	0.8	160	80	19	15	15	19	20	16
Onion	0.4	80	40	9	7	7	9	10	8
Potatoes	0.5	100	50	12	9	9	12	13	10
Tomatoes	1.1	220	110	26	20	21	27	27	22

Table - 4 Irrigation Schedule for the onion farm of Ambo College of Agriculture
Note: Ian = number of Irrgation application; Da = dept of application in mm

Month	J	F	M	A	M	J	J	A	S	O	N	D
Ian	3	2	2	2	0	0	0	0	0	0	2	2
Da	40	40	40	40	0	0	0	0	0	0	40	40

In computing the balance of storage, the considered minimum outflow (Qmin) of 0.5 hm^3/month was secured by keeping Sh not to be negative. For this purpose, the filling of storage at the beginning of January was taken to be equal to 2.72 hm^3 (Table 6 column 8). At the end of December 1973 the filling of storage should be approximately equal to this value, so as to secure the minimum outflow of 0.5 hm^3/month. For this purpose, the auxiliary magnitude for balancing Sh was taken at the end of August to be equal to 4 hm^3. Under this assumption, the filling of storage at the end of December 1973 was computed to be equal to 2.761 hm^3 (Table 6 column 9). The computation, therefore, gave a usable storage of 4 hm^3 for the suggested Farise reservoir on the Teltele River. This usable storage secures a certainity of almost 100% in water supply for a referenced period of 1966 - 1984. In addition, volumes of sedimentation and flood control can be considered in the design of the reservoir.

Conclusion

The investigation showed the possibility of designing a reservoir in an ungauged watershed. The parameters of a gauged watershed can be used for the simulation of hydrologic events for an ungauged watershed. These hydrologic events can be used for estimating usable storage in the ungauged watershed. The estimation of a usable storage is a prerequisite for the design of a reservoir. The method is important especially for countries like Ethiopia, where only limited streams do have gauged streamflows.

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Note :for abbreviation refer to the end
Note: for abbreviation refer to the end of introduction part

Note: for abbreviation refer to the end

Table - 5 Monthly evaporation from free water surface after penman and Richter

Year/ month	Ta (°C)	Dsa (h/d)	Rh (%)	Ws (m/s)	Ew in mm after	
					Penman	Richter
1972						
January	15.6	9.3	55	4.1	181.39	264.64
Feb.	15.7	6.8	63	3.4	127.79	227.16
March	17.0	8.9	52	4.4	179.37	154.91
April	16.6	5.1	68	2.8	98.90	129.95
May	17.6	8.1	52	5.1	157.55	204.52
June	16.8	5.6	60	8.0	218.05	128.99
July	15.7	2.6	77	2.1	57.81	112.76
August	15.5	4.0	76	3.4	81.84	101.80
Sept.	15.9	5.5	69	4.2	120.00	130.36
October	15.9	8.6	53	4.5	192.97	211.50
Nov.	15.6	9.7	54	4.2	185.93	156.64
Dec.	15.4	9.5	55	3.8	176.63	188.78
1973						
January	16.5	9.7	56	4.0	180.47	272.87
Feb.	17.5	9.9	40	5.1	256.64	327.58
March	19.1	10.0	39	4.7	253.54	219.70
April	19.7	8.1	43	5.0	241.03	235.40
May	17.8	6.3	57	4.7	174.03	214.58
June	16.8	4.9	66	3.2	106.87	112.32
July	15.9	3.1	78	2.5	63.56	115.81
August	15.4	2.5	82	2.5	51.46	79.19
Sept.	15.5	4.6	74	3.8	95.58	111.97
October	15.1	8.2	57	5.6	199.21	194.54
Nov.	14.3	10.1	52	4.5	200.44	154.05
Dec.	12.9	9.3	49	4.6	207.06	183.19

***Note:** for abbreviation refer to the end of introduction part*

Table - 6 Storage balance for the Parise Reservoir after Monte-Carlo-Method

Year/ mon.	Q (mm)	Qin (hm^3)	Ew (mm)	RET (mm)	Ve (hm^3)	Qmin (hm^3)	Sb (hm^3)	Sh (hm^3)	O (hm^3)	Qir (hm^3)	B (hm^3)
1972											
Jan.	3.8	0.065	264.6	43.6	0.008	0.50	2.720	2.277	0	0.120	0.620
Feb.	3.3	0.056	227.2	27.5	0.007	0.50	2.277	1.826	0	0.096	0.596
Mar	3.0	0.051	154.9	58.1	0.003	0.50	1.826	1.374	0	0.080	0.580
Apr	2.8	0.048	130.0	53.3	0.003	0.50	1.374	0.919	0	0.064	0.564
May	2.6	0.044	204.5	91.1	0.004	0.50	0.919	0.459	0	0.000	0.500
June	2.4	0.041	129.0	127.5	0.000	0.50	0.459	0.000	0	0.000	0.500
July	81.7	1.389	112.8	43.3	0.002	0.50	0.000	0.887	0	0.000	0.500
Aug.	126.4	2.149	101.8	60.5	0.001	0.50	0.887	2.535	0	0.000	0.500
Sept.	88.7	1.508	130.4	103.4	0.001	0.50	2.535	3.542	0	0.000	0.500
Oct.	8.7	0.148	211.5	125.8	0.003	0.50	3.542	3.187	0	0.000	0.500
Nov.	5.0	0.085	156.6	62.1	0.003	0.50	3.187	2.769	0	0.080	0.580
Dec.	3.5	0.060	188.8	46.5	0.005	0.50	2.769	2.324	0	0.080	0.580
1973											
Jan.	2.8	0.048	272.9	24.5	0.009	0.50	2.324	1.863	0	0.120	0.620
Feb.	2.5	0.043	327.6	14.5	0.011	0.50	1.863	1.395	0	0.096	0.596
Mar	2.3	0.039	219.7	9.9	0.007	0.50	1.395	0.927	0	0.080	0.580
Apr	2.1	0.036	235.4	53.3	0.006	0.50	0.927	0.457	0	0.064	0.564
May	9.7	0.165	214.6	71.8	0.005	0.50	0.457	0.117	0	0.000	0.500
June	60.2	1.023	112.3	70.0	0.001	0.50	0.117	0.636	0	0.000	0.500
July	151.6	2.577	115.8	48.2	0.002	0.50	0.636	2.714	0	0.000	0.500
Aug.	141.5	2.406	79.2	39.0	0.001	0.50	2.714	4.000	0.619	0.000	0.500
Sept.	66.3	1.127	112.0	82.4	0.001	0.50	4.000	4.000	0.626	0.000	0.500
Oct.	8.1	0.138	194.5	135.5	0.007	0.50	4.000	3.631	0	0.000	0.500
Nov.	4.7	0.080	154.1	61.6	0.003	0.50	3.631	3.208	0	0.080	0.580
Dec.	3.4	0.058	183.2	32.9	0.005	0.50	3.208	2.761	0	0.080	0.580

Note: for abbreviations to their list at the end of the intrduction part

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4th Symposium on Engineering Turbulence Modelling and Measurements. Corsica, France, 24-26 May, 1999

Topics : Eddy-viscosity and second-order closure models; Direct and large-eddy simulations and deductions for conventional modelling; Measurements and visualisation techniques; Turbulence control; Transition and effects of curvature, rotation and buoyancy on turbulence; Heat and mass transfer and chemically reacting flows; Compressible flows, shock phenomena; Two-phase flows; Applications in aerospace engineering, turbomachinery and reciprocating engines, industrial aerodynamics and wind engineering, and selected chemical engineering problems. Contact: D. Laurence, EDF DER, Laboratories Nation d' Hydraulique, B.P.
49,78401 Chatou cedex, France.
tel.: + 33-1-30-877257
fax: + 33-1 30-878086
e-mail: Dominique. laurence @ der. edfgdf.fr

8th Int. Conference on Urban Storm Drainage Sydney, Australia, 30 August - 3 September 1999

Topics: Urban drainage hydraulics; Roof and property damage; Water quality; Impact assessment and controls ; Modelling of drainage systems and receiving waters; Integrated urban drainage planning and management; Policies and regulatory programs, emerging issues.
Sponsoring organisations: **IAHR (Joint IAHR/ IAWQ Committee on Urban Storm Drainage)**, IAWQ, IE Australia
Contact: Dr.J.Ball (ICUSD99), UNSW
Water Research laboratory, 110 King
Street, Manly Vale NSW 2093, Australia
Fax: + 61 2 9949 4188
e-mail: J.BALL @ UNSW. edu.au

Int. Conference on Calibration and Reliability in GroundWater Modelling Model CARE '99
Zurich, Switzerland, 20-23 September 1999.

Topics: Comprehensive use of Field information; Model Calibration; Reliability of model predication; Stochastic modelling; Modelling Concepts; Data processing; Selected special focus.

Sponsoring organisations: IAHR (Groundwater Section) ETH, IAHS, EAWAG, UNESCO.
Contact: ETH, Institute of Hydromechanics and water Resources Management, ETH-Hoenggerberg, Ch-8098 Zurich, Switzerland
Tel: + 41-1-633-3075
fax: +41-1-633-1061
e-mail: stauffer @ihw.baum.ethz.ch
Fifth Int. Conference on Coastal & port Engineering in Developing Countries. (CopEDECV)
Cape Town, South Africa, April 1999
28th IAHR Biennial Congress " Hydraulic Engineering for Sustainable Water Resources Management at the turn of the Millennium"
'Graz, Austria, 23-27 August 1999
Topics: Theme A: Sub-surface hydraulics and engineering
Theme B: Hydraulic structures
Theme C: Information technology in water resources modelling and management
Theme D: Hydraulics in a vulnerable environment -geosphere, hydrosphere, atmosphere
Theme E: Fluvial systems -processes, functions and management
sponsoring organisations: IAHR,

Effectiveness of land preparation methods in surface drainage

Teklu Erkosse, P.O. Box 32, Debrezeit, Ethiopia

Abstract

Vertisols, which cover over ten percent of the total land mass of Ethiopia, are under utilized under the traditional management system due to severe water-logging and moisture deficit during the main rainy season (July to August) and the end of the growing season (December to May), respectively. To partly bridge the gap, different surface drainage methods were evaluated for their effects on crop yield. Among such practices, a surface drainage method, broadbed and furrow (BBF), was recently introduced although the basic technology has been in use traditionally since antiquity. The BBF system improves yields over the traditional methods of ridge and furrows (RF) and flat (FL). Yet little is known of the effectiveness of the improved technology and that of the traditional methods on runoff and root-zone soil water balance.

To this end, a field experiment was conducted at Ginchi on a pellic Vertisol in 1996/97 to evaluate the above surface drainage methods (BBF, RF and FL) using durum wheat (*Triticum durum*) as the test crop. The runoff per unit area relative to measured rainfall was determined using runoff plots. Soil moisture content was determined gravimetrically while the FAO CROPWAT model was used to calculate the Penman-Monteith reference evapotranspiration (ETo) and crop consumptive use (ETc).

Of the total seasonal rainfall [1](rainfall as the start of runoff measurment) of 387 mm, BBF and RF resulted in substantial increases in surface drainage thus transforming 53% and 44% of incident rainfall into runoff, respectively. The finding could help develop technologies to mitigate inefficient water use. In addition, it would enhance water utilization for prospective dry season cultivation for double cropping, thereby increasing land use efficiency. Furthermore, it would promote crop-livestock productivity, as a consequence of increasing the availability of water for human and livestock use.

1. Introduction

The importance of water as an essential part of all living cells can by no means be over estimated. Life can hardly be imagined without it. Firenze (1996) explains that almost every process occurring in plants is affected by water. He also distinguishes four main functions in which water plays a major role:

1. Water is the major constituent of physiologically active plant tissue;
2. It is a re-agent in photosynthesis;
3. It is the solvent in which salts, sugars and other solutes move from cell to cell, and from one part of the plant to the other;
4. It is an essential element for maintenance of plant turgidity necessary for cell elongation and growth.

As with most biological conditions, the availability of water has an optimum- there can be too much, or too little for good progress of the above processes. Animals are not exceptions to the problems of such extremes.

In the case of the Ethiopian highland Vertisols areas both problems are often exhibited. During most of the main rainy seasons, since the rate of precipitation is far above infiltration rate, water ponds on the land surface. This results in poorly aerated root environment. Consequently, all cultivation activities and crop performance are constrained. Few weeks after the end of the rainy season, on the other hand, due to the high evaporative demand of the environment, the soil starts to dry up. Although these soils have a tremendous water holding capacities, due to the nature of their clay mineralogy, cohesive force with water and cracking up on drying, the availability of water for most annual crops is limited Consequently crops suffer of water deficit. Therefore, land drainage, or the combination of drainage and irrigation, is one of the most important input factors to improve yields per unit of farmed land to feed the ever increasing population of Ethiopia.

In this paper, an attempt is made to show how much water is practically in-excess of crop consumptive use during part of the season and other forms of loss under different land management practices. Three land management practices: broadbed and furrows, ridge and furrows and flat seed beds were considered.

2. Materials and Methods

2.1The study area

The experiment was conducted on the Vertisol at Ginchi (38 E , 9 N and 2200m asl) under natural rainfall during the 1996 main rainy season. The site is characterized by mean annual rainfall of 1148 (mm), and mean annual temperature of 17°C. Derived from weathered basalt, deeper than 1 m, with 67% clay content at the surface layer, the soil is classified as pellic Vertisol (FAO, 1985). The drainage of the area is described as imperfect with slight sheet and gully erosion. The land use is mostly cultivated field crops: wheat, tef, lentil and chickpea being the major crops. The flood plains are the major grazing areas during the dry seasons (Teklu, 1997).

2.2Treatments

Three methods of land preparation arranged in RCB design with four replications were used.

These are:

a. Broad bed and furrow (BBF): is known to facilitate surface drainage through the furrows between the beds (Jutizi and Mesfin, 1987). With effective bed size of 80 cm and 20 cm wide furrows, it was constructed by the broad-bed maker (BBM) which is a low cost oxen-drawn Ethiopian traditional thyne plough that has been modified for the construction of raised beds and furrows with 20 cm high and 120 cm wide. This is the recommended improved surface drainage technique for crops sensitive to waterlogging like durum wheat.

b. Ridge and Furrow (RF): is constructed with the traditional thyne-plough after the seed was broadcast by hand such that the crop would grow on the ridges permitting the excess water to drain out of the fields through the furrows. These are "parallel" narrow structures of about 20 cm in depth and 30 cm across. This is a practice believed to be safe and sustainable alternative for the area.

c. Flat seed bed (FL): is prepared through several criss-cross ploughing to dislodge weeds and create a uniform and level seed bed. Once the seed is broadcasted, it is further ploughed with the objective of covering the seed to ensure germination. This is usually done by animal drawn plough. It is the common traditional practice and taken as control for this experiment.

2.3 Experimental set-up and data recording

The experimental field was cultivated three times using the local oxen drawn plough before the time of sowing. The plot size was 4.8m x 5m. All recommended agronomic practices were followed except the sowing date. There were two sowing dates: June 29, for the drained plots (BBF and RF) and August 12, 1996 for the control plots (FL) to simulate farmers' practice.

2.3.1 Runoff measurement

To hydrologically 'isolate' the plots from the adjacent area and collect all the runoff from the controlled plots, iron sheet boundaries were installed around each plot. Multi-slot divisors which are generally used for measuring runoff volume from small plots (Pathak, 1992; FAO, 1993) were used. There were three runoff collectors connected by plastic tubes in series. The first runoff collector boxes (FRCB) has 9 slots of equal sizes spaced at the same level and fixed intervals. The second runoff collector boxes (SRCB) had five slots arranged in the same manner as FRCB. The third runoff collector was a 200 liter barrel. The runoff collectors were arranged in such a way that the FRCB collect all the runoff from the controlled plots and convey a known fraction of it to the SRCB. Similarly, the SRCB collect all the runoff delivered to them by the FRCB and convey a known fraction of it to the third runoff collectors while the third runoff collectors were to retain all the runoff delivered to them.

2.3.2 Crop water use

Durum wheat variety *Boohai* was used as the test crop. The reference evapotranspiration (ETo) as well as the water consumptive use of the crop expressed as evapotranspiration (ETc) was estimated using CROPWAT7 model (FAO, 1993). For this analysis the geographic location of the area, altitude above sea level, monthly meteorological data including: rainfall, minimum and maximum temperature, wind speed, sunshine hours, relative humidity and sowing date (Appendix I) were the input data.

The length of growth period partitioned into four stages of development with its respective crop coefficient (kc) and rooting depths was considered in the model to convert the reference evapotranspiration to crop evapotranspiration. A maximum equivalent rooting depth of 0.6m was assumed since the very poor aeration of the lower profile, when roots are actively growing, does not encourage the vertical growth of the roots.

2.3.3 Soil Moisture Content

Soil sampling was made every ten days from separate plots adjacent to the runoff plots to avoid disturbance. Root zone soil moisture content was determined gravimetrically at two depth ranges (0 - 30 and 0 - 60 cm). The moisture content in dry weight bases was calculated as:

$$MCF = (Wetwt - Drywt)/Drywt \qquad (2.3)$$

where, MCF = Moisture Content Fraction
Wetwt = Wet weight (gm)
Drywt = Dry weight (gm)

The regression equation of moisture content and bulk density developed for the area from Selamyihun, (1996) who collected saturated core samples and measured the change in volume of the samples with the change in moisture content, was used to calculate the bulk density of the soil at respective MCF. The resulting bulk density was used to convert the MCF to volumetric moisture content as:

$$VMC = MCF * BD_m \qquad (2.4)$$

Where, VMC = Volumetric moisture content(cm^3)
MCF = Moisture content fraction
BD_m = Bulk Density at respective MCF

The volumetric moisture content at the two depth ranges were added up to get the total moisture content over the assumed equivalent rooting depth (0.6m). The moisture stock in the profile (mm) was calculated as:

$$Stockmoisture(0\text{-}60) = VMC(0\text{-}30)*300 + VMC(30\text{-}60)*300 \qquad (2.5)$$

or

$$Stockmoisture(0\text{-}60) = VMC(0\text{-}60)*600 \qquad (2.6)$$

2.4 Data Analysis

Different statistical analysis including the analysis of variance and mean separation (LSD) was made to know whether there is a significant difference between the means of each parameters as affected by the land preparation methods. Simple correlation and regression analysis was made to see whether there was a meaningful relationship between rainfall and runoff under the treatments. This was done both for the daily and decade data.

The effects of the treatments and climatological parameters on the components of water balance; rainfall, run-

Table -1 Runoff as affected by land preparation methods on Vertisols

		Runoff (mm)		
Decades	Rainfall(mm)	BBF	RF	FL
1*	31.20	-	-	-
2*	79.75	-	-	-
3	41.16	20.80	18.87	12.86
4	86.90	56.48	46.78	40.54
5	65.10	36.36	27.46	18.75
6	51.10	33.92	30.71	22.30
7	50.40	11.72	9.35	6.96
8	58.00	22.09	16.01	11.77
9	33.10	25.20	19.60	18.43
10	0.60	0.17	0.16	0.05
Total		206.74^{A}	168.94^{B}	131.66^{C}

LSD(5%) = 3.6 (mm); * runoff was not measured; CV(%) = 33.84
Totals followed by the same letter are not statistically different at 95% confidence interval

off, change in profile soil water and crop water use were analyzed. The interception loss and net discharge (q) at the bottom of the profile, which was believed to be too small for the saturated Vertisols, were neglected.

Owing to the objectives of the study and limited by data available, the water balance analysis was done only for the growth period of the crop. One of the important components of the water balance, the crop water requirement, was estimated by the CROPWAT7 model which is entirely based on pen-man Montheith method.

The ETc value was used together with the other water balance components determined in forgoing procedures for the water balance analysis. In the water balance analysis, from the continuity principle, the net balance of the inflows and outflows of water should be equal to change of storage. This means that the difference between the inflows on one hand and the outflows and change in storage on the other should be equal to zero

3. Results and Discussion

3.1 Runoff

Runoff measurement was made only during the eight decades as of the third decade after sowing of the drained plots (Table 1). Apparently, there was significant difference between runoff from the three land preparation methods resulted from the same rainfall (387mm). The highest total runoff (206.74 mm) was from the BBF plots followed by 168.94 and 131.66 mm from RF and FL respectively.

Considering the mean of the three land preparation methods, the highest mean runoff per decade (47.93 mm) occurred during the fourth decade in response to the corresponding highest rainfall (86.90 mm). This indicates that very excess water exists earlier in the season when crops require only little quantity of water (Table 2). As a result, if water harvesting is to be considered, the construction or maintenance of the storage systems has to be ready before this time to catch such a heavy discharge. Also, down stream soil erosion control measures have to be taken before this critical time.

Out of the total rainfall occurred during the same period, 53, 44 and 34 percent was removed as surface runoff (drainage) from BBF, RF and FL plots respectively. This can be an indicator of the relative effectiveness of the methods in draining the excess water. Hence, the BBF plots are the most

Figure - 1 (a-c) Scatter diagram of daily runoff as a function of daily rainfall for three land preparation methods

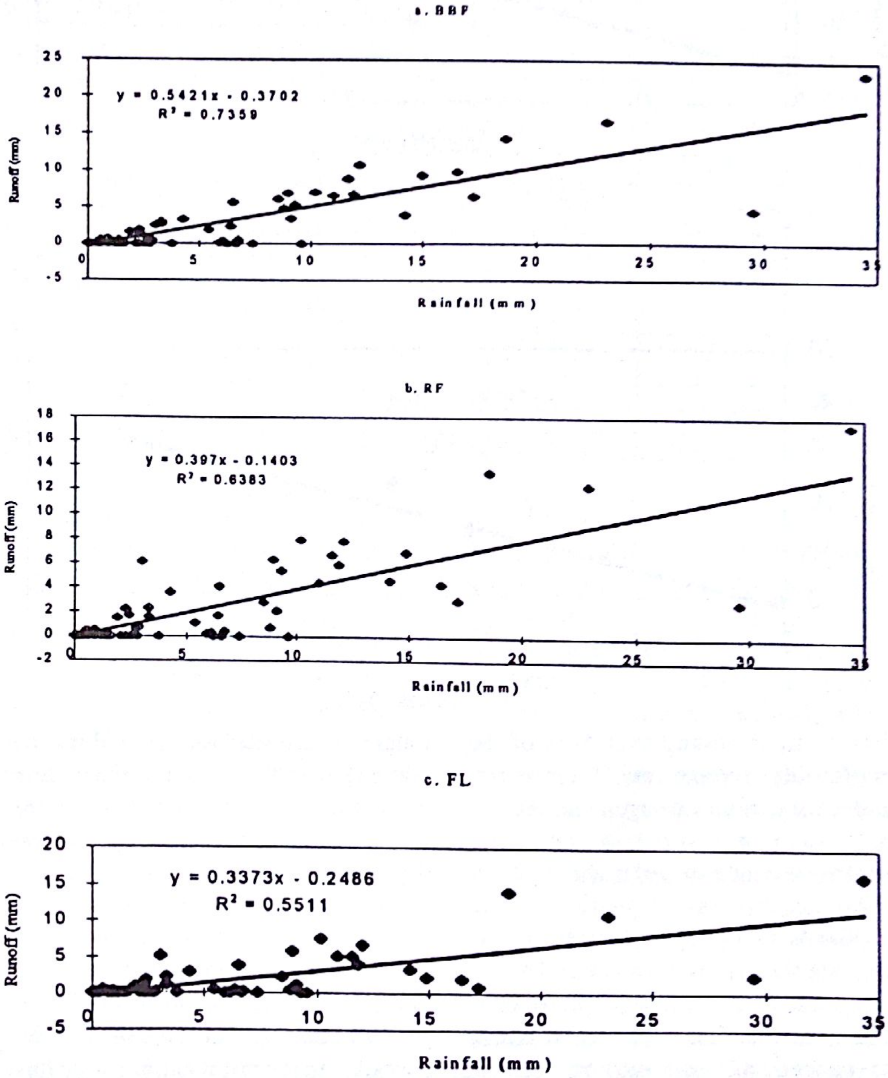
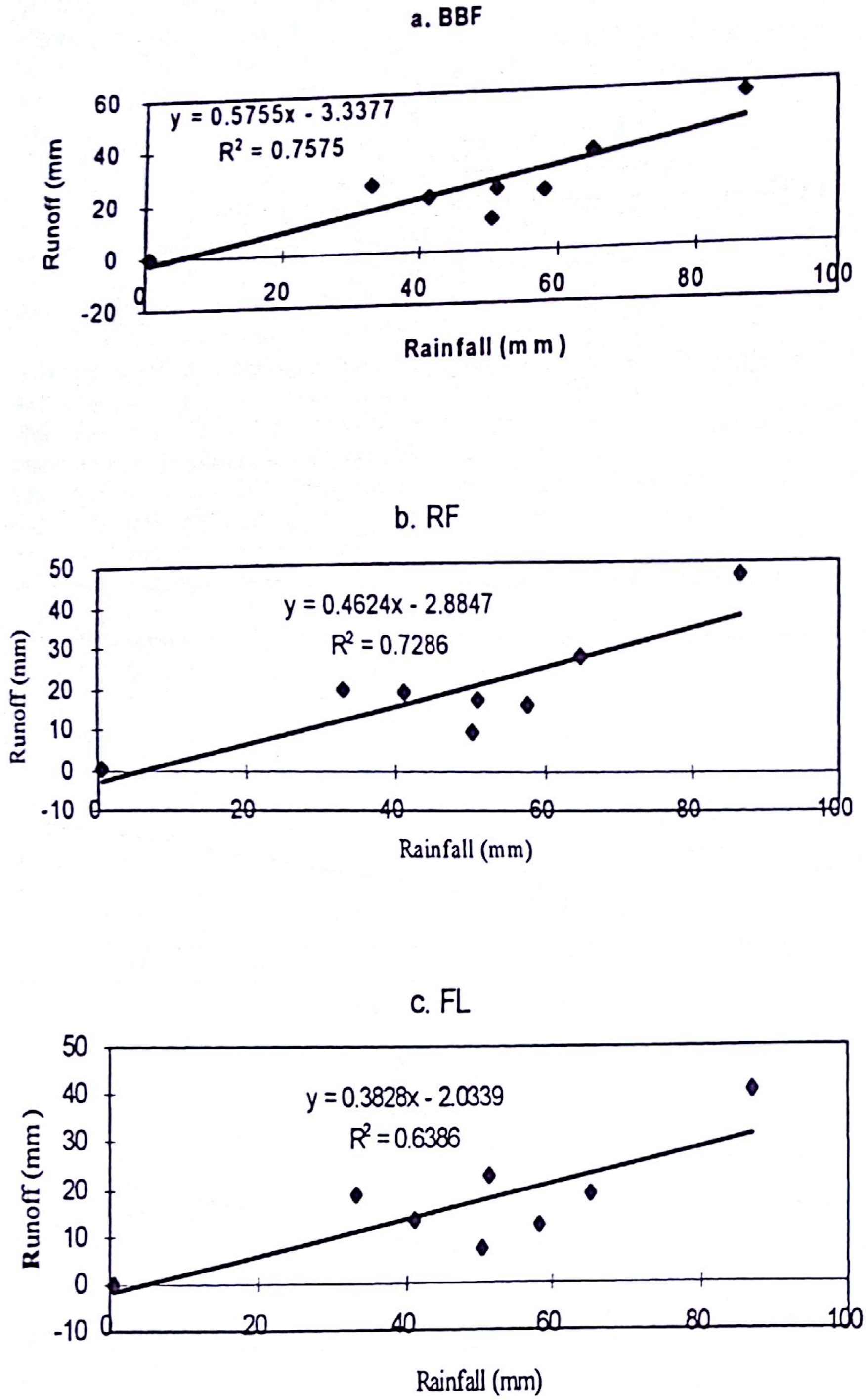


Figure 2- (a-c) Scatter diagram and best fit of the decade runoff and rainfall the three land preparation methods.



drained transforming over 50% of the rainfall into surface runoff. However, under the current management, the excess water is allowed to run down stream, resulting in soil erosion which is becoming a critical problem in the highlands of Ethiopia (Kruger, 1996) and join the natural drainage and eventually the rivers which are extremely under utilized. This high water loss and its concomitant soil erosion can no longer be afforded and should not be allowed with the alarming population growth resulting in heavy demand for food, feed, fiber, water both for human (livestock consumption) and agriculture.

It is remarkable that the BBF plot resulted in 57% increase in total runoff over FL while RF increased by 28%. The lesser runoff volume from the RF plots as compared to the BBF may be attributed to the fact that it has high furrow to effective bed ratio which allows higher depression storage from where the water may be evaporated or infiltrated.

Though the number of the decades are not large enough, regression analysis was made both for the daily and decade rainfall and runoff data (Fig. 1-2). BBF has shown the strongest linear correlation both for the daily and decade data indicating the reliability of estimates to be made on the base of the regression equations, as opposed to FL which exhibited the weakest. It can be realized that the BBF still has shown a relatively stronger linear correlation for the decade data with R^2 value 0.76 (r=8.7) compared to 0.64 (r=8) for the FL plot.

This is true for both the daily and decade rainfall and runoff. The corresponding equations of the lines are presented with their respective R^2 values on each graph for the three treatments separately. As indicated in fig.1 the daily rainfall and runoff for the three land preparation methods have correlation coefficients ranging from 0.55 for the FL and 0.74 for the BBF plots.

From the regression equations, theoretically, it is possible to determine the minimum rainfall that can cause runoff for the different land preparation methods. In other words, it is possible to determine the maximum possible rainfall without runoff by letting Y=0 in the equations and solving for x where y and x stand for runoff and rainfall respectively. However, it has to be noted that in reality, it depends on several other factors one of the major being the antecedent soil moisture. Therefore, to have good approximation, a correction factor has to be introduced for the soil moisture deficit just before the occurrence of the rainfall.

For all the treatments, reliable stochastic models may be developed with careful and accurate measurement of rainfall and runoff and undertaking rigorous statistical analysis to fit the estimated and expected values. Since runoff is the result of multi-variables in the system, other catchment properties that can directly or indirectly affect the runoff from the system have to be considered in the analysis. Nevertheless, under current investigation, only rainfall is considered as a sole determinant

Table - 2 The water balance (mm) of the root zone as affected by land preparation methods on vertisols

a) BBF

Decade	Rainfall	Runoff	Soil moisture/.6m	Change in soil moisture	ETo	Net balance
1*	31.20				9.30	
2	79.75				9.50	
3	41.16	20.80	318.30		16.70	
4	86.90	56.48	294.87	-23.43	24.30	29.55
5	65.10	36.35	300.80	5.93	29.50	-6.67
6	51.10	22.78	312.17	11.37	32.50	-15.55
7	50.40	11.72	287.00	-25.17	34.60	-29.25
8	58.00	22.09	308.87	21.87	36.70	-22.66
9	33.10	25.21	304.25	-4.63	37.10	-24.58
10	0.60	0.21	288.45	-15.80	37.50	-21.31
11	0.00	0.00	268.30	-20.15	34.20	-14.05
12	0.00	0.00	267.00	-1.30	23.40	-22.10
13	0.00	0.00	264.00	-3.00	7.80	-4.80

b) RF

Decade	Rainfall	Runoff	Soil moisture/.6m	Change in soil moisture	ETo	Net balance
1*	31.20				9.30	
2	79.75				9.50	
3	41.16	18.87	316.80		16.70	
4	86.90	46.78	272.30	-44.50	24.30	60.32
5	65.10	27.46	316.80	44.50	29.50	-36.36
6	51.10	17.32	319.30	2.50	32.50	-1.22
7	50.40	9.36	285.80	-33.50	34.60	39.94
8	58.00	16.02	313.00	27.20	36.70	-21.92
9	33.10	19.60	309.80	-3.00	37.10	-20.40
10	0.60	0.16	296.30	-13.50	37.50	-23.56
11	0.00	0.00	281.50	-14.80	34.20	-19.40
12	0.00	0.00	280.00	-1.50	23.40	-21.90
13	0.00	0.00	265.00	-15.00	7.80	7.20

c) FL

Decade	Rainfall	Runoff	Soil moisture/.6m	Change in soil moisture	ETo	Net balance
1	31.20					
2	79.75					
3	41.16	12.86	317.20			
4	86.90	40.52	277.30	-39.90		
5*	65.10	18.76	296.55	19.25	8.00	19.09
6	51.10	22.30	320.30	23.75	10.50	-5.45
7	50.40	6.95	290.75	-29.55	15.40	57.60
8	58.00	11.77	308.75	18.00	27.40	0.83
9	33.10	18.44	302.60	-6.15	35.70	-14.89
10	0.60	0.02	296.55	-6.05	38.40	-31.77
11	0.00	0.00	272.70	-23.85	38.30	-14.45
12	0.00	0.00	276.00	3.30	42.20	-45.20
13	0.00	0.00	262.00	-14.00	38.40	-36.40
14	0.00	0.00	282.00	20.00	38.40	-36.40
15	0.00	0.00	273.00	-9.00	32.80	-34.60
16	0.00	0.00	274.00	1.00	22.50	-25.60

variable. Since this result is based on data of only one season on small plots, to have a reliable correlation and estimation, one has to have enough data replicated over several years and possibly on a large watershed level.

3.2 Soil moisture

The analysis of soil moisture in cropped land, among others, aims at determining the water available for crop use and the degree of aeration. Since data on the soil moisture characteristics of the soils in the study area including: moisture content at field capacity and at wilting point, and moisture retention curve of the soil are being determined, these information are missing in this report. Therefore, only a classical comparison of the treatments' effects on the gravimetric soil moisture is presented.

Despite the significant effect of the treatments on the major water losses from the system, namely; runoff and crop use, the effect on soil moisture was not significant. The soil moisture in the top 30 cm of the profile showed slightly more variability over time in response to inflow (rainfall) and outflow (runoff and evapotranspiration) than the lower. This could be due to higher rooting density and direct impact of evaporative agents on the upper layer, resulting in higher evapotranspiration loss, on one hand, and a probable effect of the profile beneath the region considered, on the other. The moisture of the lower profile is generally over 140 mm per 30 cm which indicates almost saturation, while that of the upper is below this value as of the 11th decade (Tables .2).

There is no reasonable explanation as to why the BBF plot has the highest soil moisture despite its maximum runoff volume (loss) during the fourth decade. The RF plot has the tendency of retaining more moisture towards the end of the rain season while the soil moisture of the BBF is depleting quickly. This can be an indication of their relative effect on moisture conservation for later stage of the crop growth. Another paradox in the soil moisture dynamics in this experiment was the increase of soil moisture content between decade 13 and 14 while despite the absence of precipitation during the same time. This might have some thing to do with the possible capillary rise.

3.3 The water balance

As indicated in Table 2, the net balance is not zero implying inaccuracies in determining the components. It has to be recalled that, in this analysis, the net flux (q) of water at 60 cm was assumed to be zero. The result of the analysis, nonetheless, indicates otherwise. Since the depth of profile appears in several steps of the analysis, the fact that the equivalent rooting depth was assumed to be limited to 60 cm might also have influenced the result. Assuming the rest of the components are negligible, the net balance was calculated as:

Netbaalance = Rainfall-Runoff-CSM-ETc (3.2)

Where CSM = Change in soil moisture (storage)

ETc = Evapotranspiration of the crop (mm)

During the fourth and seventh decades for the BBF and RF plots, and during the seventh for the FL, the deviation of the net balance from expected (0) is highly positive (Table 2). In this case, there might have been net downward flux (loss) at the bottom of the profile. However, the magnitude of the deviation is too high (for vertisols) to be attributed to only percolation. Therefore, the other outflow components (ETo, ETc) might have been under estimated.

During the rest of the period, the net balance was negative indicating either over estimation of the outflows and storage or under estimation of the inflows. To expect capillary rise, normally the moisture content has to be less than the field capacity. Unfortunately, so far, there is no reliably determined field capacity moisture content for these soils. Since the deviation during some of the decades was too high, it is not realistic to attribute it to only capillary rise. Therefore, the other losses (ETo, ETc) might might have been over estimated.

Conclusion

The use of the surface drainage methods BBF and RF have increased surface runoff from Vertisols. In addition to the consequent improvement of crop performance, this has significance if water harvesting is to be considered for supplemental irrigation and other purposes during the subsequent dry season. Hence, once the estimate of total excess water is established and its potential use for irrigation, human and livestock consumption is determined, further research is required to determine the efficient harvesting methods and sustainable utilization of the water.

On a large scale, the increased runoff may concentrate and result in higher soil loss. Thus, safe out lets and conveyance systems have to be designed on the base of peak runoff rate with a required return period to be determined on the base of the rainfall-runoff relationship and long-term weather data. Since rainfall runoff relationships are the function of catchment characters, the application of the practice demands watershed management for sustainable use of the soil and water resources.

As this is based on one season data, it can only provide information for further research on the same and similar locations, further investigation on a large scale with exhaustive determination of inputs, outputs and the catchment characters are recommended.

Appendix - I

Monthly Penman-Monteith reference evapotranspiration of the study area as a function of related weather data (19996)

Month	Min. Temp.°C*	Max. Temp.°C*	Humid. (%)*	Wind km/day (MJ/m²/day)*	Sunshine (hours)*	Radiation (mm/day)**	ET0-PenMon**
Jan	9.7	23.5	67	165	8.4	19.9	3.8
Feb.	8.7	26.8	50	187	7.8	20.3	4.8
Mar	11.6	25.5	63	197	8.5	22.5	4.8
April	11.5	24.7	65	182	6.5	19.5	4.3
May	11.1	24.0	65	180	7.7	20.9	4.3
Jun.	12.2	21.6	76	146	6.4	18.5	3.5
Jul.	12.3	21.0	78	146	3.4	14.2	2.9
Aug.	12.0	21.0	78	134	3.3	14.4	2.9
Sept.	11.1	22.1	76	137	6.0	18.5	3.5
Oct.	10.5	24.3	17	50	9.0	22.2	3.6
Nov.	10.1	23.2	12	75	9.5	21.6	3.6
Dec.	11.4	23.0	12	65	8.9	20.0	3.3
Mean	11.0	13.4	55	139	7.1	19.4	3.8

* *input data* ***output data*

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Designing Sustainable Farmer-Managed Irrigation in Ethiopia

Geremew Gurmesa, Arbaminch Water Technology Institute, Arbaminch,Ethiopia

Abstract

Many modern irrigation schemes in Ethiopia produce smaller harvests than planners expected and sometimes bear crops other than those planned. This happens because the design systems do not meet the expectations of the farmers, i. e., social environment is not taken in to consideration during design. Up to now, irrigation design has been the domain of engineers and regarded as being concerned mainly, if not only, with the 'nuts and bolts' needed to build technical system. Socio-economic components have not yet fully entered the methods and concepts that engineers bring to the design job. Their conceptual tool kit has remained much the same over the past decades. To cope up with the stated problems, it is necessary to modify the method for designing farmer-managed irrigation systems by making the design pivot on use and systematically considering the social and economic factors, in addition to the physicals. In this paper; the social context of irrigation, conventional methods of design and its problems in farmer-managed irrigation system, and the necessary design improvements to be made are briefly discussed.

Introduction

The development of Irrigation in countries, like Ethiopia, with rapid increase in population, problems of food security, uncertain rainfall pattern and ample water resources is unquestionable [4]. Realizing this fact, now a days, in Ethiopia more attention is given to the water sector, of which irrigation development is one component. But the problem lies in whether the present design system matches with the farmers preferences or not.

The product of many presently existing farmer-managed irrigation schemes is less than the expectation of the planners. This is due to one or more of the following most common apparent problems:

(i) Less intensive cultivation than projected:
- Farmers may refuse double cropping.
- Farmers may not cultivate the plot every year or abandon it completely.

(ii) Mal-distribution of water and deterioration of the physical system:
- Sometimes, because of operational difficulties, entire canals are abandoned and new ones excavated .
- Water management may not be guided by a set of formal rules nor a formal organization.
- There may be little communication between the farmers themselves and between the farmers and outside actors.

Observation of many projects in Ethiopia shows that these problems come from the fact that the design systems did not incorporate socio-economic aspects of the beneficiaries. This means that irrigation design as an engineering discipline faces conceptual limitations:

- It focuses on physical factors and technical considerations.
- It implicitly uses efficiency, stan dardization and optimization of water use as guiding norms.
- It puts the physical shape of the system in the center of the design.

Therefore, it is clear that design improvement is necessary for the system to attain its intended purpose by facilitating a process whereby the physical characteristics of an irrigation system would be consciously tuned to its social environment. Such a method may help to reduce the disappointment that Ethiopian engineers and farmers encounter in irrigation development.

Social Context of Irrigation

The gap between the domain of engineering, built up of hydraulic and mechanical formulas, and the sociological analysis of Ethiopian societies is not easily bridged. Perhaps, the solution lies in harsh reality: when using irrigation facilities, Ethiopian farmers link the technical system to their social patterns.

The numerous tasks of irrigators mainly distinguished as [6]:

1.The use of the plot: preparing their land and growing a crop.

- a matter of individual farmers (or household).

Here three social aspects of the farming household can be considered.

(i) The economic rationale of the farming household is the choosing, executing and integrating of its activities. It is the outcome of the ongoing process whereby the members weigh, combine or suppress objectives of their productive and reproductive activities. The economic rationale of the household cannot be reduced to the objectives of one of its members and is generally not the result of a'consensus' process of decision making. It is the outcome of continous modification in response to changes in the composition and environment of the household.

(ii) The relationship within the households. This refers to the division of rights and obligations, of power and responsibilities between people within the farming household, for example between men and women, and between elders and the young.

(iii) Access to resources. This dimension refers to the ability of the household to mobilize means of production, such as irrigation water, land, labour, cash, equipment and knowledge.

Therefore, decisions about the use of the plot depend up on the overall household strategies, on the division of tasks and responsibilities within the household, and the availability of means of production.

2.Irrigation Organization: distributing water among each other, maintaining structures and canals.

- a matter of all water users more or less collectively.

To understand this, three social aspects of the local community may be considered:

(i) Organizational Structure
(ii) Organizational Processes and Skills
(iii) Organizational Goals

Organizational Structure refers to the horizontal and hierarchical divisions between the subunits and functions within an organization. It is usually specified by sets of rights and obligations for each function or unit. Such structures, however, do not operate by themselves. They have to be brought to life and are kept alive only through the activities and efforts of people ; activities we call Organizational Processes and Skills. These activities may include decision making, information exchange, financial management, resource mobilization, etc. Farmers involve themselves in some form of organization usually so as to reach certain aims known as Organizational goals. It is this organizational objective that contributes to the mal-functioning of irrigation systems. Hence, the organization of irrigation is directly influenced by the composition of the local community, its organizational practices and values.

3.Maintaining External Relations between farmers and actors outside the scheme (government officials and traders) to obtain inputs and market the output.

Irrigation systems can operate only if certain external requirements are met. These requirements can be categorized in to four: *inputs, credit, services and marketing.*

Input: for agricultural activity
- seeds
- fertilizers
- chemicals
- equipment
- Labours

for operation and maintenance
- Labours
- spare parts
- fuel
- cement
- other construction materials

Credit:-seasonal for crop production
- long term loans for investments in infrastructures or equipment.

Service: refers to acquiring the assistance of people (with their skills and capacities) in order to use the system.

Marketing:refers to the activity of selling the product.
- a combination of transport, storing, selling and processing.

The above *External relations* will depend up on the *willingness* of the external actors (extensionists, government officials, traders, bank officials, non-governmental organizations, etc.) and the *accessibility* of the irrigation area. Even when access has been gained, external inputs and services are available only under conditions defined by the external actors.

The use of an irrigation plot, the organization of O & M, and the mobilization of external relations for irrigation purposes are linked to wider social patterns of the farmers as discussed above and may be summarized as shown in Table-1.

Table -1 Linkages Between Physical and social enviroments.

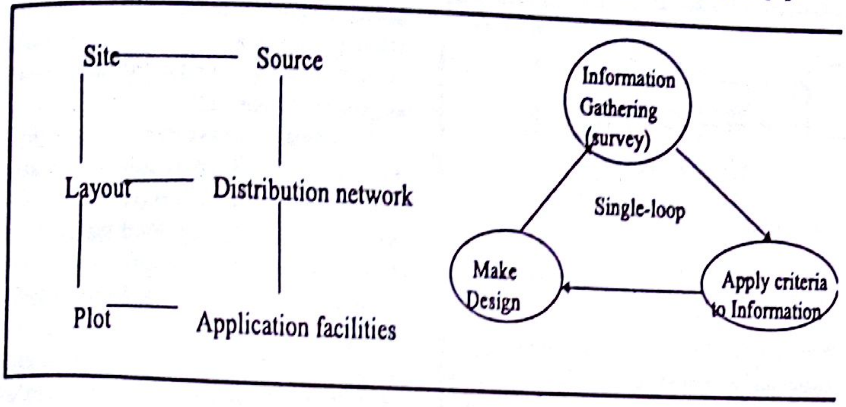
	Technical system	Forms of use	Social aspects	Social systems	
PHYSICAL ENVIRON MENT	IRRIGATIO N SYSTEM	agricultural use	-productionrationale -intra-household organization - access to resources	FARMING SYSTEM	SOCIAL ENVIRON MENT
		irrigation organization	-organizational structure - processes & skills - objectives & norms	LOCAL COMMUNITY	
		external relations	-types of external needs - accessibility - conditions posed	INSTITUTIONAL & COMMERCIAL ENVIRONMENT	

Conventional Design System

A design process is often started with a global identification of the physical environment: irrigable soils and sources of water[6]. The surveys of soils and the topographical, hydro(geo)logical, meteorological studies, etc. are followed by the actual planning and design. On the basis of available water, irrigable area and other physical limitations, the design evolves along a reiterative process in which site and source, layout and distribution network, plot and application facilities are selected, arranged and rearranged until a congruent physical system is arrived at (see Figure - 1).

Design processes like the one sketched above are normally presented as outcomes of technical considerations — built mainly around physical data — ignoring an in-depth understanding of the social environment. The technical considerations of such designs, however, are mixed with assumptions of the future use of the system. For example, the choice of plot size and water application method is based on an assumed cropping pattern, which in turn implies assumptions regarding the cultivation practices of the people involved. The water distribution network and layout are based on a rotation pattern of water over blocks and plots. Network and layout are based on, often implicit, assumptions of the organization of the farmers and the agency personnel. The choice of the crop(s) and of the type of technology are based on assumptions of the presence of institutional services and the operation of markets and transport facilities, etc.

Figure-1:Basic conventional design elements in irrigation systems [3] & [6]



Compraing Design Assumptions and Farmer Rationale

Design assumptions:

- Farmers are interested in intensive cultivation of a single or a limited number of crops.
- Farmers are interested in double cropping.
- Farmers will strictly adhere to cropping pattern.
- Farmers will strive for maximum efficiency of water use.
- Maximum yield per hectare will be obtained.
- All family members will partici pate in cultivation of the irrigated plot.
- Farming households are able and willing to mobilize labour in the quantities and/or at the times necessary.
- Farmers would apply equitable water distribution and fixed sequence of water turns.
- Farmers cooperate in dividing and rotating water amongst themselves.
- There exists a trained man power and organizational arrangements within the local community that can successfully operate and maintain the system.
- There exists sufficient labour and equipment.
- There exists institutional and commercial environment.
- The sale of the produce will achieve national economic objectives and generate cash income for the farming household, i.e., profit maximizing producer.

Farmers' attitude:.

- Subsistence oriented production may be preferred to market oriented production for at least a part of the crop, and food security to surplus maximization.
- Risk spreading by diversifying crops, plots or activities may be preferred to concentrating on the production of one or a limited number of crops.
- Labour saving by maximizing returns per unit of labour may be valued more than returns per unit of land or water.
- Flexibility to react to uncertain and changing conditions may be so highly valued that farmers avoid obligations and organizational bonds in order to keep individual 'room to maneuver'.
- Farmers may find it economically attractive to spread labour and inputs over a variety of activities, only one of which is irrigated agriculture. Other activities may include livestock rearing, fishing, commercial activities like trading, etc.
- Farmers prefer to irrigate at a time that fits in with their other activities, which changes over the year, than following a fixed interval.
- Farmers need a technology that can be managed by themselves with the existing manpower, without assistance from outside.
- Farmers may find it difficult or impossible to maintain relations with external actors.

In Ethiopia, due to the above mismatches, the actual utilization of irrigation systems often differs considerably from the expectations of engineers and planners (see Figure - 2).

Design Improvements to be Made

An improved design approach should include technical considerations as well as information on local society [2]. Possible forms of use would be considered in relation to physical conditions and technical possibilities on one hand and social requirements and limitations on the other. During this process, certain engineering assumptions would be made explicit, discussed with the irrigators and other parties and the technical design be adapted accordingly. But it may also be necessary to discuss and define changes needed in the social setting. An understanding of the desired use and its relation to technical and social aspects will usually be reached only through a process of communication and negotiation: the 'tuning' approach (see Figure- 3).

The improved approach would be an iterative process, much like the conventional design process. Its improvement lies in the fact that the social envi-

Figure -2:Discrepancies between design assumptions and farmers' reality.

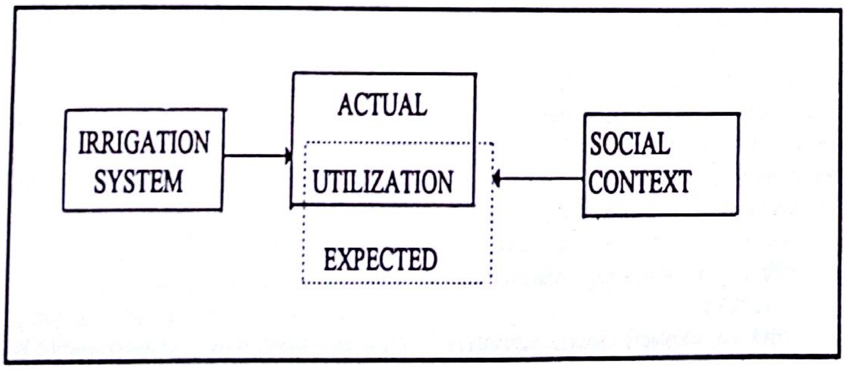
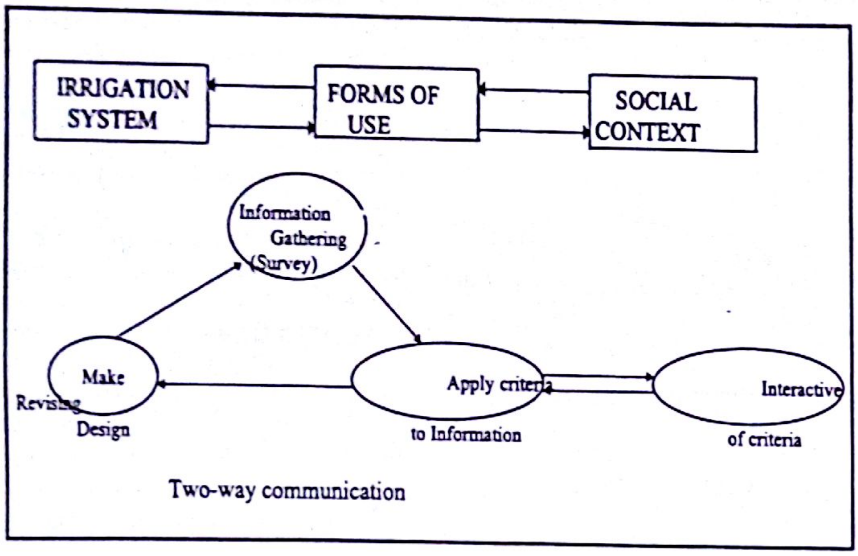


Figure -3 The tunning approach to irrigation design [3] & [6]



ronment is included. The technical design is reviewed and adapted to the social factors influencing its use; inversely, the social factors and implications are reconsidered in view of technical requirements. This means, both "*adapting the farmers to the system*" and " *adapting the system to the farmers*" should be applied.

Adapting the behavior of the farmers to the system is possible through :

- Education and extension or some subtle combination of stick and carrot.
- Developing new organizational arrangements that link technical requirements and organizational capacities.
- Pursuing certain social or organizational changes in the community to bring about new forms of organization.

-Strengthening the farmers' capacities to maintain and control external relations by

. organizing farmers in a group or association.

. creating competition among external actors.

. involving external actors in the implementation process.

- Improving the performance of external actors according to the needs of the irrigation scheme by

. creating an institutional position for the project in which it can effectively work with various institutions.

. making explicit goals, activities and strategies of change with regard to the institutional and commercial environment that have to be accomplished by the project.

Where as, in adapting the system's design to the farmers' realities the following possibilities may be used:

- Farmers should be given considerable *freedom of crop choice*. This would imply that the cropping pattern is not predicted by the designer and may be changed by the farmers. Moreover, the design should no longer be adapted to a particular crop or set of crops but allow diversification. Here at least three technical options are open:

Option 1:to design canal capacities for the maximum crop water requirement. This means an over capacity for a large number of crops.

Option 2:zoning, especially when different crops are grown at the same time. This means designing different parts of the system for different types of crops. Farming households can then be given plots in each zone.

Option 3:giving households different plots in the same system This has the additional advantage of avoiding differences in soil quality.

- In many cases, farmers appear to operate their systems in a more flexible way than the designers had envisaged (here **Hare and Wajifo Irrigation Projects**, Southern Region of Ethiopia, can be cited as a good example). They reshuffle turns, vary intervals and irrigate with varying numbers of farmers at one time. It would seem sensible, therefore, to pursue a strategy stimulating forms of organization in which explicit decision making on the water distribution can take place, at the same time providing a technical system that leaves room for flexibility.

- Design the system for low technological level which requires less specialized skills and less outside assistance. Maintenance load can be reduced by simple design or by applying principles borrowed from farmers technology.

- Adapt the technical design to prevent the need for external relations that are not feasible, through the following means:

. reduce the need for material inputs, both for cultivation of crops and for O & M of the infrastructure, especially in areas poorly connected to trading and institutional networks.

. reduce the need for outside assistance to operate and maintain the irrigation system.

. reduce the need for high profit ability by avoiding to rely on high crop prices, availability of credit, etc.

For the above suggested design improvements to be reliable, there should be a regular interaction between the farmers and the design team:

. beneficiaries (or farmers) should participate in the design of the system.

. design team should be made ac countable to the local community and ought to be stationed in the region and not in the capital.

In general, to arrive at a sketch of realistic and sustainable forms of use, a design effort must include the following five analytical elements:

(i) An analysis of the implications of the present social environment for the design;

An analysis is needed of the processes of the farming system, local community and institutional and market environment that are likely to influence the actual use that farmers will make of the irrigation infrastructure. The conclusions could be expressed interms of social requirements (for example groups that have to be represented in the irrigation organization) or interms of boundary conditions (limited availability of labour for example, or unfavorable market conditions).

(ii) A formulation of the implications of technical options for the forms of use;

Technical options would have to be 'interpreted' according to how they affect the social dimensions of the use of the system. A layout, for example, may require a certain set-up of the irrigation organization. The choice between various kinds of division and control structure may imply different organizational skills and processes and may also require different external relations for spare parts, maintenance, etc.

(iii) A description of the major choices with regard to the technical design;

If a design is seen as the search for an optimum match between the physical system and the social environment, then there is no just one optimum solution, as for a technical equation. Instead, arrange of options for matching technical and social factors, presents itself. The choices may refer to social aspects (for instance, what kind of changes can be expected in the household), to the interplay between the technical system and the social environment (should we choose technical option Xor option Y which poses different organizational requirements), and to the technical options available in view of social goal.

(iv) A presentation of the arguments and steps to arrive at these technical choices;

The technical choices should be accompanied by an account of the processes and steps taken to arrive at solutions and statements concerning the involvement of the various parties.

(V) A formulation of the assumed changes and continuities in the farming system, the local community and the external relationships;

The design should present a clear formulation of the social requirements that the technical system puts to the farming system, the local community and the relationships with institutions and markets.The use of a new system or a rehablitated one will almost always place new social demands on the users. Design reports should therefore also include a systematic account of the socio-economic measures that inevitably accompany the irrigation development efforts.

Conclusions and Recomendations

Irrigation design is usually conceived and implemented as a discrete task, rather than a gradual, incremental process. But it is a task which sets long-term management parameters. In essence, irrigation design anticipates future management modes, intensities and efficiencies and it establishes parameters for system performance.

Yet in practice, designs are often substantially assumptive and highly dependent up on a limited set of technical design criteria. The criteria are typically satisfied by the application of hydraulic and structure theory to collectable information. This conventional design approach brought differences between the concepts of engineers and farmers in many respects. For instance, Engineers tend to design uniform plots and water application methods for an intensive form of production (often mono-cropping). Farmers, on the other hand, aim to achieve a variety of goals and therefore grow more than one crop, spread labour demands, use more than one plot and cultivate plots of varying size, change irrigation intervals, etc. Engineers usually design water distribution systems for maximum efficiency of water transportation and use, where as farmers incorporate their operational criteria, such as their own method of decision making and collective work.

In this paper, new possibilities were suggested and constraints that modern irrigation systems put on farmers could be relieved. However, these technical options do not provide standard solutions and hence, must be solved based on the local situation. Structured discussions with the potential users and with other parties is unquestionable.

Engineers will have to take up the challenge demanding a more intimate adjustment of their technical design to the specific social environment. Development officers, planners, politicians, engineers, social scientists and economists should be made to realize that technical designs are far more amenable to planned change than societies are. At the same time, it doesn't mean that designs must *always* be adapted to the social situation.

Over the past years, vast sums of money had been invested in civil works in irrigation development, but far less investment had been made in developing the most important resources of all: the people who operate, maintain, and use the systems once they have been constructed. Therefore, for the system to be sustainable, training of the beneficiaries is crucial.

In general, to achieve at a successful technical design, engineers should take a closer look at the socio-economic aspects of the future users, since part of the essential local knowledge and management criteria is only in the mind of the users.

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book review

Watershed Hydrology

by Prof. R. Suresh, College of Agriculture Engineering, Agricultural University, Pusa, Samastipur, Bihar, India, Published by Standard Publishers Distributors, 1705 - B, Nai Sarak, Delhi - 110006, India, First Edition, 1997, ISBN 81 - 86308 - 23 - 7, Viii + 540 pp, Paper Back, Price: Rs. 100.00

Hydrology is a core subject for Civil Engineering as well as Agricultural Engineering. As water is the most essential requirement for the survival of human life, plants and animals, hydrology provides a tool for assessment and development of water-resources potential for a particular area. The thirteen self - contained chapters of this book contain a wealth of information which are well presented, readable and with good sketches and clear tables. All these chapters are supported with adequate illustrations. The book covers almost the complete syllabus of Hydrology subject for Diploma and Degree Courses in Agricultural Engineering and Civil Engineering.

The book starts with a chapter on introduction, through precipitation, runoff, hydrograph, stream gauging, flood routing and sedimentation.Chapter eleven is on climatic regions which is very relevant in this changing world of climatic patterns. A valuable feature of the book is that it provides the readers with clear and factually based methods for solving the complex problems of hydrology. The aim of the author is 'to be brief without omission, to be concise without being obscure'. Since there are many excellent text-books on this subject in English, many items have not been discussed in detail e.g. field and laboratory methods for determination of specific yield, the indirect method for getting specific yield from the values of hydraulic conductivity as proposed by United States Soil Conservation Service. As a result, it is not suitable as a sole text book for students. There are a few spelling imperfections, no index, an unfortunate omission in any technical book. One might well conclude that the perfection of the book fell victim to the pace of production.

It is a book for those who need to know how, rather than those who wish to know why? Nevertheless, the book is a valuable addition in the field of books on hydrology. The book is recommended as a reading material to all in water related occupation and at every level of Engineering and operational personnel. It is a timely addition to the subject of watershed hydrology.

The book itself has used more moderate language and is in metric unit throughout. In deed, the author has presented his material in dignified and gentlemanly manner. Usually the author is very accurate. However, there are a few occasional slips, for example, in Table 1.2 entitled as 'Worldwide Distribution of Runoff ' mainly Indian portion has been described. In table 4.12, page 120, f(t) should be equal to σTk^4 instead of $6Tk^4$, and in table 4.13 f(ed) should be equal to 0.34 - 0.044ed instead of 0.34 - 0.444ed. In table 4.15, page 22, f(u) should be equal to $0.27 (1 + u_2 /100)$ instead of $0.27(1+u_2)/100$. In example 4.9, page 122 - 123, in the last line, the author says that 'C' is crop coefficient, but in fact it is an adjustment factor. Also the value of 'C' can be obtained from Appendix - 7 and not from table 4.5 as indicated by the author. In Appendix - 7, RS should be written as Rs and its position should be interchanged with U_{day}. At the end of book a list of Bibliography has been included. But, it is pity that it is neither complete nor up to date, e.g. Appendix - 8 is a table from Boultan (1963), but it is missing in the bibliography. In the bibliography, there are a few books/papers without the year of publication e.g. Mutreja, Nemec, Punmia and Lal, Raghunath, Sharma, Suresh, Subramanya and Todd. The reviewer is of the opinion that these errors may be rectified in the next edition of the book. However for his relaxed and easy style and overall simplicity of the book, it is highly recommended to the students of Agricultural Engineering, Civil Engineering, Hydraulic Engineering, Irrigation Engineering and Water Resources Engineering of Diploma and Degree levels. Apart from this, the book is also recommended for the professionals engaged in the field of water technology.

Reviewer :
Dr. L. B. Roy
Associate Professor and Head
Department of Irrigation Engineering, AWTI, *P.O.Box-21, Arbaminch, ETHIOPIA*