# A Case Study on Infiltration Modeling in Upper Bhopal Lake Catchment

**T. Thomas[1], R. K. Jaiswal[1], R. V. Galkate[1] and S. Singh[1]**

[1] Scientist, GPSRC, NIH, Sagar-470001, M.P., India
e-mail: thomas_nih@yahoo.com

## ABSTRACT

The management policy for any lake depends upon the inflow of water and nutrients into the lake from its catchment. The catchment characteristics such as geomorphology, geology, hydrological soil properties influence to a great extent the magnitude of inflow into the lake. Infiltration and soil-water movement are perhaps the most important hydrological processes, since they determine the rates and amounts of water reaching the lake. For a judicious and optimal planning of water and land resources, the soil-water infiltration studies are imperative and inspite of this fact, modeling of infiltration is the area in which sufficient scope for research work exists.

An attempt has been made to model the infiltration and conductivity in the catchment of the upper Bhopal lake. Double ring infiltrometer tests and field saturated hydraulic conductivity tests using Guelph permeameter have been conducted at twelve sites within the catchment area of 361 sq. km. of the upper Bhopal lake. The Horton's infiltration model has been fitted to the experimental data and the value of parameter $(k)$ varies between 0.69 and 4.96. Similarly, Kostiakov's model has also been fitted to the experimental data for the evaluation of the cumulative infiltration depth. The infiltration capacity of the soils lying within the catchment of the upper Bhopal lake varies between 0.80 to 4.20 cm/hr. A regional infiltration model has been developed considering the experimental data of eight sites and the regional value of Horton's coefficient $(k)$ is estimated as 1.22. The model is validated on the experimental data of the remaining four sites and the correlation coefficient during calibration varied between 0.66 and 0.96 whereas the correlation coefficient during validation varied between 0.77 and 0.96. The results of the Guelph permeameter tests indicate that the field saturated hydraulic conductivity in the catchment area varies between 0.02 to 3.34 cm/hr.

## INTRODUCTION

Stream flow patterns are a major feature of lake ecosystems and are critical in shaping aquatic communities. As a consequence of changes in stream flow patterns due to the man made and climate induced changes, many lakes no longer support native species or sustain healthy ecosystems. When altered, stream flow exhibits changes in magnitude, timing, duration and frequency which ultimately affect the lake water levels. The water levels in many lakes fluctuate naturally as a result of changes in precipitation, snow melt, infiltration, groundwater inflow, and evaporation. Natural fluctuation of water levels in lakes and streams contribute significantly to ecosystem health and integrity.

Generally, lakes those are small in surface area and larger in depth exhibit better water quality than those that are larger in surface area and shallow in depth. A lake having a very large watershed area compared to its surface area will receive larger surface runoff with substantial nutrient loads. Lakes with small watersheds maintained primarily by groundwater flow exhibit better water quality. Therefore the infiltration rate plays a vital role as it is responsible for modifying precipitation and converting it into runoff and soil moisture storage and ultimately decides the quantity of surface runoff along with the nutrients that reach the lake water body. The infiltration rate and hydraulic conductivity also play an important role in the quantity of the water reaching the lake from ground water inflow. Management techniques such as loading capacity for effluents and selective removal of undesirable components of the biota are also dependent on detailed knowledge of the flow characteristics. Therefore, for the simulation of any hydrologic system, the infiltration process has to be taken care of invariably. Considering the infinite combinations of soil and other factors in nature which include properties of soil, vegetation and land use pattern, rainfall intensity and duration, surface slope, depth to groundwater, climate and man's activity, no perfectly quantified general relation exists for infiltration.

Linsely, Kohler and Paulhus, 1949 have reported that rainfall intensity has little effect on the rate of infiltration when it exceeds the capacity rate. Green, 1962 also concluded that surface sealing diminishes the effect of antecedent moisture on infiltration because the hydraulic conductivity of immediate soil surface controls water flow into the soil and surface sealing does not allow suction gradients to control the rate of infiltration. Browning, 1939 observed that the soils swell at the expense of soil pores. Christiansen, 1944 showed that the entrapped air in the soil decreases infiltration considerably. Musgrave and Horton, 1964 have shown that infiltration characteristics are affected by grain size and grain size distribution in the soil. They also stated that vegetation is one of the most significant factors affecting the infiltration of water.

Rauzi and Fly, 1968 found that the unfavorable surface soil conditions markedly reduce water intake rates. Hay and Subramaniam, 1955 found that generally infiltration rates become constant after three hours and increases in the order of bare land, scrub, forest and ploughed land respectively. Mistry and Chaterjee, 1965 conducted infiltration studies in Bihar and recorded average infiltration rates of 26 cm/hr, 12 cm/hr and 9 cm/hr under forests, grasslands and croplands respectively. Tejwani et. al., 1975 reported average infiltration rates as 1.0 cm/hr, 2.60 cm/hr and 17.0 cm/hr for agricultural land, grassland and woodland respectively in Bellary, Karnataka. Mathur et. al., 1982 found higher infiltration rate in the forest soils than in adjacent agricultural soils subjected to continuous cultivation. Dhruvnarayan and Sastri, 1983 conducted a comparative study on different forest covers in Dehradun and recorded initial infiltration rates as 54.0 cm/

hr, 21.4 cm/hr, 12.0 cm/hr, 9.6 cm/hr, 9.6 cm/hr and 7.6 cm/hr under eucalyptus, sal, chir, teak, bamboo and grassland respectively. Soni et. al., 1985 conducted infiltration studies in experimental plantations in Forest Research Institute, Dehradun under pinus, sal, teak, bamboo, eucalyptus and ungrazed land. Duley and Kelly, 1939 tested soils on different slopes and noted that there was a tendency for the amount of water intake to decrease slightly with the increase in slope, owing to the faster runoff along slopes.

## STUDY AREA

The upper Bhopal lake is one of the two twin lakes located at Bhopal, the capital of Madhya Pradesh, also called the *'City of Lakes'* owing to the large number of water bodies present in and around the city. The upper Bhopal lake lies between longitude 77° 18¢ 00¢¢ to 77° 24¢ 00¢¢ E and latitude 23° 13¢ 00¢¢ to 23° 16¢ 00¢¢ N. The lake was formed with an aim to supply drinking water to the city of Bhopal. Apart from the water entering from the catchment area during the rainy season, the upper Bhopal lake gets continuous inflow of water through the seasonal river Kolans originating from Sehore, 48 km. away from Bhopal and is a major source of drinking water supply to a considerable portion of the population. Additionally, it is used as a fisheries resource supporting a number of fishermen families and is also a recreational attraction for boating since it is located in the midst of Bhopal city. It has a catchment area of 361 sq. km. and water spread area of 31 sq. km. and is spread southeastwards upto Sehore district. The mean depth of the lake is 3.17 m. The annual rainfall of Bhopal varies between 672.1 to 1869.8 mm. The land use in the catchment area comprises of agriculture, forests, wetlands and urban area, but major part of the catchment area comprises of agricultural land. The Deccan trap basalts and Vindhyan sandstones are the principal rock formations and black cotton soils are mostly encountered in the study area. Over the years, the water quality in the upper Bhopal lake has deteriorated due to inflow of wastes and sewage from human settlements and siltation. The causes of siltation are manifold, including agricultural residues, soil erosion, human activities in catchment area and inflow of waste. The map showing the upper Bhopal lake and its catchment area is given as Fig. 1.

## METHODOLOGY

Twelve sites well distributed over the study area were identified for carrying out the infiltration and saturated hydraulic conductivity tests. The infiltration capacity tests were conducted using the double infiltrometer and hydraulic conductivity tests were carried out using the Guelph permeameter. The most commonly used models of infiltration are Horton's model, 1940 and Kostiakov's model, 1932 owing to their simplicity and few parameters. Horton's model, a three-parameter infiltration model states that the relationship of infiltration capacity ($f_c$) to time ($t$) may be expressed as given by Eqn. 1

$$f_t = f_c + (f_o - f_c)e^{-kt} \qquad (1)$$

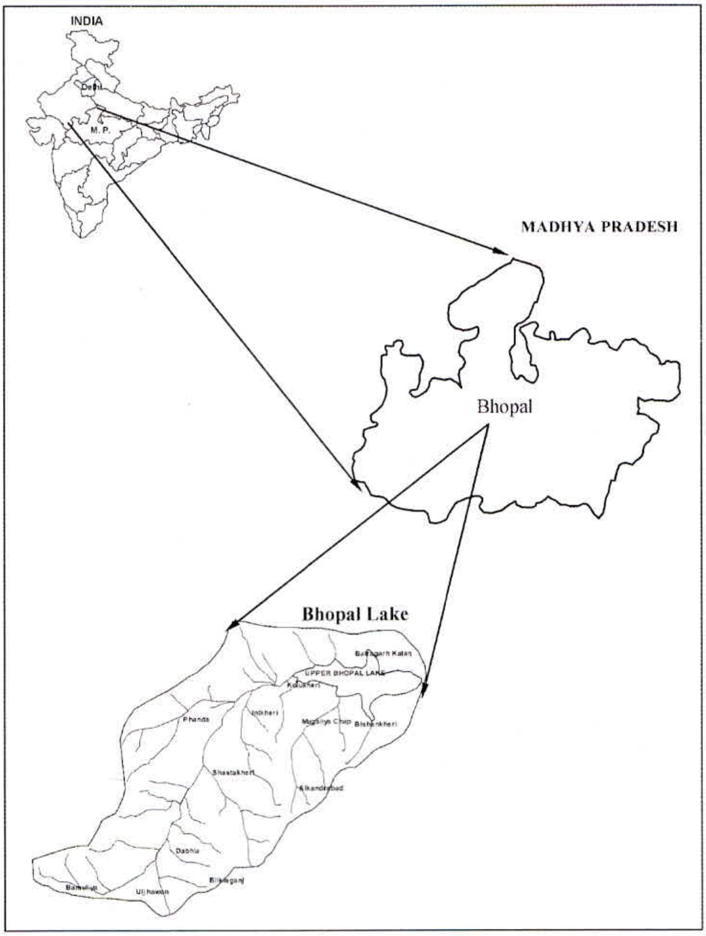


**Fig. 1: Index map of Bhopal lake catchment**

is greater than $(f_c)$. Kostiakov (1932), proposed a simple infiltration model as given by Eqn. 2,

$$F_p = K_k \times t^{\alpha} \tag{2}$$

where, $F_p$ = cumulative depth of water infiltrated

$t$ = time elapsed from start of ponding of water

and $(\alpha)$ are parameters, which depend on the soil and initial conditions and may be evaluated using the observed infiltration rate-time relationship.

Guelph permeameter has been used for estimation of field hydraulic conductivity. In the test, initially a well-head height of 5 cm $(H_1)$ is established and the rate of fall of water in the reservoir is observed. The monitoring is continued till the rate of fall does not change significantly in three successive time intervals. This steady state rate of fall of water in the reservoir is denoted as $(R_1)$ . Similarly a wellhead height of 10 cm is established $(H_2)$ . The rate of fall of water is monitored and the steady state rate of fall of water in the reservoir is denoted as $(R_2)$. The field saturated hydraulic conductivity $(K_s)$ is calculated using the following Eqn. 3 given as,

$$K_s = 0.0041XR_2 - 0.0054XR_1 \qquad (3)$$

where, $X$ reservoir constant equal to 35.39 when reservoir combination is used and 2.14 when only inner reservoir is used

$R_1$ = steady rate of fall of water in the reservoir for a well head of 5cm

$R_2$ = steady rate of fall of water in the reservoir for a well head of 10 cm

## RESULTS AND DISCUSSION

The topsoil in the catchment area of the upper Bhopal lake is mostly clayey in texture and normally forms a layer of considerable thickness which have been derived from the weathering of the Deccan trap rocks abundantly present in the surrounding areas. In the initial period of the water application, the infiltration rate is very high which reduces rapidly with time. The infiltration curve at Bamuliya is given in Fig. 2.

The soils have low infiltration rates varying from 0.8 to 4.2 cm/hr. In the summer months the soils in the entire area develops wide cracks of 1 to 2 feet deep, but as the time of application of water increases, the infiltration rate decreases rather very rapidly,

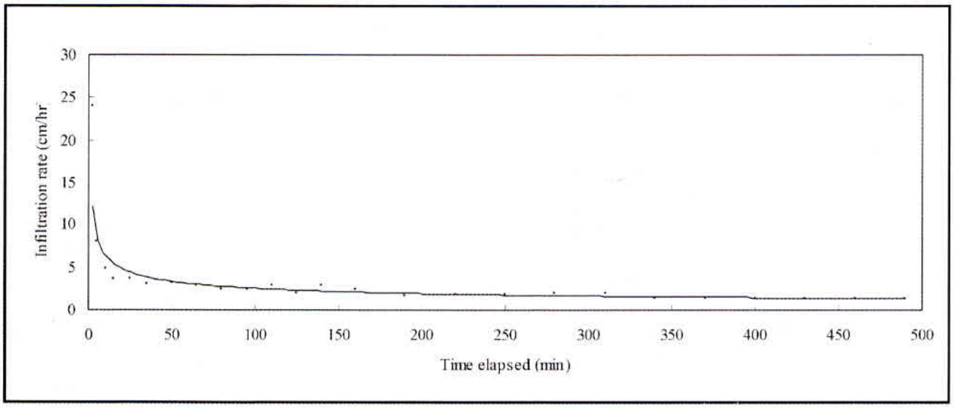


**Fig. 2: Infiltration capacity curve at Bamuliya**

due to the swelling of the clays. The Horton's model was applied to the experimental data at the various test sites to evaluate the value of the parameter $(k)$ in the Horton's equation. The parameter $(k)$ varied between 0.69 and 4.96. The Kostiakov's model was applied for determining the relationship between cumulative infiltration depth and elapsed time. The experimental data obtained from the field tests were processed to compute the field saturated hydraulic conductivity $(K_s)$ of the soil at different test sites which varied from 0.02 to 3.34 cm/hr. The infiltration capacity, Horton's model for infiltration rate, Kostiakov's model for cumulative infiltration and saturated hydraulic conductivity at various test sites are presented in Table-1.

An attempt was made to develop a regional model for the lake catchment wherein the observed data of eight test sites namely Bamuliya, Uljhawan, Bishenkheri, Bilkisganj, Intkheri, Phanda, Sikandrabad and Sahastakheri were used and a regional model based on Horton's equation was developed for which the value of $(k)$ was evaluated as 1.22.

**Table-1: Infiltration capacity and saturated hydraulic conductivity of soils in the lake catchment**

| S. N. | Test site | Infiltration capacity (cm/hr) | Horton's model | Kostiakov's model | Saturated hydraulic Conduct. (cm/hr) |
|---|---|---|---|---|---|
| 1 | Bamuliya | 1.4 | $f = 1.4 + (24.0 - 1.4)e^{-0.82t}$ | $F_p = 0.42 \times t^{0.59}$ | 0.02 |
| 2 | Uljhawan | 2.6 | $f = 2.6 + (24.0 - 2.6)e^{-1.27t}$ | $F_p = 0.61 \times t^{0.58}$ | 2.34 |
| 3 | Bairagarh Kalan | 1.6 | $f = 1.4 + (84.0 - 1.4)e^{-4.96t}$ | $F_p = 2.24 \times t^{0.52}$ | 0.46 |
| 4 | Kolukheri | 1.4 | $f = 1.4 + (57.0 - 1.4)e^{-1.03t}$ | $F_p = 1.32 \times t^{0.41}$ | 0.16 |
| 5 | Bishenkheri | 0.8 | $f = 0.8 + (33.0 - 0.80)e^{-1.34t}$ | $F_p = 0.90 \times t^{0.41}$ | 0.89 |
| 6 | Mugaliya chap | 2.2 | $f = 2.2 + (54.0 - 2.2)e^{-1.49t}$ | $F_p = 1.61 \times t^{0.47}$ | 0.23 |
| 7 | Sahastakher i | 3.0 | $f = 3.0 + (51.0 - 3.0)e^{-1.02t}$ | $F_p = 1.09 \times t^{0.55}$ | 0.22 |
| 8 | Bilkisganj | 4.0 | $f = 4.0 + (57.0 - 4.0)e^{-0.69t}$ | $F_p = 1.57 \times t^{0.58}$ | 2.22 |
| 9 | Dabhla | 4.2 | $f = 4.2 + (27.0 - 4.2)e^{-0.85t}$ | $F_p = 0.65 \times t^{0.72}$ | 0.43 |
| 10 | Intkheri chap | 2.8 | $f = 2.8 + (57.0 - 2.8)e^{-1.95t}$ | $F_p = 1.35 \times t^{0.49}$ | 0.77 |
| 11 | Phanda | 2.4 | $f = 2.4 + (75.0 - 2.4)e^{-1.95t}$ | $F_p = 2.38 \times t^{0.38}$ | 3.34 |
| 12 | Sikandrabad | 0.8 | $f = 0.8 + (12.0 - 0.80)e^{-0.73t}$ | $F_p = 0.29 \times t^{0.57}$ | 0.46 |

The regional infiltration model for the upper Bhopal lake can be expressed as given by Eqn. 4,

$$f_t = f_c + (f_o - f_c)e^{-1.22t} \quad (4)$$

The performance of the model has been evaluated on the basis of correlation coefficient between the experimental data set and model simulated data. The correlation coefficient between during calibration varied between 0.66 and 0.96. The regional model has been validated on the remaining test data of Kolukheri, Mugaliya Chap, Bairagarh Kalan and Dabhla. The correlation coefficient between the infiltration rates computed from the regional model and observed values varied between 0.77 and 0.96. The comparison of the observed and computed infiltration capacity curve at Dabhla using the regional model during validation is given in Fig. 3.

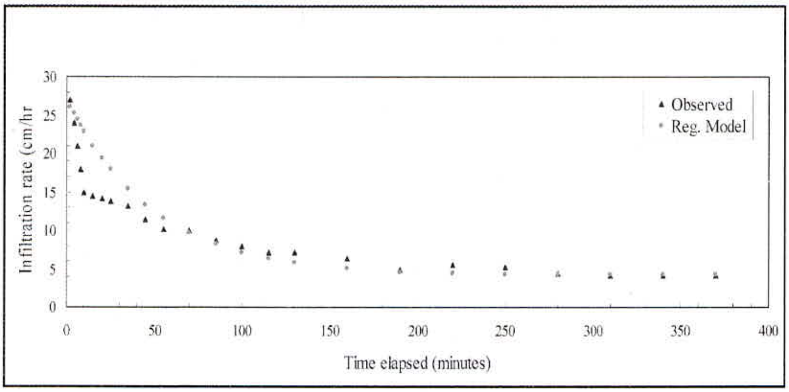


**Fig. 3: Comparison of observed & computed regional infiltration capacity curve at Dabhla**

The regional infiltration curve developed for the lake catchment is able to simulate the infiltration pattern at remaining four sites with a appropriately as is demonstrated from the good fitting between the experimental and model simulated infiltration data sets represented by the correlation coefficient which are given in Table-2. The regional infiltration model can be used in the simulation studies for the estimation of inflows into the lake from its catchment area. The infiltration capacity map of the area has also been prepared by transferring the soil infiltration capacity values to the base map of the area and is given as Fig. 4.

## CONCLUSIONS

The results of this study which are based on the field experiments at 12 test sites aimed to determine the infiltration capacity and hydraulic conductivity of soils in the catchment area of the upper Bhopal lake, show that infiltration capacity varied between

**Table 2 : Correlation coefficient during calibration and validation with the regional model**

| S. No. | Test Site | Correlation coefficient | S. No. | Test Site | Correlation coefficient |
|---|---|---|---|---|---|
| *Calibration* | | | | | |
| 1. | Bamuliya | 0.86 | 5. | Intkheri chap | 0.82 |
| 2. | Uljhawan | 0.82 | 6. | Phanda | 0.75 |
| 3. | Bishenkheri | 0.66 | 7. | Sikandrabad | 0.77 |
| 4. | Bilkisganj | 0.96 | 8. | Sahastakheri | 0.94 |
| *Validation* | | | | | |
| 1. | Kolukheri | 0.77 | 3. | Mugaliya chap | 0.79 |
| 2. | Bairagarh Kalan | 0.81 | 4. | Dabhla | 0.96 |

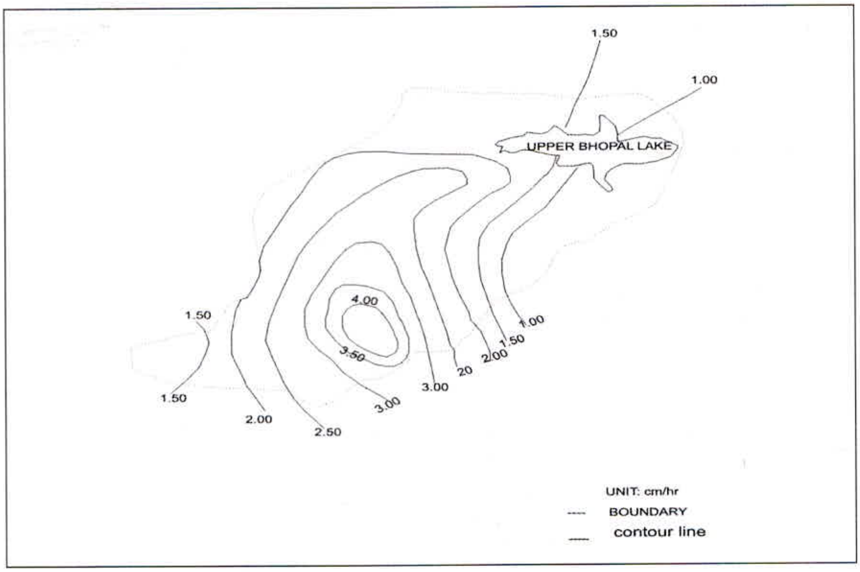


**Fig. 4: Infiltration capacity contours**

0.8 to 4.2 cm/hr and the field saturated hydraulic conductivity varied between 0.02 to 3.34 cm/hr. Site specific infiltration model based on Horton's and Kostiakov's equation have been developed for estimation of the infiltration rate and cumulative infiltration respectively and parameters evaluated. These test results of these models have been compared with the actual field experiment data and it is demonstrated that the developed models are able to simulate the infiltration appropriately in the catchment area of upper

Bhopal lake. A regional infiltration model based on the Horton's equation have been developed expressed as, $f_t = f_c + (f_o - f_c)e^{-1.22t}$ which is able to model the infiltration rate adequately, the performance of which has been evaluated based on the correlation coefficient between the field experimental data and model simulated data. The study will be useful for modeling the flows which ultimately reach the upper Bhopal lake, as surface runoff and groundwater contribution. The results of infiltration and hydraulic conductivity tests can be comprehensively used for the effective management and conservation of upper Bhopal lake. The developed regional model can be effectively used for infiltration modeling in watersheds and river basins with similar soil and land use characteristics.

## REFERENCES

1. Browning, C.M. 1939. Volume change in relation to their infiltration rates, Soil. Science Soc. Amer. Proc. 4, pp. 23-27.
2. Christiansen, J.E. 1994. Effect of entrapped air upon the permeability of soils, Soil. Science. 58, pp. 355-365.
3. Dhruvanarayana, V.V. and Sastri, G. 1983. Annual Report, CSWCRTI, Dehradun.
4. Duley, F.L. and Kelly, L.L 1939. Effect of soil type and surface conditions on the intake of water. University of Nebraska, Agri. Exp. Sta. Res. Bull. 112, pp. 1-16.
5. Green, R.E. 1962. Infiltration of water into soils as influenced by antecedent moisture, Ph.D dissertation, Iowa State University, Iowa.
6. Hay, R. and Subramaniam, T.K. 1955. Rate of water intake of the soil under different soil treatments, J. of Soil and Water Conser. in India. 4(1), pp. 9-13.
7. Musgrave, G.W. and Horton, H.N. 1964. Infiltration, A handbook of applied hydrology (Ed. V. T. Chow), Sec. 12, McGraw Hill Book Co. NY.
8. Linsely, R.K., Kohlar, M.A. and Paulhus, J.L.H. 1949. Applied Hydrology, McGraw Hill Book Co. NY. pp. 689.
9. Mathur, H.N., Soni, P. and Jain, N. (1982). Impact of burning splashability and infiltration capacity of soils under chir pine plantation, Proc. Symp. Trop. Pines, Koraput, Orissa.
10. Mistry, P.G. and Chaterjee, B.N. 1965. Infiltration capacities of soils in Ranchi, J. of Soil and Water Conser. 13, pp. 43-47.
11. Rauzi, F. and Fly, C.L. 1968. Water intake on mid-continental range lands as influenced by soil and plant cover, USDA Tech. Bull. 1390, pp. 58.
12. Soni, P., Naithani, S. and Mathur, H. N. 1985. Infiltration studies under different vegetation cover, Indian Journal of Forestry. 8(3), pp. 170-173.
13. Tejwani, K.G., Gupta, S.K. and Mathur, H.N. 1975. Soil and water conservation research, ICAR publication.