Efficiency Study of Percolation Tanks in Basaltic Terrain Using Chloride Mass Balance Method

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ABSTRACT

For meeting the growing demands of groundwater in hard rock areas, artificial or man-made percolation tanks have become important structures for augmenting groundwater recharge for future development and management of groundwater resources. To evaluate the performance of these structures, a methodology using environmental chloride mass balance is applied in two water tanks in basaltic terrain namely Pangri and Martala in Nanded to study the performance of these water tanks in augmenting the recharge to the groundwater system. The chloride concentration in Pangri tank ranges from 40 to 55 mg/l, while in Martala it ranges from 13 to 18 mg/l. The chloride concentration in up-stream and down-stream side of Pangri tank is more indicating the non-communication between tank water and well water, while that of Martala tank indicate the communication between tank water and groundwater. Based on qualitative environmental chloride studies it indicates that Pangri percolation tank is behaving like an evaporation tank and Martala tank is able to contribute some recharge to groundwater system.

INTRODUCTION

Over exploitation of groundwater from aquifers coupled with less recharge rates results in constantly declining groundwater levels. Consequently measures are being adopted to augment groundwater resources artificially. The artificial recharge techniques comprises percolation tanks, check dams, sub-surface dams, injection of water into well, surface spreading etc., and recently rain-water harvesting by roof top methodology. Percolation tanks, the most popular artifical recharge structures are simple earthern dams constracted across natural streams to enhance the recharge to groundwater by harnessing surface run-off. The surface run-off impounded during rainy season is subsequently expected to percolate and increase the downstream well yields.

The importance of percolation tanks has been well recognised and their number is increasing every year in hard rock regions of southern India comprising Andhra pradesh, Karnataka, Maharashtra and Tamil Nadu states, where the average annual rainfall is ~700 mm. The average annual natural recharge in these areas is 6-8%, while average anuual pan evaporation is very high ~3000-3500 mm.

Many researchers have carried out studies on efficiency of artificial recharge structures all over the country. Studies carried out by Nair et al (1978 and 1980) and Raju (1985) are worth. Nair et al (1978 and 1980) study was based mainly on environmental injected tracer techniques, whereas Raju (1985) study based on hydrological balance for the estimation of percolation from tank to groundwater. The water balance studies carried out by (Raju, 1985) in Ponnani Basin (Tamil Nadu and Kerala) provided that large percentage about 85% of tank water percolates and recharges to groundwater and only 15% of storage water evaporates. Sharma (1985) also reported similar observations for tank in basalts in Saurashtra region. The above studies have certain dis-advantages for providing reliable estimates of efficiency of percolation tanks.

The chloride mass balance techniques is based on the measurement of chloride concentration in tank and in upstream/downstream wells or in catchment area of percolation tank at regular interval and monitoring rainfall and evaporation rate. From variation of chloride concentration from tank water to upstream/downstream wells water, the efficiency of percolation tank can be estimated and its behaviour in contribution to groundwater aquifer system for uplifting of water table, which is useful in future development and management of groundwter resources.

The main objective of the study to assess the efficiency of percolation tank using conventional techniques of chloride mass balance situated in deccan trap region for estimation of recharge through these tanks to groundwater system for future development and management of groundwater.

STUDY AREA

The study area falls in Nanded District, Maharashtra State adjacent to Adilabad District of Andhra Pradesh and is bounded by Latitutes 19° 0' to 19° 5' North and Longitudes 77° 15' 45" to 77° 23' East as shown in Figure 1. The entire area is underlain by Deccan trap formation of Cretaceous to Eocene age. The major soil type of the area is black cotton soil. The drainage pattern follows the dendritic to sub-dendritic pattern. The area comprises of undulating plains and meadows with broad river valleys. The district is well drained by river system which are dendritic type and have mature valleys/ coarses. The principle rivers are Godavari, Penganga, Manjira and Manar. The average annual rainfall over the district ranges from about 850 mm/year to 1150 mm/year. It is minimum in the western parts of the district and increases towards eastern parts and reaches the maximum in the extreme north-eastern part of the district. The temperature ranges from 29° C to 42° C and humidity ranges from 60 to 80%. The comparision of rainfall and pan evaporation rate in the year 2000 is shown in Figure 2.

LOCATION OF PERCOLATION TANKS STUDIED

In order to assess the efficiency of percolation tanks in basalts terrain, two tanks were selected south of Nanded town. The brief discussion of these percolation tanks is given below.

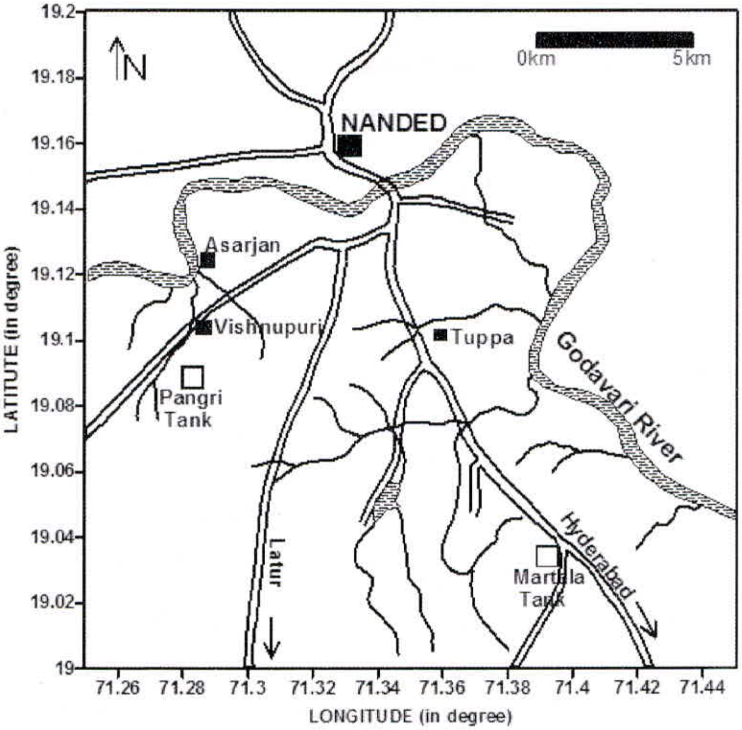

Fig. 1: Key map of the area showing the location of Pangri and Martala Percolation tanks

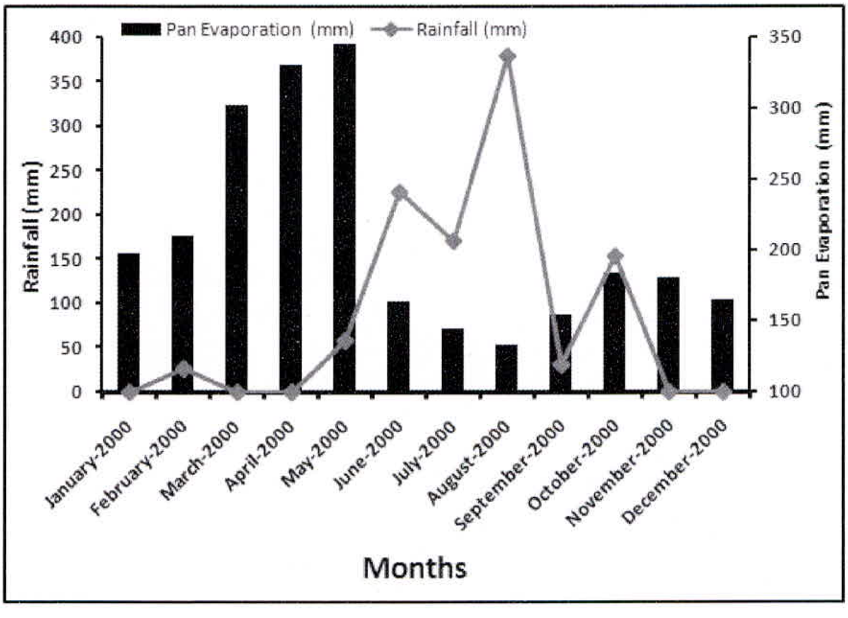

Fig. 2 : Rainfall and pan evoporation rate in the study area.

PANGRI PERCOLATION TANK

This tank is situated southern side of Nanded about 11 km on Latur road. It is constructed on a first order stream, which is merging to Manjira River. About 500 meter long earthen dam is constructed during 1975-76 to a height of 9.3 meter with water storing capacity of 14.5 MCM and catchment area of 1 sq. mile. Though this tank has gross command area of 296 acres, later it has been coverted into percolation tank. The schematic diagram of Pangri tank is shown in Figure 3.

MARTALA PERCOLATION TANK

This percolation tank is also situated about 15 km southern side of Nanded on Digilur (Hyderabad) road and is about 15 km east of Pangri percolation tank. This tank was constructed during 1976-77 across another samll nala, which is also merging to Manjira River. Total water storing capacity of this tank is about 9.09 Mcft with catchment area of 0.97 sq. Mile. The schematic diagram of Martala percolation tank is shown in Figure 4.

GEOLOGICAL BACKGROUND

About 70% of the district is underlaned by basaltic lava flows belonging to the Deccan Traps. The basaltic flows overlie granites and gneisses all along the Trap/ Archeans contact. The Dharwar system in the district occur as thin band of banded haematite quartzite and epidiorites enclosed in granites and gneisses. Granites occur in about 25% of the district area in its eastern and sout-eastern parts. The granites show three sets of joints which trent towards NNE, WNW and as a sheet joints which are horizontally disposed. The gneisses occur as lenses within the granite and these rocks are intruded by pegmatite and quartz veins. Infra trappena beds are lameta beds comprising fespatic grits and sandstone with calcareous cemeting material. The generised geological sequence of the district is given in Table-I.

HYDROLOGY OF THE AREA

Groundwater in this region occurs under water table condition in weathered, jointed, fractured and vesicular zone of the flow exposed at the surface. Groundwater occurs under confined conditions in jointed, brecciated or fractured and vesicular zone of lower flows. The vesicular and zeolitic basalts are highly susceptible to weathering as interconnected vesicles form conduits for weathering agents. Areas along stream courses and local depression carved out along inherent weaker zones of rocks like joints, fractures, brecciated zones have greater permeability. Such areas form groundwater discharge zones, which are rich in groundwater potential and are suitable for future development of of groundwater resources. Wells located in such areas yield copious water supply ranging from 125 to 350 m^3/day. Transmissivity of shallow aquifer in basalts range from 30 to 80 m^2/day, specific capacity of well ranges from 75 to 270 lpm/m with an average of about 110 lpm/m.

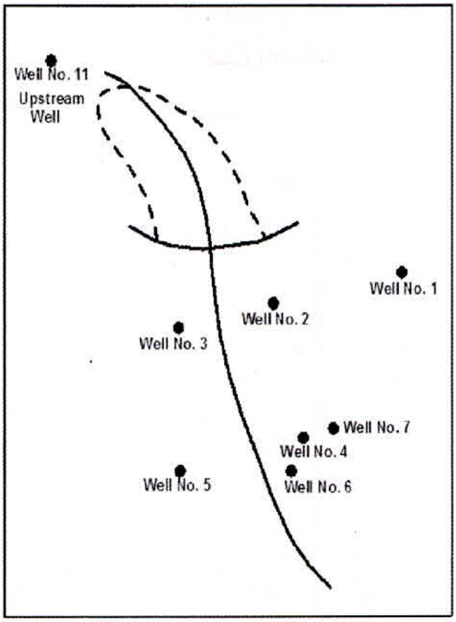

Fig. 3: Schematic diagram of Pangri percolation tank showing catchment well locations.

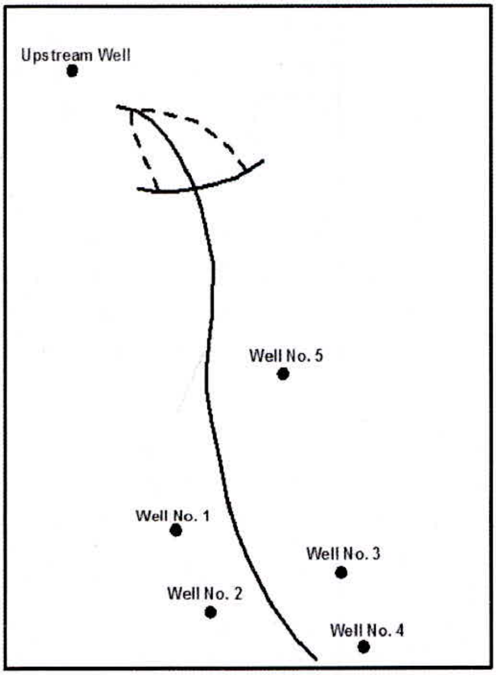

Fig. 4: Schematic diagram of Martala percolation tank showing catchment well locations.

Table-I: Generalised Geological Sequence of the district.

Age	Lithology
Recent	Alluvium
Cretaceous to Eocene	Basaltic lave flows (Deccan Traps) with intertrappean beds.
Eocene	Lameta beds.
Archaean	Epidiotites and banded haematite quartzite of Dharwar system. Pink Peninsular granites, grey granite, gneiss, quartz and pegmatite veins.

ENVIRONMENTAL CHLORIDE METHOD

Environmental chloride is deposited on the land from the atmosphere by rainfall and dry fallout. The fallout is more along the coast and decreases with increasing distance from the coast. The contribution from rainfall is measurable but the due to dry fallout, especially in the inland area is negligible. Jacks et al. (1980) estimated the dry fallout in southern India, about 200 km away from the coast, to be about 0.02 mg/cm^2/yr. It is expected that dry fallout will be lower in the further inland areas. Thus in case of percolation tanks, chloride input from dry fallout is expected to be negligible, since the chloride from dry fallout is dissolved in the surface runoff and reaches to tanks as initial input. Post monsoon component of dry fallout, occurring over the tank water spread area is relatively small and change in chloride concentration of tank water because of dry fallout during period is negligible and thus not considered.

In recent years there has been an increase in utilising environmental chloride as a tracer for various geohydrological studies. This is due to two reasons: (1) chloride is a conservative tracer (Hem, 1970; 1985) and (2) it can be measured using a simple technique, in a situation when no additional sources or sinks of chloride are available, it can be effectively used.

Environmental chloride tracer has been previously used to estimate the natural groundwater recharge rate. This method has been applied all over the world for example by Eriksson and Khinaksem (1969) in Israel, Sukhija and Rama (1973) in India, Allison and Hughes (1974, 1978) and Sharma and Hughes (1985) in Australia to estimate the natural groundwater recharge. Edmunds et al. (1990) used the method for past and present recharge evaluation in semiarid and arid terrain. Sukhija et al. (1988) estimated natural groundwater recharge in coastal aquifers of India by measuring the chloride present in soil profiles in repeated experiments and the results were found to be comparable with those obtained with the injected tritium method.

Sharma and Hughes (1985) have used chloride in the soil profile and in groundwater to know the mechanism of soil-water movement, and Tariguchi and Sharma (1990) used the tracer to estimate the ratio between mobile and total water content in soil profile. Sukhija and Reddy (1987) demonstrated the importance of chloride method to detect the presence of percolated water in wells situated downstream of a percolation tank.

PRINCIPLE OF CHLORIDE ESTIMATION

The main principle of environmental chloride techniques is assuming that there are no additional sources or sinks of chloride in the percolation tank after impounding, and further, there is no loss of water by factors other than evaporation and percolation i.e. seepage from the dam, if any, should also be accounted, the mass balance of chloride in the tank water can be used in estimating the percolated fraction of total volume of water. When the tank dries up during summer, some chloride stays back in the top soil. However, this may mix back with the tank water when the tank get full during rainy season. Since the observations are started at the end of the rainy season i.e. after three or four months

Table 2 : Rainfall and Pan Evaporation at Nanded for the year 2000

Month	Rainfall (mm)	Pan Evaporation (mm)
January-2000	0.0	197.4
February-2000	26.6	210.6
March-2000	0.0	302.6
April-2000	0.0	330.62
May-2000	57.8	345.2
June-2000	226.6	163.6
July-2000	171.3	144.5
August-2000	379.8	133.2
September-2000	31.0	154.2
October-2000	154.0	184.2
November-2000	0.0	180.3
December-2000	0.0	164.4
Total	908.5	2510.8

of water collection and compute the balance of chloride in tank water before the tank completely dries up. Further, it is assumed that the contribution of chloride by diffusion of soil water to the tank during experimental period would be negligible, though it needs to be ascertained. The total chloride content of tank water at any time is estimated from the volume of tank water at that time and its chloride concentration which is measured regularly i.e. Every week and after the end of rainy season. As there is no loss of chloride by evaporation, the chloride concentration of the tank water should increase with time beacuse of evaporation. This generally happens, as there are long dry spells of several weeks after the monsoon. The percolating water, howerver, takes chloride with it.

Thus, by measuring the chloride concentration and the volume of water in tank at different times after monsoon, assuming that there is no seepage leakage from the dam, the fraction of tank water can then be calculated (Sukhija et al., 1997), as follows.

The chloride balance in the tank water at time t_1 and t_2 can be written as follows:

$$V_1C_1 = V_2C_2 + (1\text{-}f)(V_1\text{-}V_2)\,C_p \qquad (1)$$

where V_1 is volume of water in the tank (after monsson) at time t_1,

C_1 is chloride concentration in the tank water at time t_1,
V_2 is volume of water in the tank at time t_2,
C_2 is chloride concentration in the tank water at time t_2,
$(V_1 - V_2)$ is loss of water between time t_1 and t_2,
f is the fractional loss of water by evaporation,
(1-f) is percolation fraction or efficiency,
$f(V_1 - V_2)$ is loss of water by evaporation,
$(1\text{-}f)(V_1 - V_2)$ is loss of water by percolation

$$C_p = ÓC_iV_i/ÓV_i$$

Where C_p is time weighed average concentration of chloride percolated water.
Hence percolated fraction,

$$1\text{-}f = (V_1C_1\text{-}V_2C_2)/\{C_p(V_1\text{-}V_2)\} \qquad (2)$$

The percolated fraction i.e. artificial recharge from tank can be evaluated if V_1V_2 and C_1C_2 are known. The weighed chloride concentration (C_p) of the percolated water is estimated from $ÓC_iV_i/ÓV_i$ weighing done from V_1 to V_2. It is assumed that percolation (and also from fractional evaporation loss) remains constant during the period (t_1 to t_2) i.e. when the volume decreased from V_1 to V_2.

METHODOLOGY

The developed technique necessitates the working of the chloride balance in tank water at any time, provided there are no additional sources or sinks of chloride in the tank during the experimental period. Further for obtaining the balance at any time, the volume of water and its chloride concentration are fundamentally required parameters. Volume of water in tank at any instant can be estimated from the depth of the water column and the area occupied by the water body at that time. In order to obtain this, a rating curve (stage vs volume) is required to be obtained. A detailed (very close interval, ~5 m grid) topographic survey of the tank bed has to be made and volume of water in tank is calculated for changing water column in the tank.

The chloride measurements are to be carried out at regular intervals, say over week, and water level in the tank has to be recorded daily using the installed staff guage. Since the chloride concentrations are expected to be rather low, it is desired that they are measured very accurately. Low concentration in water sample can be measured by the mercuric thiocyanate and ferric nitrate method (Navada, 1982) using a Spectrophotometer. The chloride ions react with mercuric thiocyanate to form soluble mercuric chloride releasing the thicynate ions. In the presence of ferric ions, a highly coloured ferric thiocyanate complex is formed. The absorbance of this complex is proportional to the orginal chloride concentration. Using this technique, it has been possible to measure chloride concentration down to 1-2 ppm. In the range of 5-30 ppm chloride could be measured with precision bettern than 10%.

RESULTS AND DISCUSSIONS

In order to assess the efficiency of percolation tank in basaltic terrain, chloride mass balance methodlogy is adopted in two percolation tanks namely Pangri and Martala for the year 2000 are percolation tank. For the study period the meteorological data of rainfall and pan evaporation is collected from the Nanded Meteorological Station as given in Table 2 and shown in Figure 2. The rainfall is high during the months of June to August, similarly pan evaporation is also high during the months of March to May. Regular water level were monitored and water samples were collected with an interval of 10-30 days for chloride analysis from these two percolation tanks. The analysis results of water level and chloride concentration in tanks and in upstream and downstream wells of Pangri and Martala percolation tank are given in Table 3 and Table 4. The comparision of tank water level and chloride concentration in tanks are shown in Figure 5 and Figure 6 for Pangri and Martala percolation tank respectively.

It can seen from Table 3 and Figure 5, the chloride concentration in the Pangri percolation tank water during the first week of December is about 40 mg/l and it is enriched to about 55 mg/l in the month of March (i.e. After 102 days). During this period, the water level in the tank is also reduced from 0.86 meter to 1.68 meter i.e. 0.82 meter. From the measuring point this is 0.80 meter drop in tank water level. It is observed from Figure 5 that there is a good inverse correlation between chloride concentration and tank water level, i.e., chloride concentration is increasing with decreasing water level in the tank. The chloride concentration measured in the groundwater samples in the

Table 3 : Chloride concentration of water samples collected in and around Pangri Tank and Tank water level

Date/Chloride Concentration	5.12.2000	25.1.2001	4.2.2001	12.2.2001	19.2.2001	8.3.2001	17.3.2001
Tank water	40.83	48.31	49.81	51.10	52.10	53.78	54.62
Well -1	02	03	03	07	04	05	06
Well-2	38	39	40	41	41	46	42
Well-3	32	38	36	41	40	38	41
Well-4	38	44	50	52	42	54	52
Well-5	42	40	46	47	41	46	47
Well-6	41	44	45	46	42	45	44
Well-7	38	36	52	39	40	38	41
Upstream Well	32	35	38	38	36	34	38
Water level in Tank	0.86	1.29	1.33	1.38	1.44	1.59	1.68

Table 4 : Chloride concentration of water samples collected in and around Martala Tank and Tank water level

Date/Chloride Concentration	24.1.2001	8.2.2001	20.2.2001	5.3.2001	13.3.2001
Tank Water	13.3	14.0	14	15	17.15
Well -1	19	21	20	21	21
Well-2	11	11	12	12	10
Well-3	19	20	19	19	17
Well-4	17	17	17	17	24
Well-5	18	19	19	19	20
Upstream Well	35	42	42	43	43
Water level in Tank	0.98	1.10	1.18	1.25	1.28

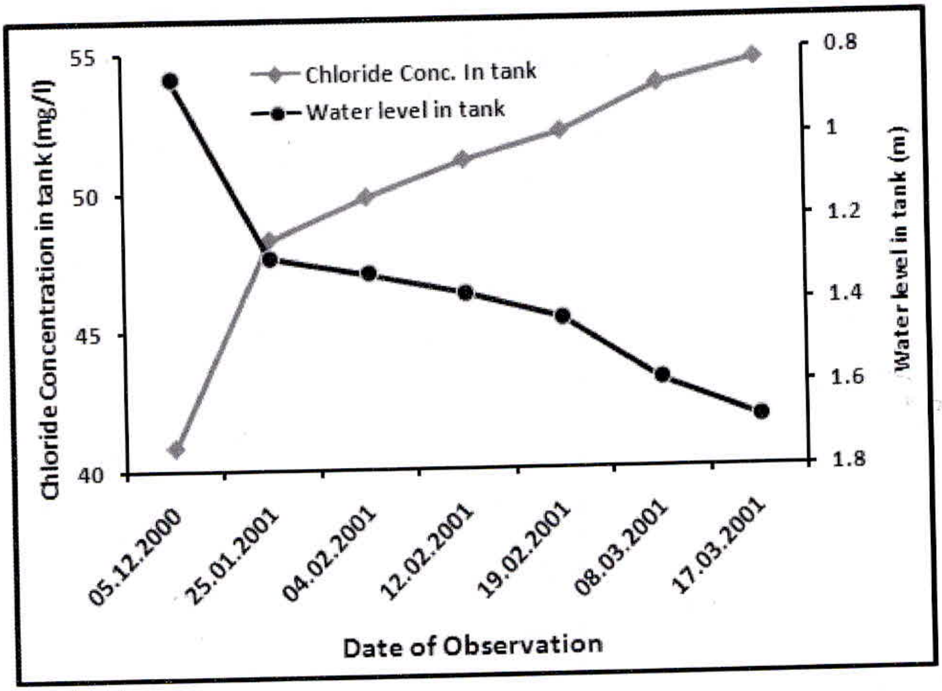

Fig. 5: Comparision of chloride concentration and water level in Pangri percolation tank

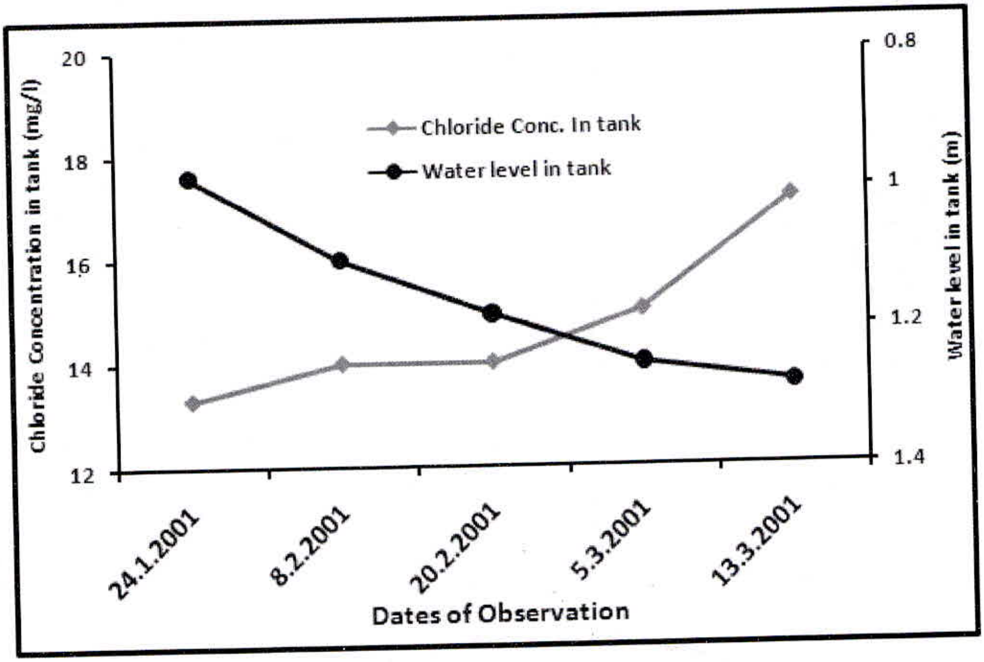

Fig. 6: Comparision of chloride concentration and water level in Martala percolation tank.

upstream area is around 32 to 38 mg/l, however, the chloride concentration in dowstream wells is about 32 to 54 mg/l except for Well No. 1, which is almost a side away from the catchment area of percolation tank.

Similarly, only limited measurements were carried out for Martala tank i.e. From January to March 2001. The analysis results of water level and chloride concentration in this tank is given in Table-IV. A graph of water level in tank and chloride concentration is shown in Figure 6. The chloride concentration for this tank varies from 13 to 17 mg/l in tank water, 35 to 43 mg.l in upstream well and 10 to 24 (as per take-iv) mg/l in downstream wells. The water level in the tank varies from 0.98 meter to 1.28 meter i.e. , total change in water level is 0.30 meter.

It is observed from the above study that the Pangri tank water shows very high chloride concentration, when the tank is more than half full. As the dimension of the tank is very large, it never goes dry during summer season. The chloride concentration in tank water, upstream well and in downstream wells are high, the reduction of water level in tank and enrichment of chloride concentration even after 100 days of time, indicate that there is non-communication between tank water and well waters. While in case of Martala tank through available limited data shows that there is communication between the tank water and groundwater chloride concentration. The concentration of chloride in tank water after 50 days of time increases only from 13 mg/l to 18 mg/l it shows low percolation please examine. The chloride concentration in upstream side of this tank varies from 35 to 43 mg/l, while in downstream side it is varies from 10-24 mg/l, this indicates that natural groundwater flow from tank dilute the chloride in the downstream side.

CONCLUSIONS

Based on the qualitative environmental chloride studies the concentration of chloride in Pangri percolation tank ranges from 40.83 mg/l to 54.62 mg/l and that of Marthal tank ranges from 13.3 mg/l to 17.15 mg/l. The water levels in Pangri percolation tank ranges from 0.86 m to 1.68 m and in Marthal tank it ranges from 0.98 m to 1.28 m. The environemtnal chloride concentration in catchment wells of Pangri tank ranges from 32 mg/l to 54 mg/l and in upstream site it ranges from 32 mg/l to 38 mg/l, while in case of Marthal tank catchment well it ranges from 10 to 24 mg/l and in upstream site it ranges from 35 to 43 mg/l. It is also observed that the pan evaporation rate is also high in the study area. From environmental chloride mass balance studies, it indicates that Pangri percolation tank is behaving like an evaporation tank and Marthal tank is able to contribute recharge to groundwater.

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