A Process for Organic Water

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Abstract

We present a local, self-sustaining, natural and economic way to secure a quality drinking water resource for a town or city. Most local rain fed aquifers in the environs of cities suffer from long term contamination by chemical waste – either fertilizers and pesticides or urban effluents. We propose a process by which such aquifers can be restored to quality. This is accomplished by, first, changing the land use of the catchment area of local aquifers to forest, and then, by a yearly evacuation of the water in the aquifer till quality is restored. A model is used to estimate that, typically, by a yearly evacuation of the aquifer, the pollution in the aquifer water is reduced to 10% of its initial value in 5-7 years. This is an organic process to purify the water in the aquifer. We also find that the area required for this, falls within 10%of the total area of the city, well within the green area norm for a city.

I. INTRODUCTION

It is common knowledge that the planet is faced with a major problem in the available water resource. This problem has two dimensions :

1) The first is with respect to the *quantity* of water available. With increasing population, the demand of water, both for human consumption and agriculture, has been steadily increasing. Also, the melting of glaciers, deforestation, and general environmental degradation, in particular, of rivers, have cut the retentivity, flow, and availability of water on the planet.

2) The not so obvious problem, which is perhaps more serious, has to do with the *quality* of water, which has so deteriorated over the last 50 years, as to render most water unfit for drinking. How has this happened ?

   Excessive urban migration has inflated cities beyond manageable limits, to produce such quantities of effluents so as to render both the local groundwater and rivers flowing by cities to be criminally polluted. This has happened mostly due to leaching of contaminants from landfills, indiscriminately disposed anthropogenic toxic wastes, unplanned application of agri-chemicals and surface runoff from farm lands [1].

   More surprising is the state of the ground water in rural areas which do not have waste disposal problems like metropolitan areas. The pollution here has occurred due to the heavy doses of fertilizers and pesticides used for modern agriculture. The cumulative effect has been to contaminate the near surface ground water base with fertilizer and pesticides. This pollution is long term and has no simple solution.

The USGS (http://water.usgs.gov) has extensive data available for the quality of ground water for different land use across the country. One such set of data is shown in Fig. 1 for the Long Island - New Jersey coastal drainages [2]. It is quite evident that the quality of water in the undeveloped areas is far superior to the one where there is urban or agricultural land use. The quality can only improve further for the case of a protected forest where the root system of trees provides additional filtering of pollutants.

Quality drinking water is thus very hard to come by except in wilderness areas. which are generally far away from the populations that require water. Transport of water from such areas to cities is then a high entropy, high cost major pipeline project. Furthermore, transport of a fundamental and local resource like water is ecologically very unsound and wasteful.

The other possibility for producing potable water is the technological fix of chemical treatment (reverse osmosis and resin), but this has the disadvantage of high cost, leaching of important healthy minerals – which yields only processed and not mineral water and producing a sludge which causes a disposal problem. Anyhow, this makes it impractical for poor, underdeveloped and remote areas.

We now describe a process for purification of natural aquifers that occur in the environs of a human settlement but have been cumulatively polluted by human activity over the years (we use the term "human settlement" to mean any village/town/city and hereafter, we abbreviate it further to a "settlement" throughout the text of this document). The water stored in these aquifers is purified in the process and a local, self sustained source of high quality drinking water is created.

II. THE PROCESS

Using a conservative figure of three liters per person per day, we get the annual requirement of drinking water for the settlement. Once aquifers with the appropriate recharge capacity have been located, we must create and protect forest on their entire catchment so that the total recharge capacity is equal to or exceeds the requirement computed above. Further pollution can be eliminated by changing any urban or agricultural land use in the catchment to a protected forest area. This enables the water recharging the aquifer to be free from agricultural and other contaminants like fertilizers and pesticides (nitrates, phosphates, fluorides, etc.), and instead, makes it rich in natural minerals.

A simple way to estimate the ground water recharge for an area based on rainfall and pan evaporation data was presented in Ref. 3. After estimating the total evaporation loss and subtracting it from the total rainfall, we find the balance available for recharge and runoff. For a large and heterogeneous area, the aquifer potential or recharge, has to be determined from the hydrogeology of the area. This can be done using, for example, empirical data from the curve number technique which gives the recharge from the porosity data of the local terrain.

Once the land use in the catchment area of the aquifer has been changed to forested land, our process of purification involves yearly evacuation of the water in the aquifer by pumping out for agriculture (or other use) to a location outside the aquifer catchment. The efficacy of this method is illustrated using a simple but realistic model in the next section.

After annually pumping out the contaminated water in the aquifer, for a period of 5 -7 years, the fresh recharge flowing into the aquifer through the protected forest then gives us high quality spring water ideal for drinking. We dub this as O*rganic Water.* As outlined above, the process involves an integration of natural processes.

Purification of Unconfined Aquifers : A Model

One of the most pressing issues in this process is the time scale in which the water in aquifer can be decontaminated and purified. We turn now to this. Once the land use is changed and no fertilizer is applied to the ground, the unpolluted rain water will pick up contamination from the top sublayer leaving it less polluted in its passage. The rainwater will then move to the next sublayer carrying some pollutant picked from the previous sublayer. Assuming the same initial pollutant concentration (uniform) in the sublayers, the concentration in this sublayer, after mixing with the incoming rainwater, will be more than for the one sublayer above. Thus, the pollution concentration gradient in the soil will be positive with depth. Every succeeding rain will keep lowering the concentration of pollutant in the soil and washing it into the aquifer.

We shall consider this problem using a simple model shown schematically in Fig. 2 below. This model needs some relevant parameters to be specified. We discuss below, stepwise, these parameters, the details of the model, and the results.

1) We assume an unsaturated zone of porous soil of depth, **H.** This is simply the layer of soil that starts at ground level and extends down till the subsoil level at which the aquifer begins. A unit volume in this layer fractionises thus : ***m*** is the volume fraction of polluted water which we term, specific moisture**,** ***s*** is the volume fraction of soil matter, leaving a fraction ***(1- m -s)*** as empty volume.
2) Rain falls on the ground, which is the top of this layer, and percolates down through it to the aquifer. We shall consider only soluble contaminants (as any insoluble one will not percolate down in the recharge). The model does not distinguish between contaminants.
3) We have a dilution model of pollution, in which we assume ideal mixing between the specific moisture in the soil and the inflowing rainwater. Thus, when a certain volume of rainwater enters a sublayer of soil, the pollution concentration in the sublayer becomes the weighted average of the two.
4) The initial pollution concentration in the soil and its depth profile are inputs to the model. For simplicity and convenience in discussing the model, we take the initial concentration of pollutant to be uniform through the depth, ***H***, of the unsaturated zone. However, the model equations apply to any given concentration profile.
5) A differential equation for the above model can be written in the following way. Consider a thin horizontal layer of unit area and thickness ***dz*** at depth ***z*** below ground. Let the infiltration rate of rain water volume per unit area be denoted by ***R*** and the pollution concentration at depth ***z*** and time ***t*** by ***p(z,t).*** In a time

interval ***dt***, the rainwater entering the thin layer from above has a volume ***Rdt*** and carries a pollution concentration ***p(z-dz, dt)***. Assuming that this rainwater mixes completely with the specific moisture in the layer, we can write an expression for the pollution concentration at time ***t+dt*** in this layer, given by

$$p(z,t+dt)=\frac{m\,p(z,t)\,dz+R\,dt\,p(z-dz,t)}{m\,dz+R\,dt} \qquad (1)$$

The rainwater entering the layer can at most occupy the full empty volume in this layer. Writing

$$R\,dt = \alpha\,dz\,, \qquad (2)$$

the maximum value of α is given by α_{max} = ***1-m-s***. Substituting Eq.(2) in (1), a Taylor expansion of ***p(z, t+dt)*** and ***p(z-dz, t)*** around ***(z,t)*** gives the differential equation

$$\frac{\partial p}{\partial t}+\frac{R}{m+\alpha}\;\frac{\partial p}{\partial z}=0 \qquad (3)$$

From the above equation the average velocity of the displacement of pollution downwards is ***[R / (m + α)]***. Given an initial pollution concentration profile, the above equation can be solved to obtain the concentration profile in the ground at any later time.

We have ignored effects of diffusion in deriving the above equations. Diffusion terms do not affect the average velocity of downward displacement of pollution. It is also straightforward to have the specific moisture ***m*** depend upon the depth. In that case ***m*** gets replaced by ***m(z)*** in the above equations.

Our results above are summarized by the simplistic piston model. This states that purification is achieved when the total recharge inflow, which is the annual recharge multiplied by the number of years is equal to the specific moisture, ***m***, multiplied by the depth, ***H.***

Significant Parameters for Aquifers

To understand this better we need to breakdown the hydrology of precipitation, ***P***, into its various and distinct parts. Once rain falls on any area, firstly, there is surface evaporation loss, ***S.*** This depends on the climate and the soil. Next, we have to account for runoff and transpiration from the vegetal cover. For example, on flat agricultural land or flat pasture or woodland, the runoff is small, and for forests, transpiration is more than that for pasture. On the other hand, on land that is contoured by slopes a large portion of the balance goes in runoff. Also, if the soil is impervious, like clay, runoff is dominant. Depending on their geographical location aquifers present varying situations.

There are four main parameters in this estimate

1) Rainfall : (i)A rainfall, ***P*** ~ 50 – 60 cm, presents arid condition. This would apply, for example to Delhi, where, after surface evaporation, only 15 cm may be left for recharge, transpiration and runoff, of which we find 60% recharge for the forested catchment, or 9 cm of recharge. (ii)A rainfall of **,** ***P*** > 100 cm (e.g., Bangalore , Pune Dehradun) will have no more evaporation than in (i) above and could leave 75 cm for recharge, transpiration and runoff of which as much as 30 cm or more may be available for recharge.

2) The specific moisture or field capacity, $\boldsymbol{m}$

i) For sand, $\boldsymbol{m}$ = 0.05 (for e.g. desert conditions in Rajasthan, Gujarat).

ii) For sandy loam as occurs around some areas in Delhi, $\boldsymbol{m}$ = 0.15.

We shall use a typical average value of, $\boldsymbol{m}$ = 0.10.

3) The depth, $\boldsymbol{H}$, of the unsaturated layer can vary from aquifer to aquifer. We have shallow aquifers in mind, which can vary from, $\boldsymbol{H}$ = 10 – 30 meters, and for our estimation we use an average value, $\boldsymbol{H}$ = 20 meters.

4) The specific characteristics of an aquifer : the ratio of the catchment area to the aquifer area, $\boldsymbol{r}$. Assuming, $\boldsymbol{R}$, to be the normal recharge in cm,. we can define a catchment augmented effective recharge, $\boldsymbol{E_r = R \times r}$.

III. RESULTS

A Typical Example

Based on the above model, we present below results for a typical situation with the following parameters :

Specific Moisture $\boldsymbol{m}$ = 0.1

Soil Fraction, $\boldsymbol{s}$ = 0.2

Effective Recharge (annual), $\boldsymbol{E_r = R \times r}$ = 35 cm.

Depth of aquifer, $\boldsymbol{H}$ = 20 m.

The initial ground water pollution is assumed uniform. A yearly plot of the ground water pollution profile is shown below in Fig. 3. The curves correspond to profiles after each consecutive year respectively. For the given aquifer characteristics, in six years the aquifer water pollution drops to about 10% of the original.

Implementation of such a scheme requires

1) An intervention in public policy that for towns and cities, all nearby aquifer catchments be declared vital state assets and be protected.
2) Cooperatives or water companies to step in and manage drinking water services derived from these aquifers. As we indicate in Table I in the appendix this is highly profitable economically. The main cost is the renumeration to the farmers who own the land. A renumeration of even five times the maximum agricultural income from the land makes hardly a dent in the earnings from the service.
3) A space of 5-7 years for such quality drinking water sources to be operational.

IV. DISCUSSION

The main advantages of the process are that there is no use of chemical technology and production of no toxic waste. It uses a natural percolation process for rainwater to come into the aquifer. Foresting the catchment provides good foliage and humus to supplement water retentivity. The roots of the trees consolidate the soil and provide additional natural filtration to enhance the quality of the water. Runoff and erosion is reduced thereby increasing the ground water recharge. Hence, recharge estimates in the examples are lower bounds. Natural green wooded area, which is less than 10%

of the city area, is required for this purpose. This falls neatly into the urban planning norm of having about 20% green area in a city. Due to it being a natural process, the main costs involve the remuneration given to farmers whose land has been converted to wooded area. Even if the estimated remuneration is about 5 times the annual income of the farmer from the said land, the cost of generating pure drinking water of high quality is extremely cost-effective (see Table I), as compared to the ecological and financial costs involved in bottling and transporting water from remote unpolluted wilderness sources, such as mountain streams or purification of water by chemical or osmotic process.

At the present time, it is estimated that almost half the world's population has no access to good drinking water. This is considered an essential cause of several debilitating water borne diseases. This is the primary component in preventable human mortality. At a cost of $0.02 per liter (see Table I), the annual cost of providing two liters of good drinking water per day per person works out to approximately US Dollars 15 billion for every billion people. The UNEP experts have estimated the cost of providing safe drinking water and proper sanitation to every one in the world by 2025 at US $180bn [4]. Needless to say the present cost in terms of health is much more. Providing a simple, natural, low cost, local, and self sustaining solution to the drinking water problem is vital. Organic Water will do just that.

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Figure Captions

1. Selected indicators of ground water quality for various kinds of land use in the Long Island - New Jersey coastal drainages.
2. A schematic of the model for purification of unconfined aquifers.
3. Ground water pollution profile as a function of depth below ground into the unsaturated zone at yearly intervals after flushing with recharge rain water. The aquifer is 20 m. deep, soecific moisture $\boldsymbol{m} = 0.1$, soil fraction $\boldsymbol{s} = 0.2$, and effective recharge $\boldsymbol{E_r} = 35$ cm.. The curves from left to right correspond to profiles after one to six years, respectively.

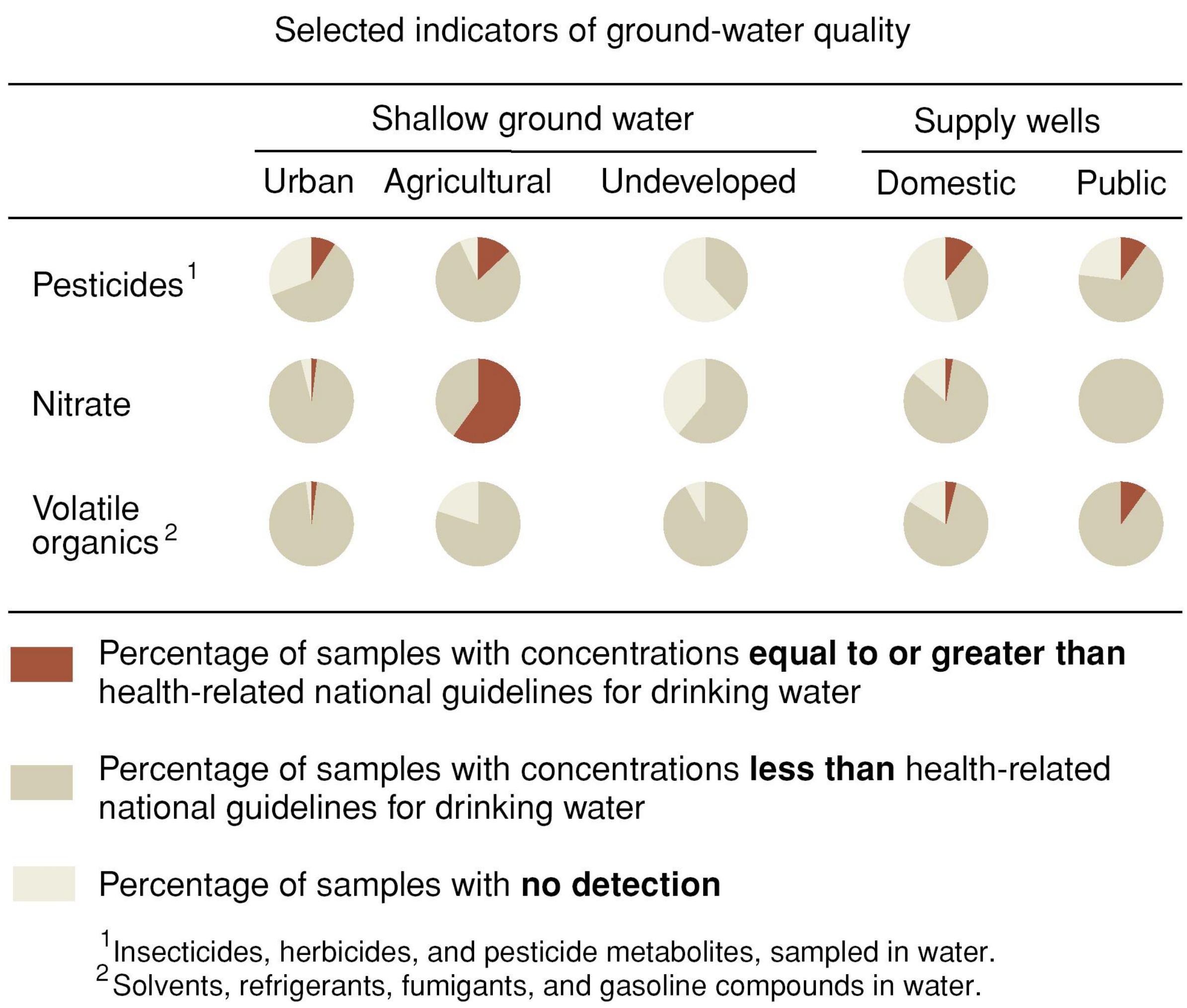

Figure 1. V. Soni et. al.

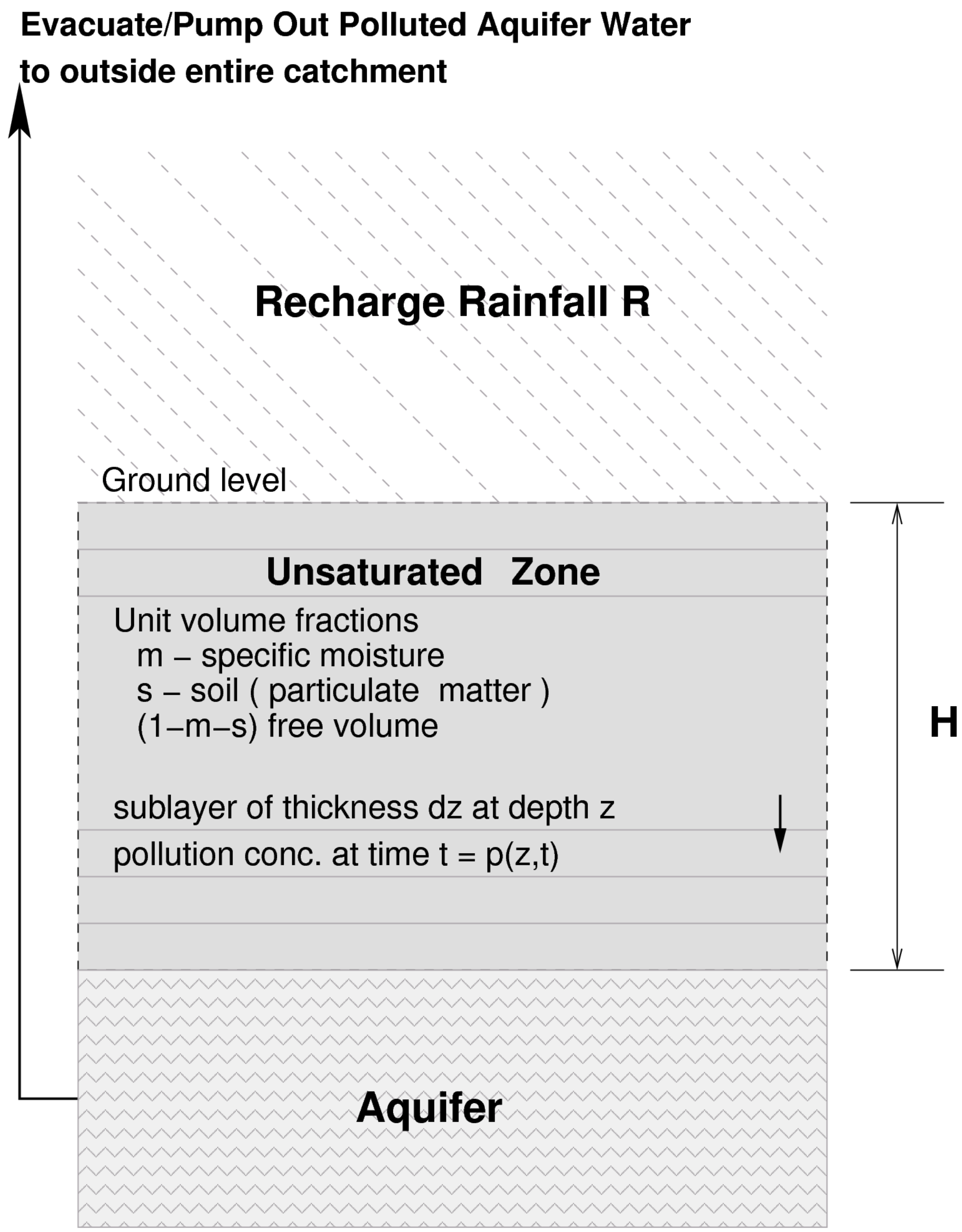

Figure 2. V. Soni et. al.

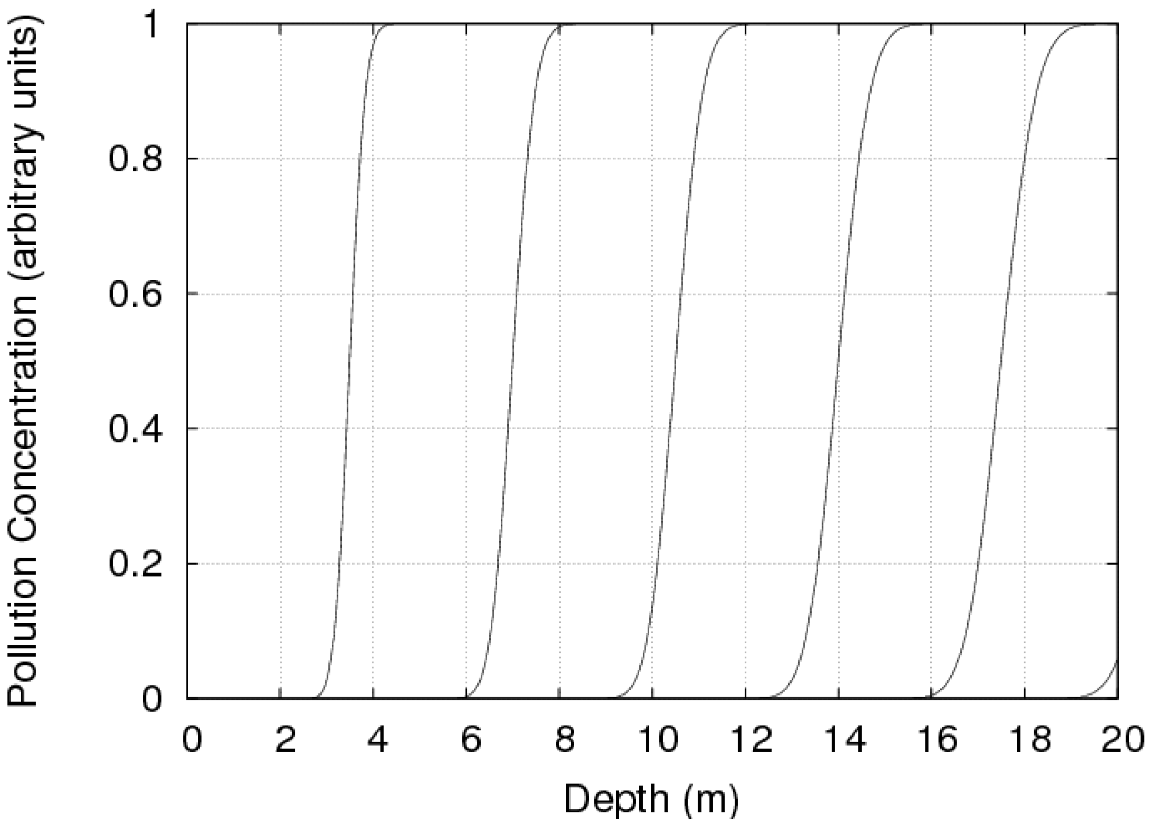

Figure 3. V. Soni et. al.

Appendix : Economic Viability for Generation of Organic Water

Table 1. Annual Balance Sheet for a sq. km. of aquifer receiving 30 cm. of recharge per year (300 million litres per year) and organic water @ $0.02 per liter. All figures are in US Dollars.

Costs and Overheads	
Land Rental reimbursement to farmer / landowner @ four times the gross value of agriproduct ($ 2400 per hectare)	$240 000
Delivery costs from zonal focal points to vending outlets @ $10 per trip for a tanker of 10 000 litres	$300 000
Maintenance / running cost	$20 000
Total	$560 000
Capital Costs	
Land rental cost for six year idle purification time (@ four times the gross value of agriproduct as above)	$1.44 million
Afforestation costs @ $0.20 per sapling at 5 m. distance and Labour cost @ $ 1 per sapling	$48 000
Maintenance cost for six years	$120 000
Pipeline cost	$200 000
Interest on the above total @ simple interest of 10% a year	$1.08 million
Total	$2.9 million
First Year of Operation	
Market value of organic water	$6 million
Capital costs	- $2.9 million
Running costs	- $560 000
Profit*	$3.5 million
Profit / cost (including capital investment)	70.00%
Second Year Onwards of Operation	
Market value of organic water	$6 million
Capital costs	0
Running costs	- $560 000
Profit	$5.4 million
Profit / cost	900 %

Note : The above figures have included in rental the gross value of agricultural produce instead of agricultural returns which would be lower. Also any additional income from using the forest itself as a crop has not been included.

*For the case of borewell harvested water, only the capital cost goes up by $800,000.