Conjunctive use of Aquifers and Ulhas River in Ulhas River Catchment

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Abstract— The paper focus at storing surplus water in the monsoon season and utilizing the same when the water demand is high (non-monsoon season). It also throws a light on encouraging the water resource development by an integrated approach towards the use of surface and sub-surface water resources

Index Terms— conjunctive use, groundwater and surface water

I. INTRODUCTION

The Ulhas river is a perennial river and originates in a valley north of the Rajmachi hills formed by mountains streams draining the north slope of these hills which are part of the Sahyadri range of the western ghats in the Raigad district of Maharashtra.

Course of the river

From the point of origin, the river flows north turning left where it is joined by river Salpe, its right bank tributary. As the river bypasses the Palasdhari village, it receives the discharge from the Palasdhari Dam. Further north, it is met by the river Peg and river Poshir near Neral. At Badlapur, it receives the run-off from Chikloli dam and river Barvi.

Catchment area

The Ulhas basi lies between North latitudes of $18^o 44'$ to $19^o 42'$ and East longitudes of $72^o 45'$ to $73^o 48'$. The river has a draining area of 4637 km^2 in size and the average annual rainfall in the basin is 2934 mm. The transmissivity of the soil is 40.80 to 50.52 m2/day..

II. THEORY

The state of Maharashtra gets monsoon rainfall for a period of four months from June to September and the waning precipitation in the month of October and November. Coincidentally, the water demand in this period is also less. This necessitates the need of storing water in the water surplus season and utilizing the same the same when the water demand is high (non-monsoon season). The option of storing water may be construction of dams (surface storage) or the recharge of groundwater (sub-surface storage). Both the surface and the sub-surface water storage methods has its own advantages and dis-advantages to be considered while opting for the water storage system to be implemented.

Groundwater aquifers are incapable to absorb large volume of water in a short period of time due to the basin characteristics like permeability, particle size distribution of the soil, temperature, humidity and other allied factors. Hence the need of artificial recharge of groundwater needs to be highlighted.

The surface water storage system on the other hand requires huge capital investment, considerable time for construction and operation, has huge submergence of land, evaporation losses among the factors to be considered in the pros and cons of surface storage system.

A reasonable solution to overcome the demerits of both surface and sub-surface storage systems is the conjunctive use of surface and sub-surface water. Conjunctive use of surface and sub-surface water essentially consists of concordant use of both sources of water in order to minimise ill-effects of each individual water storage system and to optimise the water demand- water supply balance.

The conjunctive use of surface and sub-surface water is more pronounced within a water shed management programme for a river basin- i.e. aquifers and the river belonging to the same basin. The surface and the sub-surface sources of water should be considered as an inter-dependent entity. This enables to avoid the double counting of the available water resources. The very basic intent of storing the surplus rain water is to use it at a later stage i.e. during the non-monsoon period. The main factor in storing groundwater is to ascertain the potential storage capacity of the groundwater reservoir, its recharge capacity and the ease of withdrawal of the stored water when required. The factors essentially to be considered in case of sub-surface water storage are:

- Underground storage capacity of the ground strata below.

- Potential discharge capacity of the aquifers.
- Natural recharge rate of the aquifers.
- Artificial recharge rate of aquifers.
- Comparative socio-economic and environmental benefits.

The underground strata should have enough free space (permeability) between the ground surface and the water table to collect and store the water to be recharged, during the monsoon period. This requires a thorough knowledge of the hydro-meteorological characteristics of the river basin. The soil should be highly un-saturated and contain large number of voids and inter-molecular porosity, and the aquifer transmissivity should be high.

Natural recharge of the aquifers occurs when the aquifers near the river flow are exploited, thus lowering the ground water level and the river water siphoned into the aquifers. Artificial recharge of the sub-surface water resources can be done by surface spreading, water-shed management, recharge wells, check dams, underground dams, or spate irrigation techniques. The important character to be considered in the conjunctive use of surface and sub-surface water sources is that, there is always an interaction and inter-relation between the river and the aquifers in the river basin.

Resource allocation before undertaking individual case studies

Before undertaking individual case studies, it is necessary to quantify various demands on water resources. The potential recharge of an aquifer is dependent on the intensity and rainfall distribution and the nature of run-off. Considering a typical rainfall recharge of 100 mm/year, the area of aquifer with a recharge equivalent to the per capita annual requirement of 60 m^3 is 600 m^2. This simply implies that one sq.km of aquifer area can supply 1700 people if the aquifer is assumed not to be over-exploited. A city with population of one lakhs requires an aquifer area of 600 sq.km to meet the domestic requirements on the assumption that no over-exploitation occurs and that no water is used for agricultural, industrial and allied purposes.

Actual recharge if sub-surface water

The quantity of water actually reaching the aquifer depends upon the physical properties of the soil strata. It is easy to estimate the potential recharge leaving the soil zone, but the soil conditions in the unsaturated zone dictates the water quantity reaching the groundwater table. The low permeability zone allows water to pass at a low velocity than the rate at which water drains from the soil zone. The limiting effect of these low permeability zone can be elaborated by the aquifer response to the heavy rainfall in Chennai in November 1985 when almost one meter of rainfall occurred in four days. Yet, there was hardly any significant rise in groundwater level indicating that the main aquifers hardly received the percolated rainfall.

Recharge from rivers

River basin aquifers get recharged at a steady state in case the river flow is perennial. The flow process can be approximated by the aquifer ability to accumulate water and the quantity of water available in the river. The aquifers withdraw water from the over-lying river due to vertical hydraulic gradient. The discharge of water vertically downwards into the aquifers is limited and hence much of the river flow does not infiltrate but continues downstream.

Examples of conjunctive use

The surface water supplies can be taken from rivers, reservoirs, lakes, etc. and the sub-surface supplies withdrawn from deep aquifers or shallow wells.

Conjunctive use in Chennai, Tamil Nadu, India

Chennai in south India is a typical example where most of the water is supplied by surface reservoirs, but in addition there are deep tube wells and numerous shallow domestic wells. The various sources of supply and their approximate capacities and yields are as follows:

Main reservoirs

Poondi reservoir (capacity 75 mcm)
Cholovaram tank (capacity 15 mcm)
Red Hills Lake (capacity 30 mcm)
These three reservoirs are inter-connected.

Major well fields

Alluvial aquifers 30-60 meter thick
Minjor well field (yield 45 Mld)
Panjetty well field (yield 34 Mld)
Tamoraipakkam well field (yield 21 Mld)
These major well fields supply water mainly to industries.

Agricultural wells are found throughout these alluvial aquifers, their yield approaches ten times that of the major well fields during the main irrigation season.

Conjunctive use in Uttar Pradesh, India

Foster et al (2010) have described the setting for conjunctive use in Uttar Pradesh State in India, categorised as humid and drought prone alluvial plain. The alluvial plain of river Ganges are underlain by an extensive aquifer system holding subsurface water as much as 70% of overall irrigation water supply. This is one of the largest sub-surface water storage reserves in the world. Its utilisation as a water resource has primarily arisen in response to reduction in supply and unreliable operations of the irrigation canal systems. The aquifers are directly recharged from monsoon infiltration and indirectly from canal leakages and poor irrigation practices. Increasing sub-surface water abstractions have resulted in a declined water table in high intensity sub-surface water exploitation zone, whereas in other areas, flood irrigation and canal leakage have maintained shallow water tables.

Conjunctive use in Hyderabad, Telangana, India

Hyderabad in central India has plenty of surface reservoirs, but when the rainfall is below the annual average, the scarcity of water is pronounced to meet the water requirement. In this situation, the over-exploitation of the aquifers occurs. Existing shallow wells drilled n the weathered zone are exploited and gets recharged naturally at a very slow rate due to low permeability of the strata. A remedy to this situation is to drill the wells up to the fractured zone, which increases the well yield by ten times as compared to the shallow wells.

Aspects of conjunctive use of surface water and subsurface water

An important factor to be considered while studying and implementing the use of surface water and sub-surface water resources conjunctively is the degree of connection between the two water resources. It is possible that no natural connection exists between these two resources, but an engineered intervention can create or modify the degree of connectedness where it is desired and economically beneficial. Fundamentally, connectivity has nothing to do with conjunctive management. One is physical attribute of the water system; the other is a form of management. It provides the context and framework within which conjunctive management policies are formulated and implemented.

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Advantages of conjunctive use of surface water and sub-surface water

- Sub-surface water can be used to provide a back-up when the surface water is not adequate or diminishing.
- Sub-surface water abstractions can induce natural recharge from surface water resources, thereby augmenting the sub-surface water potential and decreasing the run-off losses.
- The cost of developing the sub-surface water resources is often less than that of surface water resources.

Concept of optimization in conjunctive use of surface water and sub-surface water resources

Optimization techniques were introduced by Castle and Linder burg (1961), who formulated a linear programming model to allocate water from two sources (surface and sub-surface) to agricultural areas. Aron (1969) developed a dynamic programming model to determine the optimum allocation of surface water and sub-surface water. Yu and Haines (1974) researched on developing hierarchical multi-level approach to conjunctive use of surface water and sub-surface water. Ian and Smith (1994) developed the Integrated Groundwater and Surface water Model (IGSM).

Selection of conjunctive use model

Surface water and sub-surface water conjunctive use models has wide applications in river basin management, ecology, eco-hydrology and agricultural water management. Conjunctive use models are developed based on the purpose and objective. The types of models used can be simulation and prediction models, dynamic programming models, linear programming models, hierarchical optimization models, non-linear programming models and others.

Examples of conjunctive use models

- A simple sub-surface water balance model.
- A GIS linked conjunctive use surface water-sub-surface water flow model (MODFLOW).
- Interaction of surface water and sub-surface water modelling.
- Integrated Groundwater and Surface water Model (IGSM).
- Conjunctive use optimization model.
- Linear optimization model.
- Non-linear optimization model
- Multi-objective conjunctive use model.

Conjunctive use modeling options

- Surface water and sub-surface water interaction model.
- Managing soil salinity through conjunctive use model.
- Sub-surface water recharge estimation.
- Optimal allocation of surface water and sub-surface water through conjunctive use model.

Steps in conjunctive use of surface water and sub-surface water

- General sub-surface water surveys and identification of the sites that requires in-depth studies.
- Geo-hydrological investigations aimed at determining more accurately sub-surface water availability and quality in terms of time and space, using mathematical analysis in order to establish aquifer conditions and behaviour.
- Integration of the physical characteristics and prevailing conditions studied and analysed, with socio-economic parameters to formulate suitable policies and strategies for surface water and sub-surface water use, planning and management.

Demographics of the Ulhas River

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Proposed conjunctive use of Ulhas river water and aquifers in Ulhas river basin

With reference to the examples of conjunctive use of surface water and sub-surface water resources in India, citied above, in a similar way in Ulhas river basin, emphasis should be laid to use extensive datasets and associated analysis to understand the hydro-geological, agronomic and socio-economic conditions. Strategies should include efforts to reduce irrigation canal losses, implementation of optimal surface reservoir operation policies, promotion of tube wells use in non-command and high water table areas, and investment into research and specialist extension in study of geo-technical investigation. Large wells with horizontal addits can be constructed in and near to the river bed. These wells can collect water into the aquifers resulting in little flow in the river on the downstream side of the wells during the non-monsoon period. Considering that the permeability of the soil in the river basin is sufficiently high, this method of induced natural recharge can be implemented successfully. In addition to the induced recharge, artificial recharge of the aquifers can also be resorted to.

A planned approach implementation at the regional scale aimed at effecting changes to the water supply/demand balance by considering the nature of the complete water cycle for the area and its spatial and temporal distribution. To optimize the existing infrastructure so as to enable a huge quantity of water to be available in a more efficient context. A regional conjunctive use model with the existing Ulhas river and near-real aquifer system with some reference to the geo-climatic conditions prevalent I the region can be developed.

III. CONCLUSION

An integrated approach towards the use of surface and sub-surface water resources for the development of the water resources should be encouraged. The government should legalize this aspect while formulating water development, management and conservation schemes. Research is needed, to elaborately understand the significance of conjunctive use of surface and sub-surface water and the water-soil conservation practices in the earth's hydrological cycle. The transparent and efficient data collection and monitoring of ground water through observation wells, use of GIS techniques, optimal operations of the surface reservoirs systems within a river basin will help in harnessing the available water resources to the benefit of the society.

Modeling acts as a link for transforming information between the engineers and the policy makers as a basis for testing different scenarios and allows integrating sound planning and management, strategies with economic development by means of cost-benefit analysis and finding optimal solutions. To predict the anticipated impacts of any proposed plan and management policy, modeling is a must. The reliability of a model depends upon the quantity and quality of available data. An enhanced basic and applied research and the use of advanced engineering technology for water control and regulation such as models, remote sensing, Geographic Information Systems, Decision Support Systems and Spatial analysis procedures. All the tools have to be considered under a broad and integrated approach for the use, planning, conservation and protection of both surface water and sub-surface water resources.

New water resources cannot be created but only the available water resources explored to fullest for optimal use and the benefit of the mankind.

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