Synopsis

Title: Integrated Cost-effective Model for Augmenting Sustainable Water Supply through Surface and Groundwater Interaction in Hydrological and Hydro-geologically Critical Areas of West Bengal.

Water is the most precious and a universal asset. Water provides life supporting system of human beings, vegetation/plants and animals. It is also very important part of socio-ecological environment. It is evident from the fact that without water no civilization can sustain. That is why; ancient civilizations are developed along the water courses and near water bodies. Great importance of water and its utility for all kind of needs including environmental functions can be found in ancient texts, local traditions and archaeological remains. But this vital natural resource is depleting rapidly, as this life saving resource is always taken for granted in the name of development. The twentieth century has seen phenomenal growth in the use of water and the easy accessibility of groundwater by even small-scale users. Its local availability and the difficulty of coordinating and governing many users of the same aquifers across wide geographic spaces has frequently led to indiscriminate extraction of this precious natural resource for domestic, industrial and agricultural uses around the world. Groundwater exploitation, particularly in India, has increased by leaps and bounds over the last 50 years along with the expansion of shallow, mostly private, wells. The growth of groundwater abstraction from 1950 to 1990 clearly depicts the increasing use of groundwater utilization across sectors. Groundwater is not an independent entity as it is only one of the phases of the Hydrologic cycle. This cycle is maintained by precipitation, runoff, evaporation, and transpiration, groundwater flow, each one of which is dependent on the other. Though precipitation is the main source of groundwater, all of the precipitated water does not form groundwater. Only a part which gets infiltrated into the ground reaches the groundwater aquifer underneath and the rest flows down to the sea as runoff and goes back to the atmosphere. It is, therefore, obvious that the occurrence, movement and storage of groundwater would be intricately related to the climatological behaviour, the quantum and subsurface geological conditions. Groundwater recharging has become an emerging new paradigm in water resource development and management. Through different type of groundwater recharging methods this over exploitation can be mitigated to great extent. Apart from natural recharging areas it is essential, not only for avoiding less amount water pollution but also to rise the water level to a high level in the long run, to provide a good quantum of water for supply at all situations. Therefore, today groundwater recharging is an urgent need for sustainable development.

Groundwater in the area of the western part of West Bengal, with the rocky terrain and literate bearing undulating uplands, occurs under water table condition in the near surface aquifers and under confined conditions in the deeper aquifers. Except some local recharge zones which replenish groundwater in the near surface aquifers, the deeper aquifers in the eastern parts, separated by impermeable clay zones, get replenished by infiltration of the precipitated water from the distantly located recharge zones. These recharge zones are located along the boundary of the rocky and the alluvial areas to the west and also in the northern portion of this part of the state located in the Murshidabad and Nadia districts, where a thick granular zone from the surface down to 150 m depth occurs. The deeper aquifers below Kanchrapara in the North 24 Parganas to far south up to the coast are recharged from the north. The above discussions clearly depict the close relationship between the physical and geological factors with regard to groundwater occurrence and availability. Over the past three decades, government policies that subsidize credit and rural energy supplies have encouraged a phenomenal increase in the growth of groundwater development as the groundwater abstraction structure have increased from 4 million in 1951 to nearly 17 million in 1997. Groundwater extraction is convenient since it is available on demand. The status of groundwater development for West Bengal state is in stress condition reported thus .At present, the groundwater contributes about 50 percent of water for irrigation, 80 percent for domestic use in rural areas and 50 percent in urban and industrial areas. Out of assessed 23.09 bcm of replenishable groundwater, a provision of 3.46 bcm is made for domestic, Industrial and other uses, with remaining 19.63 bcm for irrigation. Rapid pace of groundwater development is resulting in over-draft and water table is declining at an alarming rate. Excessive extraction of groundwater by tube wells in the sweet water zone of West Bengal, declined its water table at the rate of 23 cm per annum. An area is said to be over exploited when the level of groundwater utilization exceeds the annual recharge of groundwater in that area. Hydrological classification constitutes the first step of a new holistic framework for developing regional environmental flow criteria, the aim of this study is to develop a cost effective technology model for recharging in over-exploited groundwater resources through application of different groundwater conservation structures(check dam, collector, well, recharge shaft, subsurface-dam) in hydrological and hydro geological critical areas of West Bengal and assess the performance of different recharging technology units including economic viability, social acceptability and technical feasibility. Eco-friendly recharging technique has come out from the field study and accordingly a map is prepared using GIS Tool. To achieve the goal initially, hydrogeological investigation done for classification of 90 stream sections of the Damodar, Kangshabati, and Darokeswar river on 10 hydrological indices that characterize their natural flow regimes and also identify hydrological & hydrogeological critical areas and to provide sustainable and Cost effective solution. The hydrological indices were calculated with 25 years of natural monthly flows (1990-2015) derived from a rainfall runoff model developed from historical data and field survey data. These indices were included many parameters such as at a monthly or annual basis, measures of duration of droughts and central tendency and dispersion of flow magnitude (average, low and high flow conditions. These classes can be simplified in three broader groups, with different seasonal discharge pattern: large rivers, perennial seasonal streams and intermittent and ephemeral streams. They showed a high degree of spatial cohesion, following a gradient associated with climatic aridity from NW to SE, and were well defined in terms of the fundamental variables. Ecological point of view have been used for hydrologic classification to place individual streams and rivers into a broader spatial context with the goal of maximizing the transferability of knowledge among rivers of the same hydrologic class and to show broader application of intensely studied sites to unstudied sites. Hydrologic classes are expected to have similar biological responses to both natural and human-induced variability in patterns of magnitude, frequency, duration, timing and rate of change in flow conditions. Consequently, systems that show commonalities in their hydrologic characteristics have provided a basis for testing whether hydrology influences the structure and function of biological communities in a similar fashion. Recent efforts have also focused on how rivers in different classes vary with respect to the degree of human influence (e.g. land use, river regulation, construction of barrier or dam, with drawl of water for Industrial and agricultural uses, drinking water and pollution concentration) thus providing a benchmark against which the response of biological communities to these factors can be accessed through detail survey. In hydrological classification within above mentioned three rivers Damodar river basin is only classified as large river catchment area, but due to human influences like construction of DVC project, Shantaldihi thermal plant and drinking water project, withdrawal rate becomes very high and reaches to hydrologic critical condition. Other two river basins Kangshabati and Darokeswar are comprised of small catchment areas and short duration irregular rain fall with high bed slope. Therefore it helps to drain quickly to downstream and creates a hydro-geological critical condition in river basin. Hydro-geologically three river catchment areas are underlain by granite gneiss and quartzite. The depth of weathering which is an important factor to locate the areas for good groundwater recharge is more in case of the former while the latter is less weathered. The northern part of the area falling along the course of Darokeswar River is underlain by quartzite while granitic rocks are available in the sub-surface along the catchment of Futiary stream. Depth to water level as observed from the wells varies from 7.5 to 11.0 m below ground level during pre-monsoon and 4.8-7.5 m below ground level during post-monsoon. Although the weathered zone is having good proportion of sandy residue with relatively high porosity and permeability, moderate to high slope of the country facilitates quick recession of groundwater during lean period. Hence, the wells located in higher topography become dry during summer. As a result these two river also reach the critical condition. As the rivers are mostly gaining in nature, groundwater recharge activities are increased in the upper catchment along the river, the same would regularly enrich the base flow of the rivers consequently the rivers become more perennial. All these scientific observations and knowledge are utilized during framing the model of conservation and recharge in the area. Economic approach to the management of water resources is one of the balancing competing objectives. It is obvious that improvement in quality of living environment enhances our sense of well-being. Water constitutes a major part of our environment, and individuals quite naturally express their preferences for clean water and in adequate quantity. Supply of safe drinking water is a global concern. In the context of developing countries where issues of poverty and inequality deserves special attention, provision of safe and clean drinking water at an affordable price is also inextricably tied to efforts to erase gender inequality, alleviation of poverty, and enhancement of productivity. Rising demand for water by ever-growing population has forced over extraction of groundwater in many areas. Contamination of underground aquifers by leached out arsenic and fluoride has further aggravated the problem. High population density and ever-degrading groundwater quality have resulted in rapid decline in per capita availability of safe and clean drinking water. Threats of climate change and inadequate rainfall have added other dimensions to the already stressed water resources. The state of West Bengal an eastern province of India is currently confronted with the challenge of supplying safe and adequate drinking water to millions of its people living in rural areas because of contamination of groundwater by arsenic and fluoride. In most of these affected areas, alternate river water sources are often far away particularly from its fluoride-affected and water stressed regions. When bringing safe drinking water from faraway places is difficult, the other solution that remains is treating contaminated groundwater to the safe level using modern separation and purification technology. However, literature shows that such options have hardly been tried. Thus despite several studies on the groundwater contamination problems, people still continue to suffer as scale-up confidence is often limited for setting up such modern technology-based treatment plants. The common belief is that advanced water treatment schemes are likely to be very expensive and the affected people cannot think of such an advanced water treatment scheme. There has neither been any convincing techno-economic feasibility study. Thus developing a sustainable water resource management strategy remains a big challenge to the scientific community and the policy maker for such areas facing acute drinking water crisis. This necessitates thorough economic evaluation and comparison of the alternate technologies with respect to the affected region. This thesis aims to assess the current water status of such a critically water-stressed region of West Bengal both quantitatively and qualitatively and estimate benefits of water status improvement in order to develop a sustainable water management policy for a water scarce region. The pilot model cater the need for recharging in water scared particularly in valley and foot hills areas and for project scenario through the development and management of harnessing excess water for different stake holder. The pilot model implement at identified location, it will exhibit its efficacy in the rocky terrain and it would be a tool for policy maker for sustainable water recourse development in other similar terrain not only in West Bengal but also in the states like Jharkhand, Bihar etc. To identify the suitable areas for recharging structures with low cost technology models through people's participation and their willingness so that the overall storage water could be augmented after implementation in the defined catchment and also the water table and the soil moisture would be raised as well to mitigate the water problem contaminated with fluoride and other metal substances. Keeping in view, to mitigate the acute water crisis not only in drinking water but also to provide irrigation water in Purulia district, an extensive water harvesting through recharging structures have been envisaged. Under these circumstances, the overall objective of the thesis is to identify the suitable areas for recharging structures with low cost technology models through people's participation and their willingness so that the overall storage water could be augmented over implementation in the defined catchment and also the water table and the soil moisture would be raised as well.

This thesis contains eleven chapters. **Chapter 1** starts with some overview of some key concepts regarding groundwater recharging, watershed management and importance of current research in regional and global perspective. It also depicts about the research objective, methodology and new dimensions in this research. In **Chapter 2** a critical review of literature regarding studies to developed rain water harvesting, groundwater recharging and regional studies of groundwater surface water interaction estimation is made. The **Chapter 3** focused on the study area including socio-economical and natural profile containing geology, hydrology, hydrogeology, drainage pattern, land use pattern etc. Water resource scenario and water scarcity impact of human health are also discussed in this chapter.

Methodology is the prerequisite for research work. It helps to maintain consistency and coherence to arrive at a conclusion and to give recommendation. For launching any research work, the researcher first has to be certain about the methodology adopts. Methodology should provide the reader with definite directions, the bases of moving from one point to another and different technical matters which have to be followed in the research work undertaken. Methodology is required to remain consistent to reach conclusions and arrive at decisions. Therefore, in categorization of any research work, the methodology helps us to arrive at such characterization. It describes different steps in the research and working principles of survey, numerical model development, design and estimation and implementation of field model. The entire methodology has been narrated in **Chapter 4.**

Chapter 5 deals with the survey and investigation which includes reconnaissance survey, hydrological investigation, VES survey, hydrogeological investigation for aquifer parameter determination and river profile survey. Sustainable yield were also determined in this chapter through pumping tests. Results of different investigation are also summarized in this chapter which gives key inputs in numerical and field model development.

Chapter 6 presents application of GIS and multi-criteria evaluation technique (MCET) approaches for site selection. MCET plays a critical role in many real life problem. It becomes difficult to take proper decision if number of closely related criteria or alternatives arise. The Analytic Hierarchy Process (AHP) is an effective approach in dealing with this kind of decision problems. Details of this technique also has been discussed in this chapter.

Chapter 7 depicts the water quality scenario of the study area and field testing, as well as laboratory testing results are shown in this chapter. For the reliability analysis of the tested results statistical analysis has also done. On the basis of the water quality results in study area hydro- geochemical framework is formed to study relationship between the change in chloride concentrations and the water table level fluctuations. With help of GPS readings at sampling points the chloride concentration distribution maps were developed and analyzed to determine Chloride concentration scenario of the study area. Finally, a fluoride contamination prediction model is also developed in this chapter.

Chapter 8 discusses about hydrological data analysis and processing with help of Groundwater Modeling System (GMS) for modeling the effect of stream flow on groundwater flow fields. Another software, HEC-RAS is used for the study. It reveals that the application of GIS and HEC RAS model can save an enormous amount of time and money in comparison with traditional methods of hydraulic analysis, mapping flood prediction, and generating a water surface elevation. Steady flow simulation of the river Futiari of Purulia district is developed by inputting geometric data such as the river system schematic, cross section geometry, reach length, hydraulic structures or obstructions, energy loss data, Manning's n, contraction/ expansion coefficient, flow data i.e. flow rate, profile, boundary conditions in the software. **Chapter 9** is focused on the technology description of cost effective integrated model. In this chapter scientific description of the integrated model design with estimation discussed thoroughly. Implementation and construction process also stated in this chapter. Application of numerical model with help of the SEEP-2D tool is designed to integrate biophysical, socioeconomic, and structural perspectives into a single prediction way of dam design. SEEP-2D is a 2D finite-element flow model designed to compute seepage on profile for earthen dam and levee cross sections. Analysis of numerical model gives more reliability to the adopted constructed model of integrated cost-effective technology and gives an output scenario of earthen dam construction. Suitability analysis is also revealed from this chapter. **Chapter 10** demonstrates the result and impact analysis of the whole research work. In this chapter, hydrological and groundwater recharge impact, socio-economic impact, agricultural impact, health impact in connection with drinking water are also stated. The detail result and impact of hydro geological investigation numerical model are also described in this chapter. **Chapter 11** is related with conclusion part. In this chapter synthesis of proper evolution of plan and design of integrated model with cost-effective groundwater recharging structures and evaluation of their economic feasibility for the semi-arid regions in India has been done. Four types of water recharging structures, i.e., check dam with recharge shaft, multipurpose collector well with infiltration gallery has been considered in this study. The detailed cost analysis of integrated model of cost effective technology revealed that the integration of different groundwater recharging structures using local material is more cost effective than installation of single structure. It is also more efficient than single recharging structure. The cost benefit analysis also stated that above designed structures are feasible because they have BCR value more than 1. Recommendations and future scopes of study are also discussed in this chapter. Feasibility study for integration of River Bank Filtration (RBF) with the integrated model can show good results in future for water scarce regions, so recommended.