Ocean is getting deformed since 8 Ma. This area is considered to be a site of future subduction. The region close to 13°N in the Indian Peninsula is also getting deformed. The convexity or the bulge in the coastline near 13°N is a consequence of this deformation which has resulted in the emergence of land and relative fall in the sea level. The WCI is divided into two prominent units – the Konkan and Malabar coasts. The Konkan region has characters of a submergent coast where as the Malabar coast has an emergent character. The youngest submarine terraces occur at shallower depths in the southern offshore compared to northern offshore. These features indicate that the WCI has a northerly tilt.

During the past 50 years, there has been a rise in the sea level globally and the rate of rise (~1mm/year) is expected to go up, resulting in the inundation of the low lying coastal regions. What will be the influence of the predicted Sea Level Rise (SLR) on the WCI? Along the Konkan coast, because of its cliffed nature, lesser area will undergo submergence. The Malabar Coast, which exhibits prograding nature, will be affected less, provided the rate of progradation keeps pace with the SLR. Along the ECI, emergence of the southern part, deltaic progradation, high volume of northerly littoral drift will counteract a slow SLR. The recent changes in the climatic and weather pattern are conclusive that there is global warming. Melting of snow caps in Arctic and Antarctic regions, unusual hurricane/cyclone activity, erratic rainfall, are all pointers in that direction. There can be a rapid SLR because of the combined effect of thermal expansion of sea water and addition of water due to melting of ice. In such a scenario, both WCI and ECI will be affected. It is in this context that the need to have a coastal buffer zone assumes urgency and stricter implementation of the Coastal Regulation Zone (CRZ) an imperative.

AN OVERVIEW OF THE WATER RESOURCES AND HOW IMPORTANT IS THE GROUNDWATER RESOURCE FOR THE DEVELOPMENT OF THE COUNTRY AND THE ROLE OF GEOSCIENTIST IN MAKING IT A SUSTIAINABLE RESOURCE*

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EXTENDED ABASTRACT

Introduction

Indian subcontinent with a geographical area of 329 million hectares is the seventh largest country in the world and second largest of Asia. It possesses 2.11% of land area of the world and 16% of the world's population. It has a land border of 15,200 km in the north and a coastline of 7516 km along the peninsula in the south with varied physiographic features with tallest snow covered Himalayan mountain ranges in the north with mercury dipping below the freezing point to the desert condition in the west with mercury shooting up to 50 degrees centigrade. It receives an annual average rainfall of 1150 mm, which is highest in the world for a comparable geographical area and the second wettest country in the world. Rainfall varies from 100 mm in the northwest to more than 12,000 mm in the northeast. The rainfall is highly variable in its distribution over space and time. Orography plays a significant role in the distribution pattern of the rainfall. The southwest monsoon contributes nearly 74% of the annual rainfall between June and September. During October and December the northeast monsoon and depressions in the Bay of Bengal bring rainfall to Tamil Nadu and east coastal districts of Andhra Pradesh. It is endowed with a network of 2.8 million sq. km of river basins, with an average annual discharge of 1900 BCM which accounts for 4.9% of the world's runoff and occupies fifth position. The runoff is more than that of USA which has a land area about thrice that of India.

There are seven physiographic divisions namely, the northern mountain ranges; the great plain; the central highlands; the peninsula plateau; the east coastal belt; the west coastal belt and the islands. Geologically rocks ranging in age from the Recent deposits to the oldest Archaean crystalline complex formed under different environments occur. The Peninsular shield is essentially

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**K.R. Karanth Endowment Lecture delivered at the Geological Society of India, Bangalore on 29 December 2005* made up of Archaean basement complex of gneisses, granites, charnockites etc , metasedimentary and metabasic rocks of the Dharwar system followed by rocks of Cuddapah and Vindhyan system The Deccan volcanics occupy an area of 500,000 sq km in the west central part and Gondwanas occupy the rift systems Along the coastal region a few Mesozoic and Tertiary sediments occur The Extra Peninsular region predominantly consists of the sediments laid down in vast geosynclines continuously from the Cambrian to early Tertiary The southern fringe towards the plain consists of fresh water and estuarine deposits of Mio-Pliocene age

The Indo-Ganga-Brahmaputra plains consists mostly the sediments derived from the rocks of Peninsular and Extra Peninsular region deposited in a sag formed with uplift of Himalayas

Hydrogeologically there are three major regions namely the area underlain by unconsolidated sediments, the area underlain by semi=consolidated formations and the areas underlain by consolidated or hard rocks

Unconsolidated formations These are Quaternary sediments occurring in Indo-Ganga-Brahmaputra basins, coastal deltaic regions and the river terraces of the inland river system These formations are classified as Recent alluvium, Older alluvium and coastal alluvial deposits which occur over 30% of the area and possess 55% of the groundwater potential of the country The Recent alluvium consists of sand, silt, gravel, clay and calcareous nodules etc , and contains fairly thick and extensive aquifers to great depths which occur under unconfined and confined conditions with large yield prospects The Older alluvium consists of sand, silt, gravel, laterite, lithomargic clays etc , and contains good aquifers which are discontinuous in nature and occur under unconfined and confined conditions with good yield prospects The semi consolidated formations consisting of sandstones, shale, limestone, flysch and molasses beds, etc , belonging to Carboniferous to Mio-Pliocene periods These formations contain moderately thick and extensive aquifers under unconfined and confined conditions with good to large yield prospects These sediments occupy 5% of the area and possess 13% of the groundwater potential of the country Hard rocks consisting of igneous, metamorphic and volcanic rocks which are devoid of primary porosity occur over an area of 65% of the country and almost the entire peninsular shield is occupied by these rocks and possesses 32% of the groundwater potential of the country The ability to store and transmit groundwater is dependant on the development of secondary openings formed by fracturing and weathering

Water Resources

The water resources of the country are mainly dependant on the rainfall varying from 10 cm in the northwest to 120 cm in the northeast with an average of 115 cm amounting to 4000 BCM annually Nearly 74% of the rainfall is received during the southwest monsoon between June and September and the remaining during the northeast Between October and December and from the cyclones and depressions in the Bay of Bengal, Tamil Nadu and east coastal districts of Andhra Pradesh receive heavy rainfall during this period

Surface Water

The river systems of India are classified into following categories viz the Himalayan rivers, Deccan rivers and Coastal rivers and the Rivers of inland drainage basin and Desert rivers There are 70 river basin systems with a network of 2 89 million sq km carrying an annual average discharge of 1900 BCM The Indo-Ganga-Brahmaputra basins contribute 66% of the surface water resources However, only about 690 BCM could be harnessed through conventional schemes The total surface water, which could be stored is 420 BCM and the storage built so far is about 180 BCM The estimated irrigation potential feasible through irrigation projects is 76 million hectares The irrigation potential created so far is about 43 million hectares

Groundwater

The estimated annual, replenishable groundwater resources of the country is 432 BCM of which utilizable resource is 395 6 BCM and 325 6 BCM is allocated for agriculture The estimated static resource is about 10,350 BCM The ultimate irrigation potential is 64 million hectares and the irrigation potential created so far is about 46 million hectares by developing nearly 160 BCM

Groundwater Development Groundwater is being developed through wells and tube wells for agriculture, domestic and industrial uses Nearly 85% of groundwater is consumed for agriculture This is reflected in the increase in the number of wells from 4 million in 1951 to about 18 million by 2000 to create an, irrigation potential of 6 5 and 46 million hectares respectively

Overexploitation With the present rate of groundwater development of about 160 BCM, in many arid, semiarid, and hard rock and drought prone areas of the country, the groundwater development has exceeded the annual replenishment and associated problems like steep declining water levels, decline in well yields, drying of shallow open wells, deterioration of groundwater quality and sea water intrusion into coastal aquifers and shortage of availability of fresh water for drinking purposes are increasingly emerging Cause for this is that the groundwater development is an individual enterprise in the country with no knowledge about limitation of its availability and management besides there is no legislation to control its development The populist measures like, supply of free power and subsidies to agriculture sector has complicated the issue further Added to this, recurring droughts, urbanization, excess watering in irrigation, population increase, reduction in recharge mechanism due to human intervention have accelerated the overdevelopment of groundwater resources

Remedial measures Harvesting the wasteful runoff at appropriate places and recharge the depleted aquifers making them sustainable This requires multidisciplinary approach and people's participation for its success

There are various techniques available for this and the Government, agencies and NGOs are implementing such measures from last two decades But the resultant effect is not very much as they are sporadic when compared to the magnitude of the problem

Water Demand The medium water requirement for agriculture, domestic and industrial use is about 615 BCM, 807 BCM and 1156 BCM over the years 2010, 2025 and 2050 respectively

Role of Geoscientists in Making the Groundwater Resource Sustainable

Groundwater is a natural resource which is being renewed annually through precipitation The balance between the annual recharge and development has to be maintained for its sustainability 'But this is neglected and thrust is given only on development to meet the immediate needs Being a natural resource, groundwater investigation, exploration, assessing the potential and hydrogeological mapping of the country was with Geological Survey of India till 1972 The Prime Minster of India in order to increase the agricultural production, the groundwater investigating agency of the GSI and the Exploratory

Tube well Organization (ETO), the drilling agency, were bought under Ministry of Agriculture to accelerate the groundwater development program These two agencies after merging had become the Central Ground Water Board (CGWB) Later on it was realized that the surface water agency and groundwater agency should be under one department for its proper development and management of the water resources of the country as they are integral part of the hydrological cycle

The irony of it is that water is a state subject and there is no legislation to control its development even after six decades of independence except for some states which have introduced some controls in certain parts Recently a Central Ground Water Authority has been created to control the drilling of wells but how far it is being effective is to be known As we could see that the groundwater occurrence and movement is controlled by the hydrogeological features Therefore, who else other than a geoscientist can understand the complexity of the hydrogelogical system to assess the groundwater potential, assist the groundwater development and management This has been proved in many instances like Kandla Port water supply, Neyveli lignite mining, Haldia refinery water supply project etc , have been solved by the geoscientists through highly sophisticated scientific studies But at present the Apex body CGWB which has inherited the responsibility from GSI, is still not able to cope up with the demand of scientific assessment, development and management which are briefly mentioned below The groundwater potential assessment was made in 1969 by Dr Raghavarao and others in 1969 which underwent so many refinements suggested by the Groundwater Estimation Committee in 1984 and again in 1992, but the estimates are not still reliable as there is a vast differences observed between the development and actual assessed potential as there is an imbalance between the recharge and development in many parts of the country In the arid, semiarid regions of Gujarat and Rajasthan and in the hard rock areas of southern states ground water is already being mined to meet the existing demand for domestic purposes and agriculture Hence, this has to be rectified by adopting reliable methodology for estimation of groundwater resources The water level fluctuation method, which is the most reliable method, should be adopted for the estimation of the groundwater resources

Groundwater availability, that is, water budget on annual basis with the recharge should be predicted for proper planning of agricultural activity Similarly watershed wise and aquifer wise (hydro geological unit) availability of groundwater should be estimated not only for its development but for its management by adopting suitable measures like rainwater harvesting, artificial recharge, water conservation techniques, change of crop pattern, etc , for its sustainability

In the twentieth century it was a distant dream for a geoscientist to do this type of estimation But in the twenty first century, it is a dream come true, as he has latest gadget like large scale satellite photographs of even up to one meter resolution for many periods in a year, good topographic maps, GPS and GIS systems, internet, website to get the latest information on the subject, fast and big computers for data storage and retrieval, for quicker analyses of the data, preparation of contour and other maps, utility maps like groundwater availability, isomorphic, panel diagrams etc., and umpteen number of programs for mathematical modeling to simulate the aquifer conditions or river basins for prognostication of the dynamic changes in the system under various stresses.

Similarly proper groundwater quality management should be considered a part of the overall management of the groundwater resources wherein the proper strategy for groundwater quality management is the one which incorporates the knowledge of hydrogeology as well as understanding the processes and measures that would limit their deleterious consequences wherein the factors are optional.

Contamination of aquifer system by human interactions is not instantaneous but a delayed one and with a good monitoring system, the contaminant can be identified, its movement established and remedial measures taken to prevent groundwater pollution.

In areas where a particular chemical constituent is increasing in groundwater in certain area, is dependent on the mineralogical and petrographic composition of the rocks, the physical and technical properties of permeable and impermeable beds.

The other very important issue is the correct assessment of brackish and poor quality of the groundwater resources. It is estimated by the CGWB that nearly 1,93,00 sq. km area of the country contain saline/brackish groundwater having more than 4000 micro mohs/cm and the total volume estimated is of enormous quantity up to a depth of 450 m in alluvial areas and 100 m in hard rock areas. The probabilities of improving the quality through rain water harvesting, mixing with fresh canal and other sources of water for improving the quality or to grow crops, resistant to such concentration, could be used beneficially.

Top priority should be given to identify the areas suitable for rainwater harvesting in the areas where groundwater resources have dwindled, through extensive scientific surveys and draw up a master plan for each area to improve the groundwater regimen of the area. The CGWB has already estimated that 270 BCM of surplus runoff is available for recharge. Roof water harvesting is not very much important for a geoscientist, but for him with his expert knowledge of hydrogeological conditions prevalent in the area, his responsibility would be to indicate whether the harvested water should be stored and utilized or it can be used for recharge and how much quantity.

It is seen that there are nearly 18 million wells providing irrigation facility to about 46 million hectares. This may not be a true picture as in 1951 there were 4 million dug wells which might have been dried up by now. Similarly the life a tube well is about 20 years and many wells have become defunct. So this ultimately reduces the irrigation potential created through groundwater. So it is very essential to get the correct number of operative wells at present and correct estimate made on the irrigation potential created. There is a lot of data on lithologs, electric logs, pumping test data, groundwater quality data collected from 1954 onwards up to 1972 available with GSI and later on with CGWB and State Groundwater organizations and this data should be collected and analyzed and used for updating the reports and maps. The first hydrogeological map on 2 million scale was compiled in 1965 and was published by GSI. It was revised in 1985 incorporating the data up to 1981 and published by the CGWB. Similarly hydrogeological map on 5 million scale was published in 1976 and revised in 1984 incorporating the data up to 1981. These maps require revision. CGWB also published a series of hydrogeological atlases statewise on one million scale incorporating the data up to 1981. These also require revision. Now it is better to publish district-wise hydrogeological atlases with watershed or taluk as unit, which will be more useful to planners and managers of groundwater resources, Karnataka was the first to prepare the report on groundwater resources village-wise and each state should follow this, as each Panchayat will be able to take care of its water resources. Top priority should be given to identify suitable areas for rainwater harvesting in the areas where groundwater resources have depleted, through extensive surveys and draw up master plans for each area to improve the groundwater regimen of the area.

With the above in view the Central and State Ground Water organizations should structure themselves and change their work pattern and undertake surveys, exploration and preventive measures as in the coming years groundwater is going to play a significant role in providing irrigation to large areas to increase the food production to meet the demand of increasing population which has already crossed a billion mark and the irrigation through surface water storages have reached saturation point due to very slow progress implementation of these projects as well as the gestation period to become operative and also due to inter state disputes. Hence, there is a heavy responsibility on the Geoscientist and he can playa significant role in assessing, developing, protecting and managing the groundwater resources for its sustainability.