Groundwater Resources Exploitation: Strategies for Sustainable Management and Development

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Abstract

The groundwater crisis has escalated in the 21st century due to over-exploitation and poor management, though it acts as a reliable resource during the drought situations. The hydrogeological framework of the Indian subcontinent reflects the vast replenishable groundwater reserves that exist in the alluvial tracks of the northern region, but its development is challenged in many parts of the country. This paper reviews the present situation of the available groundwater resources in terms of quality and quantity, response to climate change, unsustainable practices adopted in its development and suggest possible interventions in sustainable development of the resource.

Keywords: Groundwater Resources, Groundwater Quality, Climate Change, Sustainable Development.

Introduction

Groundwater is a finite and precious resource and is essential for life to survive on the planet Earth. It is most important for domestic, industrial and agriculture uses. Its underestimation, inefficient management and poor protection are posing a serious concern over the sustainability of the invaluable resource. It is highlighted that the over-population has created an unprecedented demand for water, with situation most critical in the developing world, especially in countries like India, Pakistan, Afghanistan etc., where several million people depend on groundwater for various purposes.

Review of Literature

Out of the total fresh water available, nearly 95% is in the form of groundwater (Morris *et al*., 2003). In some parts of the world, the extraction of resource is more than it is replenished, and resulting in decline of groundwater table levels (Glieck, 1993). The over-exploitation of groundwater not only has an impact on the global water regime, but also has a serious implication on the environment and society (Burke *et al.*, 1999; Yang *et al.,* 2006; Roy et al., 2008; Rodell *et al*., 2009; Tiwari *et al*., 2009). In addition to the existing challenges, groundwater management faces a new challenge of confronting the negative impacts of climate change. Groundwater over-exploitation has a series of consequences, such as increasing water cost, environmental changes and reduction of other water sources that are already in use, water salinization and impairment of quality.

India being the largest groundwater user in the world, it poses criticality in sustainable management and development of the resource. Through, the construction of millions of the private wells and with limited check on new well construction, there has been a phenomenal growth in the over-exploitation of groundwater in the last five decades. In addition to being accessible, groundwater quality is generally excellent in most areas and presents a relatively safe source of drinking water for the whole India. At the same time with increase in population, rapid urbanization and industrialization, the stress on water supplies have become a major challenge in terms of quality and quantity. The climate change is an important issue faced by the subcontinent owing to abnormal precipitation patterns and its indirect influence on the groundwater regime and, thereby, resulting in the crop failures, drought and drinking water crisis in different parts of the country.

In 1960s, ‘Green Revolution’ was initiated by introducing high yielding varieties of seeds in order to increase the crop production in conjunction with the use of chemicals and fertilizers to revolutionize Indian agriculture. As already pointed out by Indian agriculture scientist, Prof. M.S. Swaminathan, these initiatives sparked a vicious cycle by excess use of water for irrigation in lowering groundwater tables and soil fertility (Kesavan *et al*., 2014).

Objectives of the Study

1. To discuss the hydrogeological framework of the country, available groundwater resources in terms of quality and quantity and its response to climate change.
2. To describe unsustainable practices followed in the development of groundwater resources.
3. To suggest sustainable practices to be adopted in achieving the groundwater sustainability.

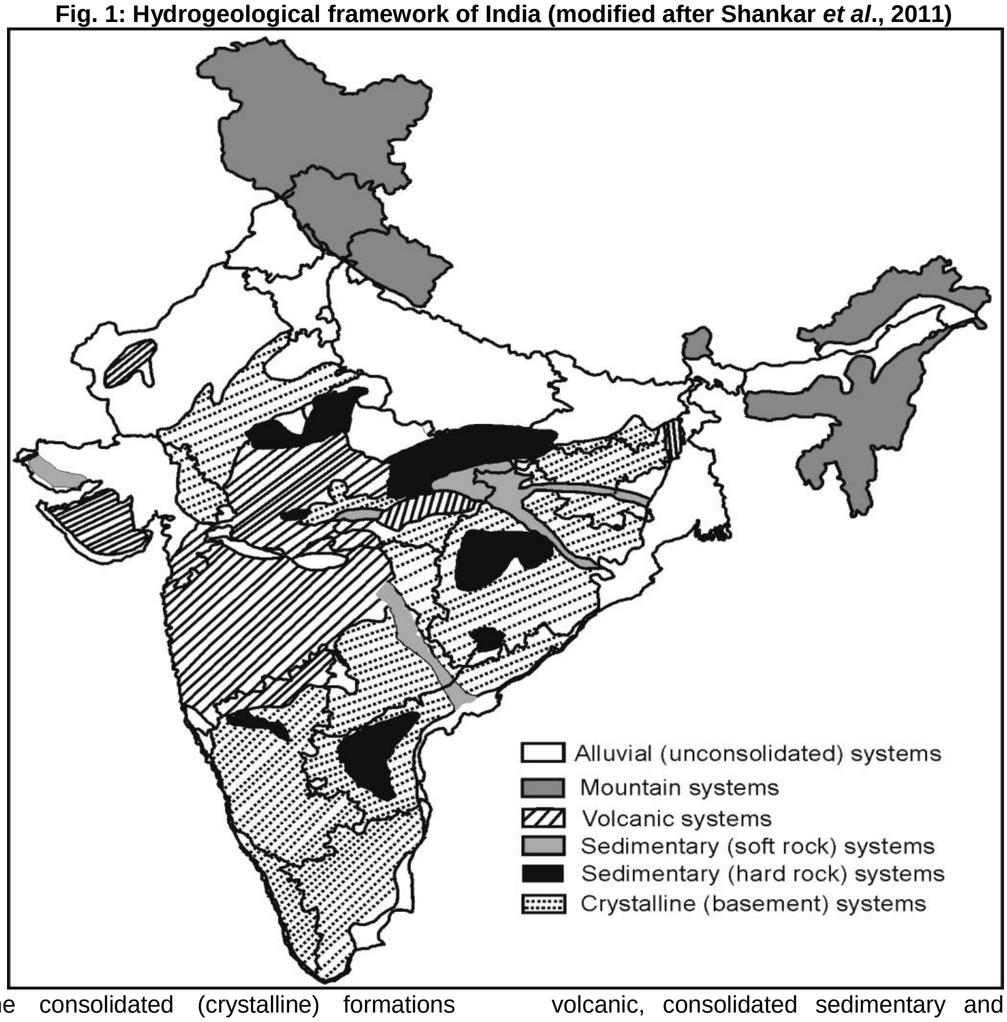
Methods and Materials

It is mainly a descriptive study. The data is generated by using the secondary sources like journals, books, reports and websites. The relevant maps and graphs were prepared to understand the resource availability and trends in groundwater depletion in India.

Overview of Groundwater

The hydrogeological setting of India is divided into two major groups: porous formations and consolidated crystalline formations (Fig. 1). Further, the porous formations are subdivided into unconsolidated and semi-consolidated (sedimentary soft rocks) formations. The unconsolidated formations constitute the major source for groundwater reservoirs covering the alluvial tracts of river basins, deltas, coastal regions and desert regions. The alluvial aquifers of the Indo-Ganga-Brahmaputra basin are bestowed with highly replenishable groundwater reserves, which are a part of unconsolidated formations in north and north-east India. But, the arid part of Rajasthan and Gujarat covered with unconsolidated alluvial formations are unproductive with less availability of groundwater and even, if available that is at greater depths with salinity hazard. Generally, the aquifers of the semi-consolidated formations are dominant in the narrow valleys and structurally faulted regions and are not that much productive as unconsolidated formations. Exceptionally, these aquifers exist in some extensive geological units like the Gondwana sediments and Cuddalore sandstone of peninsular India and the Tipam formation of the north-east India.

Fig. 1: Hydrogeological framework of India (modified after Shankar *et al*., 2011)

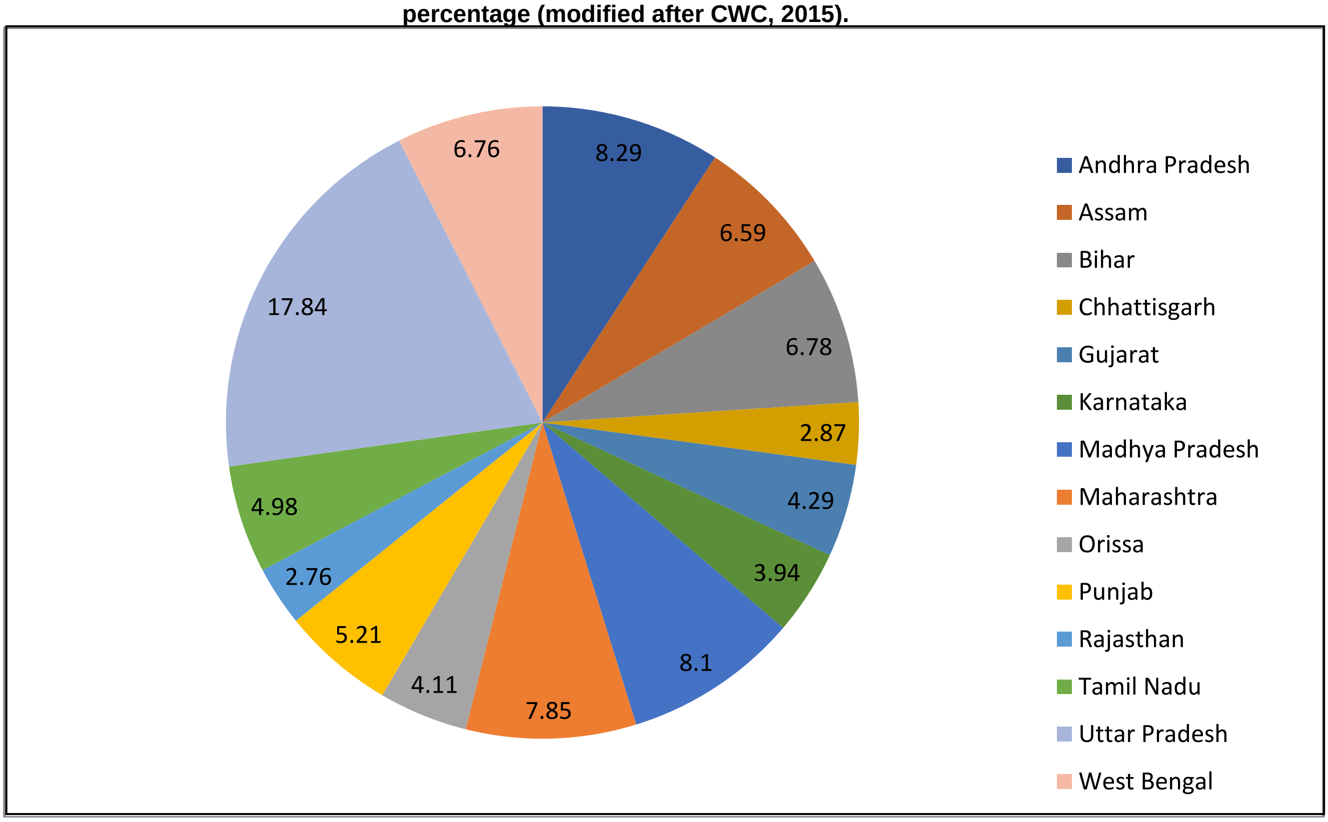


The consolidated (crystalline) formations cover around two-thirds of the country, occupying north-western and most parts of south India. In crystalline formations, the igneous, metamorphic, volcanic, consolidated sedimentary and carbonate rocks are present. These igneous and metamorphic regions have poor primary porosity and development of porosity and permeability is due to fracturing and weathering. The basaltic lava flows of the Deccan Plateau of peninsular India hosts the volcanic rocks. The groundwater regime of the Deccan plateau is generally controlled by the presence of primary and secondary porosity of different flow units having poor to moderate permeability. The consolidated (hard sedimentary) rocks are more pertinent in major Precambrian basinal areas of south and central India such as Cuddapahs, Vindhyans, where the groundwater occurrence is controlled by contact zones, fractures, joints and bedding planes. The groundwater occurrence, movement and yield in limestones of the carbonate rocks present in the Cuddapah and Vindhyan sediments are largely governed by the action of the solution cavities.

Available Groundwater Resources

It has been estimated that the total water resources including both surface water and groundwater, available as natural runoff (flow) in rivers of the country as on April 2015 is 1,869 billion cubic meters (BCM)/year (CWC, 2015). The topographic control and diversified distribution of water resources in river basins play an important role in the extraction of usable water resources out of the total available resources in the country, which is estimated at 1,123 BCM/year. Further, the groundwater share is 433 BCM/year of the total share of usable water available accounting to be 1,123 BCM/year, excluding the surface water share of 690 BCM/year. Out of the total share of groundwater (433 BCM/year) available in the country, the net useable resources are 398 BCM/year and the remaining share of 35 BCM/year is left over as natural discharge (CGWB, 2017-18). It is interesting to note that only 14 states of the country are the source of more than 90% of replenishable groundwater (Fig. 2). Rainfall plays a major role in the recharge of groundwater in India, which accounts nearly 67% of the annual recharge of groundwater. The other source of expected recharge consisting of irrigation fields, seepage from canals and ponds and other water bodies accounts to around 33% (CGWB, 2017-18).

Fig. 2: Annual replenishment of groundwater resources in different states of the country represented in percentage (modified after CWC, 2015).



Groundwater Quality

The sustainability of the groundwater is under threat in terms of its quality and quantity. Both natural and anthropogenic pollutants affect the quality of groundwater. In our country, the major natural groundwater contaminants are fluoride, arsenic and iron. The groundwater quality is affected due to various anthropogenic sources of contamination such as agriculture, mining and metallurgy, garbage dumps, tanneries and allied industries, chemical and pharmaceuticals, domestic sewage and so on. The deterioration of groundwater quality is of no excuse in many urban areas and especially, in highly populated and industrialised cities like Delhi where the geogenic contamination is supported by anthropogenic activity with over-exploitation and salinization of the resource (Kumar *et al.,* 2018).

The anthropogenic pollutants such as the waste produced by various industries generated from point source pollution and the demand in utilization of fertilizers and pesticides escalated the non-point source pollution of drinking water supplies (Taylor and Rahman, 1996). In India, there is improper disposal of domestic waste and it is estimated that only 10% of the waste generated is treated before reaching the surface water and later into the groundwater (Chaudhary *et al*., 2002). In developing nations like India, nitrate and pesticides are the major agricultural pollutants of the groundwater when compared with other pollutants even though the usage of fertilizers is comparatively less than the advanced countries (Agarwal, 1999). The nitrate contamination is mainly because of the use of nitrogen rich fertilizers and improper disposal of animal and human waste. Out of all the states in the country, the groundwater in 11 states is severely affected by nitrate pollution when compared with the permissible limits of 45 mg/l (BIS 2012). It is recorded that the pesticide contamination of groundwater is more than the surface water and is highly prevalent in rural India where the soil can store pesticide residues for a longer period of time before it reaches the groundwater. The heavy metal contamination of groundwater is very common in industrial agglomerates of different parts of the country. The shallow well aquifers are more susceptible to heavy metal contamination than the deep well aquifers. Mehta (2006) pointed out that the groundwater of 43 districts covering 14 states of the country are contaminated with heavy metals such as Hg, Cd, Cr and Ni.

The main geogenic contaminants of groundwater in India are fluoride, arsenic, iron and chloride. Fluoride and arsenic are the major groundwater contaminants causing health disorders that are prevalent in many regions of the country. The chemical contamination of fluoride in groundwater generated through the geogenic sources was first identified in 1937 in Andhra Pradesh (Shortt *et al*., 1937) and the arsenic contamination in the year 1976 (Datta, 1976). The effects of these contaminants were not addressed till 1990, until the health issues caused by them became a serious concern. The fluoride contamination of groundwater (>1.5 mg/l) is found in most of the states and accounts to 40% of the total population of the country (Chakraborti, et al., 2011). The main symptoms of fluorosis are dental carries of teeth and weakening of bones. The depth of the aquifer is of no concern when the exceeding limit of fluoride concentration greater than 1.5 mg/l is found either in shallow or deep well aquifers. Mostly, arsenic contaminated groundwater is recorded in the wells hosted in the northern flood plains (Chakraborti *et al*., 2009). As reported by many workers, the arsenic contaminated groundwaters are mainly present in six states: West Bengal, Bihar, Uttar Pradesh, Jharkhand, Assam and Manipur. Unlike fluoride, the arsenic concentration decreases with increase in depth of the tube well (Roy Chowdhary *et al*., 1999).

Iron contamination of groundwater is reported from 12 states with more prevalence in the states of Odisha, Rajasthan and Tripura. Though, there are no serious effects of iron contamination of groundwater, it is noticed that it imparts unusual taste to potable water when the iron content exceeds 0.3 mg/l (BIS, 2012). Saline water hazard became a major problem in the coastal areas where the fresh water aquifers are contaminated with the ingression of saline water. Recently, the chlorine rich salinity hazard has increased in arid and semi-arid regions due to poor irrigation practices and over-exploitation of groundwater. Other than the coastal areas, the inland salinity of groundwater is noticed in the states of Rajasthan, Punjab, Haryana, Maharashtra, Uttar Pradesh, Karnataka and Bihar. In addition to the above contaminants, some radioactive contaminants like boron and uranium are also observed in groundwaters of some states in minor quantity.

Climate Change and Groundwater

As estimated by the Intergovernmental Panel on Climate Change (IPCC) relating to global mean surface temperature from the year 1861, it was found that there is an increase in temperatures from 0.6 ± 0.2 ^{0}C and it is expected to rise from 2 to 4° C in the next 100 years. In view of the rise in temperatures, there is a likely impact on the global water regime and particularly, on the hydrological cycle that is influenced by the change in precipitation and temperature conditions. In this context, the worst effects are seen in the tropical and subtropical countries, among which India is of no exception. It is noted that increase in temperature has been affecting the global circulatory system and causing heavy rainfall in some areas and drought conditions in other parts of the globe and effecting the hydrological cycle and groundwater system.

In general, the influence of climate change on water resources was well documented; nevertheless, the considerable research was not undertaken regarding groundwater studies (IPCC, 2001). Likewise, it is easy to understand the possible impacts of climate change on water resources spread on the surface than the subsurface water (Gurdak *et al*., 2009). Hence, it is quite imperative to study the influence of climate change on ground water as it forms one of the major fresh water resources of the world (Panwar and Chakrapani, 2013). There is high variability in precipitation regime with increased intensity of precipitation in short period during monsoon season followed by extended dry spells. The temperature and precipitation changes are predicted using global climate models (GCMs) to understand the impacts of climate change on different aspects of hydrological cycle.

The snow-melt from the Himalayan glaciers increases the rate of run-off and recharge potential of major aquifers such as the Indo-Gangetic aquifer system for few considerable years. But there is possibility in rejection of recharge and simultaneously, increase in river flow that triggers in occurrence of floods. This alarming situation of flooding is most likely to happen in the eastern states of India and most parts of Bangladesh. The changes in precipitation patterns followed by dry spells, floods and other climate influenced adversities will have a negative effect on the agricultural system of India, which depends on groundwater for irrigation and drinking purposes. The changes in precipitation and evapotranspiration patterns that initate droughts, floods and tropical cyclones and other extreme events will be having a serious implication on agricultural production. In India, winter precipitation is projected to decline in the near future and resulting in increased demand of water for irrigating *rabi* crops and subsequent, *Kharif* crops in addition to the resilience to heavy floods and droughts.

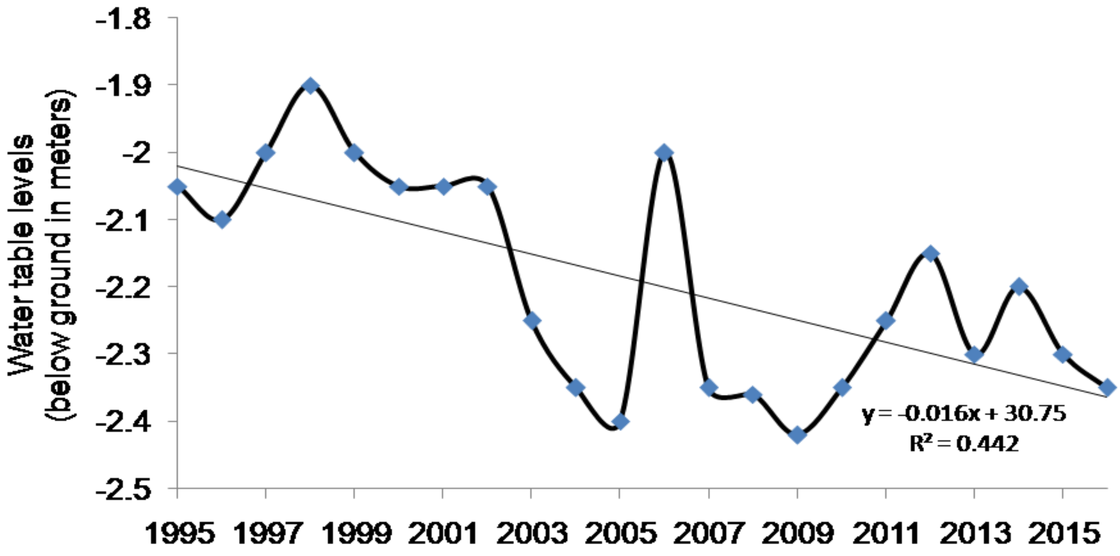
In order to study the impact of sea level rise on the Indian coastline, Unnikrishnan and Shankar (2007) developed models using the north Indian Ocean computer simulated data generated for ≥ 40 years and predicted that there is a rise in sea level within 1.06 to 1.75 mm per year as compared with the global models given by IPCC with a rise of 1-2 mm per year. The rise in sea level will have a negative impact on the coastal aquifers. The potability of fresh water is reduced with the invasion of ≤ 2% of sea water into the fresh water aquifer (Custodia, 1987). The groundwater quality of the coastal aquifers is quite alarming in many of the coastal states like Tamil Nadu, Gujarat, Andhra Pradesh and West Bengal, as they are facing saline water ingression.

Groundwater Resource Development: Unsustainable Practices

Aquifers are natural underground reservoirs of the groundwater that may be shallow or deep. The shallow aquifers are replenished in certain period of time because of their connectivity to the surface water sources for instance lakes, ponds, streams or rivers. In contrast, the deep aquifers are not directly connected to the surface water bodies and take much time to replenish. The response of groundwater in comparison to the surface water to the meteorological conditions like precipitation is less because of its residence time i.e., it takes few months in shallow aquifers and millions of years for deep aquifers for replenishing. In the wake of increase in population, urbanization and to meet day to day requirements, the people even started exploiting the deep aquifers which require much replenishing time by installing deep water tube wells; thereby, posing an artificial type of threat to the resource. In order to overcome the issues related to groundwater resources (in terms of quality and quantity) and their development has to be investigated in a holistic approach (Datta, 2015). Groundwater quality is of serious concern when both the anthropogenic and natural contaminants are taken in to consideration. The use of fertilizers and chemicals for agricultural production and rapid industrialization accompanied by urbanization has endorsed the abuse of anthropogenic contaminants in groundwater pollution. The ever increase in use of coastal aquifers for groundwater purposes has stressed the behaviour and sensitivity of the aquifer with accompanied inundation of saline waters causing serious concern to the sustenance of the coastal aquifers. It is a known fact that highly polluted natural contaminants like fluoride and arsenic of groundwater may affect the health and hygiene of the habitants residing and using the polluted waters unless substituted with safe potable water.

Groundwater over-exploitation is as a condition where the abstraction rate of groundwater for a number of years exceeds the average recharge rate (Custodio, 2002). The unsustainable practices of groundwater resource exploitation in India are a major concern in the depletion of groundwater levels (Fig. 3). The depth to water level in most parts of the country varies from 5 to 10 m below ground level (bgl). Due to scanty rainfall and over-exploitation, the recorded groundwater levels are from 10 to 40 m bgl in most parts of western and north-western India. In parts of north Gujarat, Delhi and Rajasthan generally the deeper water levels ≥ 40 m bgl are observed indicating a serious threat to groundwater availability (CGWB 2017-18). An interesting study by Rodell *et al*. (2009) on the groundwater resources in the north western region comprising Punjab, Rajasthan, Haryana and Delhi by using the GRACE (Gravity Recovery and Climate Experiment) of NASA satellite data and hydrological modelling showed that the groundwater depletion was near to 4 ± 1 cm/yr.

Fig. 3: Depletion in groundwater table levels (GOI, 2017-18)



According to Central Ground Water Board (CGWB, 2017-18), the groundwater over-exploited assessment units (Blocks/Taluks/ Mandals/Districts /Firks/Valleys) are 1034, with 253 critical, 681semi-critical and the safe units are of 4520 when compared with the total units of 6584. The stage of groundwater development in states of Rajasthan, Haryana, Punjab and Delhi is very high exceedingly more than 100%, indicating that the annual consumption of groundwater is more than annual recharge of groundwater when compared with the country overall groundwater development of 62%. The stage of groundwater development is 70% and above in union territories of Puducherry, Daman and Diu and in the states of Uttar Pradesh, Himachal Pradesh and Tamil Nadu. The groundwater development in remaining states/union territories is below 70%. The scarcity of sufficient surface water supplies in many peninsular states of the country like Kerala, Karnataka, Telangana, Andhra Pradesh, Tamil Nadu, Madhya Pradesh, Maharashtra and Gujarat led to the over-exploitation of the resources.

The national irrigational requirements are mainly met from minor irrigation structures such as canals, tanks and wells. The groundwater has a major share in usage of water for both irrigation and drinking purposes due to its easy availability and with no cap on its usage. The domestic water requirement of more than 80% of rural and nearly 50% of urban population is met by the groundwater supplies (Kumar *et al.,* 2005; Mall *et al*., 2006). Further, more than 50% of the water needs of irrigated agriculture are met from the groundwater supplies. It is interesting to note that rich yield in crop production of nearly 70-80% comes from the soils irrigated through groundwater (Mall *et al*., 2006). People look for the easy way of cultivation and depend on water consuming crops (for example, paddy and sugar cane) enhancing the way for unsustainable use of the groundwater resources and encouraging the sharp fall of the groundwater table levels. Though, knowing the condition that during the dry season or in rainfall deficit months, the groundwater acts as a buffer and to substitutes the water scarcity, but its irrational use has caused an alarming stress on the resource.

Framework for Sustainable Management and Development of Groundwater

Most of the aquifers in India have attained unsustainable stages of exploitation in response to over-exploitation and requires a congregation of decision-making practical interventions for balanced use of groundwater resources and in achieving groundwater sustainability. In the present scenario, the practical interventions required are as follows:

Effective Regulatory Mechanism

Effective administrative monitoring coupled with thorough legislation can help in sound management of the perishable resource. Even though the Indian administration is making considerable efforts in management of the resource, still suitable steps are necessary to enhance the effective management and development of the resource.

Sustainable Economic Pricing

Taxing the resource with collection of user charges and metering the resource for volumetric measurement may help in effective conservation and management of the resource. In supplement, the effective pricing mechanism must be able to consider and address the requirements of the marginalized sections of the society.

Negotiable Groundwater Rights

The high cost in regulatory mechanism of the groundwater can have a negative impact in the optimal utilization of the resource. Hence, it is the responsibility of the regulating institutions for effective monitoring and management of the resource while highlighting the fundamental requirements of the citizens.

Community Supported Management

The community supported joint management of the resource can be achieved with the active participation of the user communities who are involved in the prime usage of the groundwater resource. The major role of the communities encompasses the combination of activities including taxing, regulation and usage rights.

Enhancing Capacity Building and Institutional Capacities of State Monitoring Agencies

The role played by the state government institutions involved in groundwater monitoring is noteworthy, since water is known to be the subject of the state. The main functions of the institutional bodies are capacity building, regulating and supportive management of the communities involved in groundwater usage.

Promoting Sustainable Irrigation Practices

More optimized and conjunctive use of groundwater through increased use of micro-irrigation potentials can enhance the water conservation strategies and help in sustainable agricultural practices.

Planning Judicious Use of Groundwater in Urban Water Supply

Systematic planning and evaluation of the groundwater resources and integrating with urban water supply is very much required as it can act as buffer stock in the peak summer months. In addition, it may also fulfil the future growing demands in terms of quality and quantity on the mounting water stress.

Solutions to Agriculture Power Tariffs

The power and groundwater nexus is of great concern in depletion of groundwater resources vis-à-vis financial burden to the exchequer in providing subsidized tariffs. The current situation can be resolved with honest political interventions to safe guard the financial burdens and judicious use of the diminishing resource.

Conclusion

The groundwater considered to be an alternate source to fresh surface water, is under stress. It has become a major challenge to be addressed in the 21st century because of over extraction of the groundwater with construction of millions of wells for various purposes. Climate change is also depleting the groundwater resources, but it is complex to understand its impacts on the resource. The unsustainable practices of groundwater resource exploitation are a major concern in the depletion of the perishable resource.

The attained unsustainable stages of groundwater exploitation can be revived by following effective regulatory mechanism and practicing interventions through community-based management and farmer education. For example, the project sponsored by the United Nations Food and Agriculture Organisation (FAO) was successful in Andhra Pradesh in training marginal farmers called 'barefoot hydrogeologists' to create awareness and support in conservation of groundwater resources using the low-cost technologies (Das and Burke, 2013). The three important pillars of sustainable development: environmental, economic and social aspects are to be ascertained in proper planning, management and development of groundwater resources for future protection and in judicious usage.

References

Agrawal, G. D. (1999). Diffuse agricultural water pollution in India. Water Science and Technology Vol. 39, pp 33-47.

BIS (2012). Drinking Water — Specification (Second Revision) IS 10500 http://www.iitk.ac.in/iwd/ wq/drinkingwater.htm

Burke, J.J., Sauveplane, C., Moench, M. (1999). Groundwater management and socio-economic responses. Natural Resources Forum Vol. 23, pp 303-313.

CGWB (Central Ground Water Board). (2017-18). Groundwater year book - India 2017-18, Central Ground Water Board, Ministry of Water Resources, River Development and Ganga Rejuvenation, GOI. http://cgwb.gov. in/ Ground- Water/ Groundwater%20 Year%20 Book%202017-18.pdf

Chakraborti, D., Das, B., Murril, M.T. (2011). Examining India's Groundwater Quality Management. Environmental Science and Technology Vol. 45, pp. 27-33.

Chakraborti, D., Ghorai, S. K., Das, B., Pal, A., Nayak, B., Shah, B. A. (2009). Arsenic exposure through groundwater to the rural and urban population in the Allahabad-Kanpur track in the upper Ganga plain. Journal of Environmental Monitoring Vol. 11, pp. 1455-1459.

Chaudhary, C., Jacks, G., Gustafsson, J. E. (2002). An analysis of groundwater vulnerability and water policy reform in India. Environmental Management and Health Vol. 13, pp. 175-193.

Custodia, E. (1987). Groundwater problems in coastal areas. Studies and reports in hydrology. UNESCO, Paris, pp 1-596.

Custodio, E. (2002). Overexploitation: what does it mean? Hydrogeology Journal Vol. 10, pp 254-277.

CWC (Central Water Commission). (2015). Water and Related Statistics. Water Resources Information System, Directorate Information System Organisation, Central Water Commission, Govt. of India, New Delhi. http://www.cwc.gov.in/main/downloads/Water%20&%20Related%20Statistics%202015.pdf.

Das, S.V.G., Burke, J. (2013). Small Holders and Sustainable Wells. A Retrospect: Participatory Groundwater Management in Andhra Pradesh (India). Food and Agriculture Organization of the United Nations, Rome.

Datta, D. V. (1976). Arsenic and non-cirrhotic portal hypertension. Lancet Vol. 307, pp 433.

Datta, P. S., 2015. Ethics to protect groundwater from depletion in India. Geological Society, London, Special Publications, Vol. 419, pp 19-24.

Glieck, P. (1993). Water in Crisis: A Guide to the World's Freshwater Resources. Oxford University Press, Oxford.

GOI (Government of India). (2017-18). Economic Survey 2017-2018, Volume I, Department of Economic Affairs, Ministry of Finance, Govt. of India, New Delhi. http://www.indiaenvironmentportal.org.in/files/file/economic%20survey%202017-18%20-%20vol.1.pdf

Gurdak, J.J., Hanson, R.T., and Green, T.R. (2009). Effects of climate variability on groundwater resources of the United States. U.S. Geological Survey Fact Sheet 2009-3074, 4p. https://pubs.usgs.gov/fs/2009/3074/

IPCC (Intergovernmental Panel on Climate Change). (2001). Climate Change 2001: Impacts, Adaptation, and Vulnerability. Cambridge University Press, Cambridge.

Kesavan, P. C., Iyer, R. D., Swaminathan, M.S. (2014). A journey from the frontiers of life sciences to the state of a 'Zero-Hunger' world. Current Science Vol. 107, No. 12, pp. 2036-2051.

Kumar, R., Singh, R. D., Sharma, K. D. (2005). Water resources of India. Current Science Vol. 89, pp 794-811.

Kumar, S., Sarkar, A., Ali, S., Shekhar, S. (2018). Groundwater System of National Capital Region Delhi, India. In Groundwater of South Asia, ed. A. Mukherjee, pp.131-152. Springer, Singapore.

Mall, R. K., Gupta, A., Singh, R., Singh, R. S., Rathore, L. S. (2006). Water resources and climate change: an Indian perspective. Current Science Vol. 90, pp. 1610-1626.

Mehta, M. (2006). Status of groundwater and policy issues for its sustainable development in India. In Groundwater Research and Management: Integrating Science into Management and Decisions, eds Sharma, B. R., Villholth, K. G., Sharma, K. D., pp. 62-74. International Water Management Institute: Colombo.

Morris, B. L., Lawrence, A. R. L, Chiltion, P. J. C., Adams, B., Calow, R. C., Klinck, B. A. (2003). Groundwater and its susceptibility to degradation: A global assessment of the problem and options for management. Early warning and assessment report series, 03, 3. United Nations Environment Programme, Nairobi.

Panwar, S., Chakrapani, G. J. (2013). Climate change and its influence on groundwater resources. Current Science Vol. 105, pp 37-46.

Rodell, M., Velicogna, I., Famiglietti, J. S. (2009). 'Satellite-based estimates of groundwater depletion in India. Nature Vol. 460, pp 999-1002.

Roy Chowdhury, T., Basu, G. K., Mandal, B. K., Biswas, B. K., Chowdhury, U. K., Chanda, C. R., Lodh, D., Roy, S. L., Saha, K. C., Roy, S., Kabir, S., Zaman, Q. Q., Chakraborti, D. (1999). Arsenic poisoning in the Ganga delta. Nature Vol. 401, pp. 545-546.

Roy, M., Nilson, L., Pal, P. (2008). Development of groundwater resources in a region with high population density: a study of environmental sustainability. Environmental Sciences Vol. 5, pp 251-267.

Shankar, P. S. V., Kulkarni, H., Krishnan, H. (2011). India's groundwater challenge and the way forward. Economic and Political Weekly Vol. 46, No. 2, pp 37-45.

Shortt, H. E., McRobert, G. R., Bernard, T. W., Mannadinayar, A. S. (1937). Endemic fluorosis in the Madras Presidency. Indian Journal of Medical Research Vol. 25, pp 553-561.

Tiwari, V. M., Wahr, J., Swenson, S. (2009). Dwindling groundwater resources in northern India, from satellite gravity observations. Geophysical Research Letters 36, L18401. Doi:10.1029/2009GL-039401.

Talyor, D and Rahman, Q. (1996). The Anguish of India. Environmental Health Perspectives Vol. 104, pp 266-271.

Unnikrishnan, A. S., Shankar, D. (2007), Are sea levels trends along the North Indian ocean coasts consistent with global estimates? Global and Planetary Change, Vol. 57, No. 3-4, pp 301-307.

Yang, Y., Watenabe, M., Zhang, X., Zhang, J., Wang Q., Hayashi, S. (2006). Optimizing irrigation management for wheat to reduce groundwater depletion in the piedmont region of the Taihang Mountains in the North China Plain. Agricultural Water Management Vol. 82, pp 25-44.