Chapter 27
Climate Change and Sustainable Management of Water Resources

Golda A. Edwin and G. Poyyamoli

Abstract In recent times, several studies have shown that climate change is likely to have a significant impact on the availability of freshwater resources. Freshwater-rich regions across the globe are projected to face water scarcity if current reserves are not managed effectively. Traditionally, the Puducherry region has been well endowed with large freshwater reserves, but demand for water has already increased manifold over the years due to an increase in agriculture, industrialization, urbanization, population and economic development. This has resulted in water scarcity and water quality problems in some regions. At present, the hydrological cycle is being modified at a rapid pace due to the overexploitation of water resources, changes in cropping pattern, land use, groundwater depletion, seawater intrusion, pollution and water pricing models. Apart from these, there have also been observed changes in the increase of average temperature, humidity and coastal erosion. It is recognized that sustainable water resources development and management is an important and urgent issue to be taken up seriously. Therefore, an objective assessment of the availability of water resources in the context of the future water requirements, impacts of climate change and its variability is very crucial for sustainable development. This paper examines in detail the potential for sustainable management of freshwater resources within the constraints of climate change.

Keywords Climate change · Adaptation · Mitigation · Policy-making · Water resources management · Water quality · Sustainable management

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Introduction

Puducherry is a Union Territory in south India covering an area of 492 sq km^2 with 45 km of coastline stretching along the Bay of Bengal and to some extent along the Arabian Sea. The territory also has 675 km^2 of inshore waters. Figure 1 shows the four geographically unconnected regions of the Union Territory: Puducherry, Karaikal, and Yanam on the Bay of Bengal and Mahe on the Arabian Sea.

Puducherry, like many regions, is prone to natural hazards such as floods, cyclones and earthquakes. In the past, the northeast monsoon has wreaked havoc in many parts of the region by inundating a vast area of land along the coastal stretches. The heavy rains and cyclones due to the monsoon sometimes cause severe damage to life and property. Unchecked growth in the population during the past decade and a blooming economic activity have put severe stress on the available water resources.

With an estimated population of over 1 million, the region generates wastewater of about 50 million litres per day (MLD), with the entire amount discharged untreated into the sea through backwaters and creeks. Puducherry hosts a lot of water-intensive industries such as paper, alcoholic beverages, chemicals and pharmaceuticals. The total treated wastewater discharged from industries is over 7 MLD. Sewage wastewater contains mostly biochemical oxygen demand (BOD) compounds, nutrients and bacteria. Industrial wastewater mainly contains mostly suspended matter, BOD compounds and traces of oil and gas.

Water management is a critical issue here as the water-intensive industries and agriculture are mainly dependent on the groundwater for their needs. Because of this, the water tables have started falling throughout the region due to excessive exploitation of groundwater resources. Recent research has also revealed that the stress on the water table is resulting in the intrusion of seawater, especially in some coastal areas in the Puducherry region. Existing surface irrigation systems suffer from some inherent weaknesses that need rectification. Several of the tanks and ponds, formerly used for storing rain and surplus river water and irrigating a major proportion of the cultivated area, are already into a state of disrepair. The efforts to revive these systems will have to be speeded up considerably. Figure 2 shows the municipalities and communes of the Puducherry region.

In recent years, the government and the local NGOs have implemented various traditional, disconnected projects to promote sustainable development and improve the conditions of water resources. The predicted climate change over the coming years is likely to add greater stress to the already affected water resources in the region, including some areas that are currently well endowed. The stresses are likely to involve changes in the frequency of extreme events as well as gradual changes in mean annual net resources. Thus cooperation, proper planning and sustainable water resources management are required to address the impacts of climate change and meet the current and future demands in a sustainable way.

Fig. 1 Location map showing the four unconnected regions of Puducherry

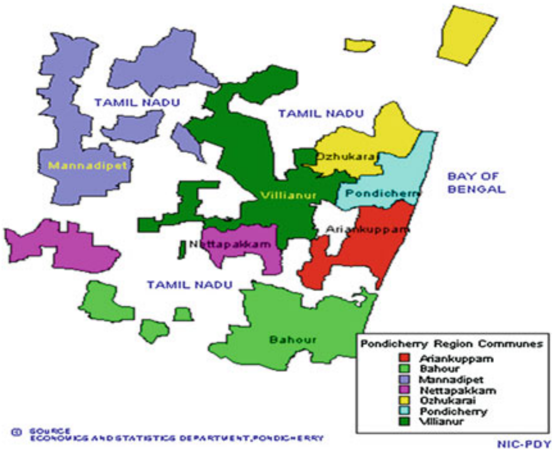

Fig. 2 A close-up view showing the major municipalities and communes in the Puducherry region

Challenges of Climate Change on Water Management

Water is the primary medium through which climate change will impact the environment, ecosystems, economies and people. It is widely accepted that integrated water resources management (IWRM) should therefore be an early focus for adaptation to climate change.

The response to the challenges posed by the new climate change conditions should be through adaptation and mitigation. Complexity, vulnerability and uncertainty are key issues to be addressed. It is in this setting that policy-makers and water managers need to tackle an increasingly scarce resource that varies greatly in space and time (Jones 1999).

Proper planning and management of water resources, comprehensive measures for the reduction of carbon and water footprint, prediction of unavoidable impacts of climate change, cooperation and coordination of actions should be among the priorities. The flexibility supported by the IWRM processes will therefore need to effectively respond to change and be capable of adapting to new ecological, economical, social and environmental conditions.

In Puducherry, the economic sectors that are mostly affected are agriculture, tourism, energy, fisheries and infrastructure, which depend heavily on climate, weather and environmental conditions. Successful adaptation to the impacts of climate change will depend not only on effective national action plans and regulations, but also on the ability of current water management strategies practised in the municipalities and communes to be integrated into affected sectoral policies such as agriculture, energy, tourism, fisheries, and infrastructure.

In the past century, in India, there has been an increase in mean annual temperature, increase in maximum temperature, increasingly trendless monsoon rainfall, decadal departures in summer monsoon rainfall are found above and below the long-time average alternatively for three consecutive decades. This has profoundly affected the environment, economy and society. Therefore, cooperation is required among the different stakeholders to concentrate on diverse measures to address the change.

On the one hand, infrastructural measures such as the construction of dams, levees, drainage canals, sewer networks, dykes, and desalination plants should be built considering the impacts of climate change. On the other hand, solutions such as crop choice (salt–and drought-resistant crops), crop efficiency, biofertilizers, decentralized demand management, water pricing, water markets, watershed management, artificial recharge, rainwater harvesting, flood proofing, and retention measures, knowledge management, decision support system and insurance should be worked upon to comprehensively address the challenges.

The challenges that face us can be better comprehended by analysing them under the areas of physical, social and economic dimensions.

Physical Dimension

Changing Rainfall Patterns

The average annual rainfall at Puducherry is 1254.4 mm. The region receives rainfall from both the northeast and southwest monsoons, with annual rainfall spread over a period of 8 months. The southwest monsoon brings 29% of the annual rainfall from June to September and the northeast Monsoon brings 63% of the annual rainfall during October to December (Puducherry City Development Plan 2007).

Table 1 Percentage deviation of the actual rainfall received from the normal rainfall for different seasons in 2009

Region	Winter period (January–February)			Hot weather period (March–May)			Southwest monsoon (June–September)			Northeast monsoon (October–December)		
	Actual	Normal	Deviation (%)	Actual	Normal	Deviation (%)	Actual	Normal	Deviation (%)	Actual	Normal	Deviation (%)
Puducherry	18	46	-60.9	224	64.3	248.4	140	378.5	-63	1238	849.4	45.7
Karaikal	44.5	66.5	-33.1	227.4	68.4	232.5	117.2	258.7	-54.7	1055.7	993.2	6.3
Mahe	0	10.4	0	272.8	279.7	-2.5	2036	2729.8	-25.4	485.6	367.2	32.2
Yanam	0	27.1	0	17.2	70.1	-75.5	688	691.3	-0.5	242.1	450.3	-46.2

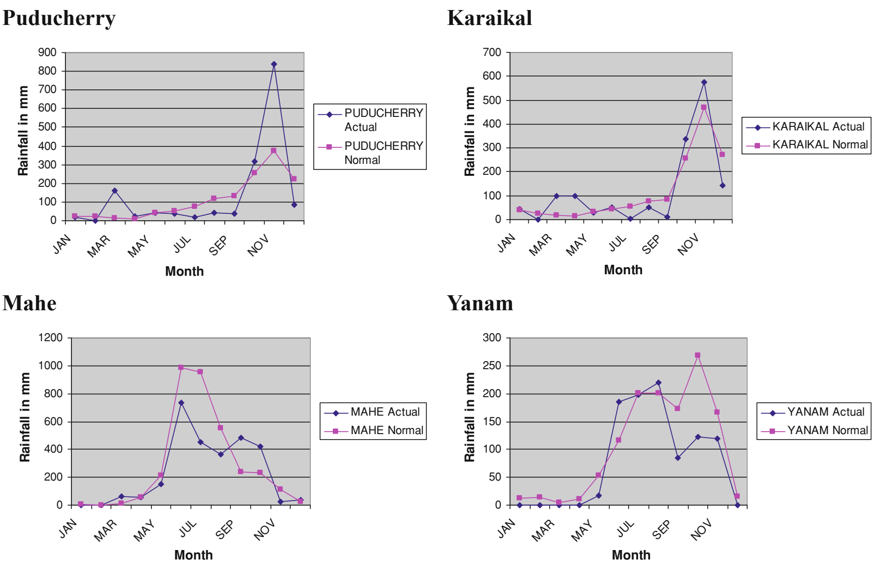

Fig. 3 Actual and normal rainfall month-wise in the four regions of the Union Territory for the year 2009

Table 1 shows the percentage deviation of the actual rainfall received from the normal rainfall for different seasons in the Union Territory for the year 2009 and Fig. 3 shows the month-wise actual and normal rainfall for the year 2009 in all the four districts of the Union Territory. The rainfall pattern is changing at random and deviation from the norm is too much and unpredictable. Although it is difficult to make good predictions about the rainfall and storms, what needs to be understood is that it is even more difficult to predict the impact of changing temperature and rainfall on water availability from rivers, aquifers and lakes.

As the majority of the water-users in this region are farmers, it is critically important to predict the amount and timing of rainfall. Excessive exploitation of groundwater in combination with climate change makes the situation difficult. In many places, groundwater wells are already contaminated, unprotected or close to becoming dysfunctional due to a lowering of the groundwater table and due to low and poor maintenance. Those wells, which serve as the basic water supply, will not be able to supply water in times of disasters and emergencies. They will either be contaminated or dried up.

The increased variability in rainfall results in change of pattern in recharging the aquifers which is the major water source for the economy. Since mostly it is a humid area, there will be a decrease in groundwater recharge because more frequent heavy rain will result in the infiltration capacity of the soil being exceeded, thereby increasing surface runoff. With such scenarios the relationship between the amount of rainfall received and the amount of water available in rivers, lakes and aquifers becomes a complex one (Stakhiv and Pietrowsky 2009).

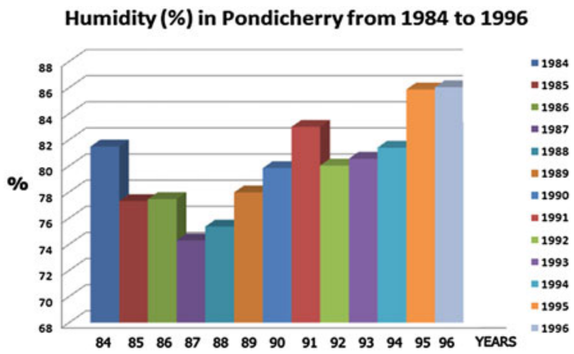

Fig. 4 Humidity (%) in Puducherry from 1984 to 1996. Source: hydrology project

A change in rainfall pattern could lead to intense and short-lived precipitation in coastal urban watersheds, which would lead to calamitous flooding. When accompanied by sea level rise, which itself is a consequence of climate change, excessive flooding of urban settlements and industrial zones is a certainty, endangering the lives of the citizens and threatening infrastructure. In Puducherry, the development is not uniform across all municipalities and communes and some areas have poor drainage infrastructure, which is a major bottleneck in addressing the impacts.

Projected sea level rise and excessive groundwater extraction in areas close to the coast also increase the salinity problems in water supplies. The quantity and the quality of groundwater depends always on recharge conditions, which are controlled by factors such as annual precipitation, soil properties, land surface characteristics and vegetation cover.

Annual Runoff and Drainage System

As a result of drier ground and increased evaporation, water percolations into the aquifers or runoff to the rivers have been drastically reduced. A reduction in runoff will be perhaps the most serious impact of global warming on the water environment. This is why climate change is "amplified" in the water cycle. But the other things, which include the types of vegetation as well as the timing and intensity of rainfall, are unlikely to remain equal. Vegetation will change as a result of changes in temperature, rainfall and CO_2 concentrations. The intensity and timing of rainfall will change as a consequence of the changing circulation patterns inherent in generalized atmospheric warming (Sadoff and Muller 2009a).

Only 10% of the sewage is treated before being discharged into the sea. Silting and uncontrolled solid waste dumping cause blockages and stagnate water channels/wastewater runoff. Consequently, drains choke and overflow into neighbouring areas. Water bodies around the city, which acted as flood moderators, have also witnessed silting. Sometimes the stormwater and domestic sewage overloads

Table 2 Groundwater utilization (in MCM/year). Source: central groundwater board

Total replenishable groundwater resources	Provision for domestic, industrial & other uses	Available for irrigation	Projected net draft	Balance for future use	Level of groundwater development (%)
174.6	26.2	148.4	115.5	32.9	77.85

the open drainage system and inundates the low-lying areas of the town in some parts of Oulgaret municipality.

The case of the Kaveri (otherwise called Cauvery) river in South India has been the focus of intense controversy since the early 1990s. The river's drainage basin provides most of the water for the states of Karnataka, Tamil Nadu, Kerala, and the Union Territory of Puducherry. Unsurprisingly, the sum of each of the water claims of the different states is far greater than the actual availability of water.

Temperature, Evaporation and Aridity

Changes in temperature and precipitation will have a direct impact on the demand and supply of energy, and the quantity and quality of water available for irrigation, hydropower, and domestic and industrial use (Mall et al. 2006). Figure 4 shows the humidity percentage in Puducherry from 1984 to 1996.

Even slight changes in temperature and precipitation will affect the quantity and quality of water available for irrigation, hydropower, domestic and industrial uses. Evaporation rates increase as a result of an increase in temperature. As a result, aridity, which is the ratio of rainfall to potential evaporation, also increases, since the rising temperatures are not matched by rising rainfalls. Changes in aridity will have a substantial impact on both surface water runoff and groundwater recharge (Mujumdar 2008).

In the present condition, the potential evaporation exceeds the amount of rainfall and actual evaporation depends on the amount of water available to be evaporated. Thus only in periods in which there is sufficient rainfall to "swamp" the evaporation does runoff infiltrate the groundwater aquifers.

Changing Groundwater Recharge Patterns

Puducherry region is situated on the Coramandal coast, covering an area of 293 km^2. The main source of water supply for all purposes such as agriculture, drinking and domestic use is groundwater, which is extracted from three major aquifers: Alluvium, Tertiary, and Cretaceous. The irrigation is supplemented by 84 system and non-system tanks. Owing to population growth, intensive agriculture and rapid phase of industrial development, the demand for water has increased

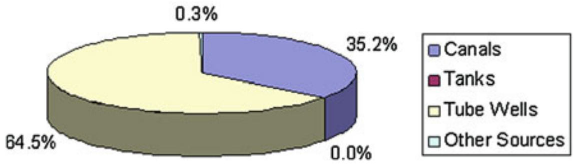

Fig. 5 Percentage area irrigated from various sources

considerably, which has resulted in the overexploitation of groundwater, which ultimately leads to drastic depletion in groundwater levels and deterioration of water quality due to seawater intrusion and also upward movement of chemical constituents present in deep-seated aquifer.

In the Puducherry region, the farmers started constructing shallow tube wells tapping alluvial aquifers up to a depth of 30–40 metres. Initially, the shallow tube wells were found free-flowing. But as the number of shallow tube wells started increasing, the water level started declining due to overload. This has been greatly felt in parts of the Mannadipet and Nettapakkam communes.

Due to the decline in the water level, the farmers had to dig out pits to lower centrifugal motors. At one stage, the centrifugal pumps were also not working as the water level declined below the lifting capacity of these pumps. The wealthy farmers switched over to submersible pumps, whereas the small and marginal farmers could not construct deep tube wells tapping older formations. They were forced to keep their land fallow or cultivate their land by getting water on a hire basis from the nearby sources at the rate of eight bags of paddy per acre per season. Whatever the farmers earned went towards hire charges for water. So the farmers could not sustain themselves and many were even pushed below the poverty line.

Table 2 provides the details of the utilization of groundwater in the Union Territory of Puducherry.

Figure 5 indicates the percentage area irrigated from various sources. 64.5% of the irrigation is through the tube wells which directly contribute to the lowering of the water table, leading to saltwater intrusion. Currently around 70 MLD is drawn through bore wells maintained by the Public Works Department for public water supply. As a result, the ground is over-pumped in many places in order to satisfy the increasing demand driven by the economy and population growth.

The impact on the environment is severe, including soil degradation, erosion and increase in sedimentation, poorer infiltration of water, reduction of aquifer recharge, loss of wetland communities, and increased concentration of pollutants and salt in groundwater. The government has already proposed a desalination plant to meet the rising demand. Though this is an option, desalination is in no way a sustainable alternative to water security, as this greatly increases the carbon footprint.

One of the most difficult water resources management challenges is monitoring and managing underground water, which many rely on for their water supply (Geocenter Denmark 2008). Furthermore, the Union Territory is already facing a growing urban demand which has to be balanced against the declining agricultural use for irrigation. These trade-offs can be managed only if there is a proper regulation of groundwater extraction.

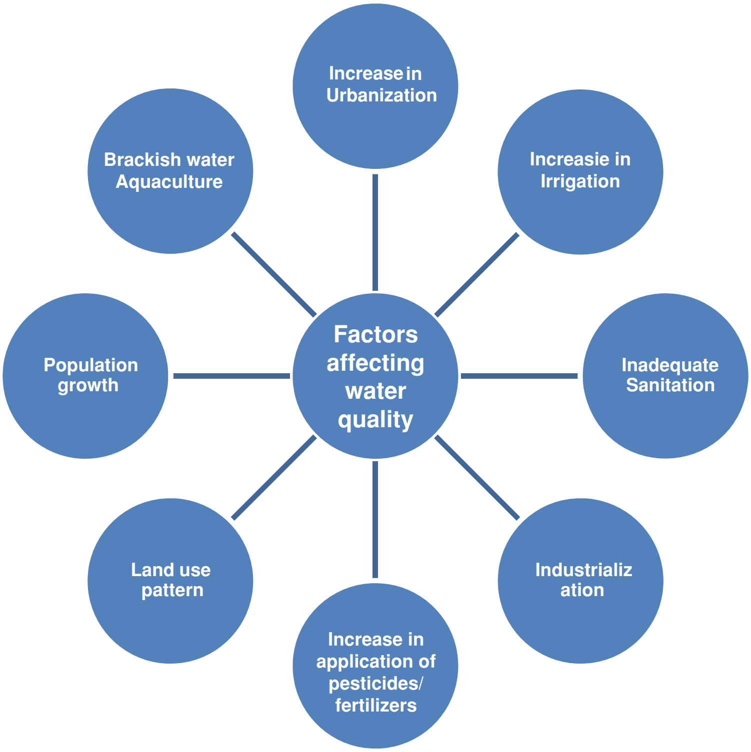

Fig. 6 Factors contributing to decline in water quality in Puducherry

Water Quality

The quality of the groundwater is greatly affected by the nitrates from agricultural fertilizers and chloride from saltwater intrusion in coastal aquifers. The seawater is affected by the disposal of untreated sewage. At present, only 10% of the sewage is treated and the rest is disposed as it is into the sea. Marine discharge from industry and heavy metal pollution also contributes to the pollution. Changing runoff patterns and increasing temperatures result in water quality effects that either render water unusable or make it require additional treatment. Figure 6 shows the factors contributing to the decline of water quality in the Puducherry region.

The poorly planned water usage patterns adopted by man, through urbanization, growth of population, growth of industries and employment of auxiliary means in agriculture, have disturbed the natural quality of water bodies in many regions, along with the water availability aspect. As a result, the water bodies have become unsuitable for potable uses at many locations. Another possible impact could be the intrusion of seawater into coastal freshwater systems. This might occur in the areas affected by sea level rise and where river flows are insufficient to prevent seawater

Table 3 Land use pattern in Puducherry region

Classification	2004–05 (%)	2008–09 (%)
Forest	0.00	0.00
Non-agricultural uses	35.22	37.58
Barren and uncultivable lands	0.14	0.15
Permanent pastures and other grazing lands	0.02	0.00
Land under miscellaneous tree crops not included in net area sown	2.38	2.49
Cultivable waste	8.44	9.02
Other fallow land	5.32	5.04
Current fallow land	5.25	6.24
Net area sown	43.23	39.48

from flowing upstream. The inland fishery which contributes to over 30% of fish/prawn production also contributes to the increase in salinity of the groundwater.

Land Use

Table 3 shows the changes in the land use pattern in the Union Territory over five years. In recent years, owing to economic growth and population increase, there has been a drastic change in land use. Puducherry is slowly moving closer to an industrialized economy. In some places, the farmers are forced to keep their land fallow owing to non-availability of groundwater for irrigation purposes (Nobi et al. 2009).

Floods, Droughts and Storms

The 2008 UN Human Development Report stated that from 2000 to 2004, some 262 million people were affected by climate related disasters annually. Over 98% of them lived in the developing world. Rising temperatures increase the evaporation from the water bodies and other sources, which in turn leads to more severe rainfall. This will lead to more floods and droughts and in a random pattern, affecting the urban and rural poor mostly. Recently the Karaikal region experienced severe drought coupled with water scarcity resulting in the reduced yield or failure of crops. Such scenarios might increase in frequency if adequate measures are not taken proactively to combat the impacts of climate change.

Social Dimension

The major impact of climate change in many areas may be to increase the cost of water services. As a result, the water required to sustain the ecosystem will be put under tremendous pressure. This will not only be the case for drinking water, but also for agriculture and power production, as well as for industry. The increased incidence of floods and droughts will impact lives, livelihoods, land values and investment incentives in vulnerable areas. Undoubtedly, it is the poor who are most vulnerable to floods, sea level rise, groundwater intrusion and loss of arable land.

The prevailing scenarios in the region that affect society are as follows:

- Over 40 villages are still to get access to potable water and over 80 villages have only partial access to it.
- The water price does not reflect the true costs of the production of potable water because of the huge and unsustainable subsidies.
- About 100% of the population are connected to the supply of potable water, but only 10% of households are connected to the wastewater system.
- The development of tourism has an impact on the water demand, so that in summer months where the demand is particularly increasing, there are problems of supply, affecting industry and tourism.
- The quality of water in rural areas is more affected because of the agricultural activities and the increasing use of fertilizers.
- The population must adapt the use of water to its availability.

Economic Dimension

The increased variability and changes in the availability and reliability of rainfall will directly impact the water-using sectors and indirectly impact the growth potential of the economy. These impacts, in turn, will affect the environmental and social needs (Report by the United Nations 2009). Recently, as a result of seawater intrusion, the water-intensive industries near the coastal zone were shut down or transferred to a different location. Climate change's impact on water resources has implications far beyond the Millennium Development Goals. The changes in distribution and timing of rainfall will change patterns of access to water, creating new surpluses in some areas and increased competition in others. Managing this evolving hydrology will impose significant demands on water management at regional, national and international level (Kolokytha 1994).

Water Security Through Integrated Water Resources Management

IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. IWRM has been the accepted management paradigm for efficient, equitable and sustainable management of water resource since the early 1990s (Sadoff and Muller 2009b).

An IWRM perspective ensures that social, economic, environmental, and technical dimensions are taken into account in the management and development of water resources. It is not an answer to climate change, but an approach that reflects the integrated nature of the water cycle by addressing different users, uses, threats, and threatened resources. As such, IWRM has to deal with all natural resources, not only water, but also soils, ecosystem, surface water, groundwater, water quantity, quality, as well as other ecological aspects.

The multi-sectoral nature of IWRM should be recognized in the context of socioeconomic development (InfoResources Focus 2003). Serious water management problems are likely to occur in the Puducherry region if adequate remedial measures and policies are not taken up proactively by the Union Territory. In recent years, the Union Territory has been spending more on water resources management by implementing various projects. The objective is mostly to meet the demand with the supply. But such a traditional and fragmented approach will not lead to sustainable growth and therefore all the current and future water planning and strategies should be aligned and integrated with social, economic, and environmental goals (Slootweg 2009).

Policy Framework to Respond to Climate Change Through IWRM

Natural and Human System Interaction

Integration can be considered under two basic categories: the natural system, which focuses on the resource availability and quality, and the human system, which determines the resource use, waste production and pollution of the resource, and which must also set the development priorities (Agarwal et al. 2000).

The natural system integration focuses on the integration of land and water management, integration of freshwater and coastal water management, integration of soil water and runoff water management, integration of quantity and quality of water management, integration of surface and ground water management and integration of the upstream and downstream water related interests.

The human system integration deals with the mainstreaming of water resources, cross-sectoral integration in national policy development, macroeconomic effects of water developments, integrated policy-making, influencing economic sector decisions, integration of all stakeholders in the planning and decision process, and integrating of water supply and wastewater management.

The different stakeholders should ensure that integration has to happen both within and between these categories, taking into account variability in time and space.

Groundwater Regulation

Bahour commune in the Puducherry region accounts for one-third of the rice cultivation in the region. Recently, salinity in the groundwater has increased in the Bahour and southern part of Villianur communes, which has affected the soil and crop yield. The increase in salinity is mainly attributed to the over-extraction of groundwater using high-energy pump sets. If this trend continues, the Bahour commune will become unsuitable for cultivation in future (National Action Plan on Climate Change—Puducherry 2009).

It is encouraging that the government of the Union Territory has passed a Groundwater Regulation Act and set up the administrative machinery for monitoring the extraction and use of groundwater. It also promotes rainwater harvesting and maintains a hydrological data centre which aids in decision-making. Groundwater levels of many aquifers in the region show a decreasing trend. This is generally due to groundwater pumping exceeding groundwater recharge rate. Groundwater will be less directly and more slowly impacted by climate change, as compared to surface waters. As many groundwater systems both discharge into and are recharged from surface water, impacts on surface water flow regimes are expected to affect groundwater. Thus, neglecting the consideration of groundwater in the process of IWRM can result in the mismanagement of surface water, with severe effects on the population and the environment (Steenbergen and Tuinhof 2009).

Water Pricing

A major cause for the over-extraction of groundwater is the subsidies provided for water. IWRM should ensure that industrial users should be required to bear the full cost while some subsidy could be given to domestic users. The pricing model should be changed in such a way that everybody gets their fair share of water for a subsidized cost, and beyond which the user should be charged heavily. This will not only ensure that the basic need is taken care of but also discourage the water-users from wasting this precious resource. But for this to happen, first precise and uniform metering should be implemented in all places (Rakesh et al. 2005).

Water Quality Monitoring

The policy framework should ensure the safe discharge of industrial effluents, biomedical waste, electronic waste and domestic waste. Waste segregation, reuse and safe disposal of hazardous wastes should be done as close to the waste generation source as possible. A water quality monitoring network has to be established involving the NGOs, elite educational and research institutions to supplement the efforts of the government.

Tank Rehabilitation

The government is undertaking several tank rehabilitation projects with aid from the European Union. The tanks and ponds of the Puducherry region have to be rehabilitated not only for irrigation but also to recharge the groundwater and restore the ecosystems.

Conservation Measures

Apart from pricing and regulation, the government should also focus on creating awareness among the schools, colleges and households. Local communities who are most affected by the impacts of climate change should be educated about climate change and its impacts and ways to mitigate the risks.

Quality Drinking Water

At least 40 villages do not have any municipal water supply system and over 80 villages are only partially covered despite the abundance of water in rural areas compared to urban parts. The women in these villages are most affected as they are forced to travel a long way to collect water and thus lead a poor quality of life. The socioeconomic conditions should be given due importance as per the IWRM principles and thus should meet the basic need for the citizens. The government must also focus on tapping the excess water from the Ousteri and Bahour tanks to augment the urban water supply.

Better Drainage System

The water is supplied at the rate of 135 litres per capita per day. Of this, 80% of the water shall be wastewater. Hence, it is estimated that by the year 2026, about 94.5 MLD of sewage will be generated in the Puducherry urban area. The existing capacity of the STP can treat only 15.3 MLD of sewage. Hence, there is shortfall of 79.2 MLD. Presently, the sewage is treated through oxidation ponds, which require a large area but lower operation and maintenance costs. Due to land constraints in Puducherry, Up-flow Anaerobic Sludge Blanket (UASB) process of STP is designed for the uncovered areas. The UASB treatment will consume a smaller area of land and have higher operation and maintenance costs.

Monitoring and Change

Water resource managers need the ability to track changes and to devise and support the implementation of appropriate responses. This requires extensive data and the ability to analyse and interpret it in order to guide planning and inform the stakeholders of its implications. Data should be cleansed and integrated from various source systems, so that intelligent reporting can be implemented to enable to policy-makers to make decisions based on the facts alone.

Conclusion

Water is the primary medium through which climate change influences the Earth's ecosystems and therefore people's livelihoods and well-being. Adaptation to climate change is mainly about better water resources management. A traditional, fragmented approach to water management is not going to yield sustainable benefits in the long run. Water resources and how they are managed impact almost all aspects of society and the economy, in particular health, food production and security, domestic water supply and sanitation, energy, industry, and the functioning of ecosystems. Thus, adapting to the new challenge of climate change requires an integrated approach to water management. Integrated solutions coupled with innovative technologies are needed at the appropriate levels, for adaptation as well as mitigation. Appropriate adaptation measures should be built upon the existing water management practices to foster resilience to climate change, thereby enhancing water security.

References

Agarwal A, delos Angeles MS, Bhatia R, Chéret I, Davila-Poblete S, Falkenmark M, Gonzalez Villarreal F, Jønch-Clausen T, Aït Kadi M, Kindler J, Rees J, Roberts P, Rogers P, Solanes M, Wright A (2000) Integrated water resources management. Global Water Partnership, Denmark

Geocenter Denmark (2008) Groundwater and climate change: challenges and possibilities, pp 1–15

InfoResources Focus (2003) Integrated water resources management (IWRM): a way to sustainability, inforesources focus, no 1/03, pp 5–9

Jones JAA (1999) Climate change and sustainable water resources: placing the threat of global warming in perspective. Hydrol Sci 44(4):541–557

Kolokytha E (1994) European policies for confronting the challenges of climate change in water resources. Curr Sci 98(8):1069–1076

Mall RK, Gupta A, Singh R, Singh RS, Rathore LS (2006) Water resources and climate change: an Indian perspective. Curr Sci 90(12):1610–1626

Mujumdar PP (2008) Implications of climate change for sustainable water resources management in India. Phys Chem Earth, Elsevier 33(5):354–358

Nobi EP, Umamaheswari R, Stella C, Thangaradjou T (2009) Land use and land cover assessment along Pondicherry and its surroundings using Indian remote sensing satellite and GIS. Am-Eurasian J Sci Res 4(2):54–58

Rakesh K, Singh RD, Sharma KD (2005) Water resources of India. Curr Sci 89(5):794–811

Report by the Government of Puducherry (2009) National action plan on climate change, Department of Science Technology, Puducherry, India

Report by the United Nations (2009) The implications of climate change on water, UN World Water Assessment Programme, Perugia, Italy

Report by Wilbur Smith Associates Private Limited (2007) Puducherry city development plan, Town and Country Planning Department, Puducherry, India

Sadoff CW, Muller M (2009a) Better water resources management—greater resilience today, more effective adaptation tomorrow. Water and climate change adaptation, produced together with the World Water Council, IUCN and IWA, Paper 4, pp 1–14

Sadoff CW, Muller M (2009b) Water management, water security and climate change adaptation: early impacts and essential responses, Global Water Partnership, pp 1–85

Slootweg R (2009) Integrated water resources management and strategic environmental assessment–joining forces for climate proofing. Water and climate change adaptation, produced together with the World Water Council, IUCN and IWA, Paper 16, pp 1–13

Stakhiv EZ, Pietrowsky RA (2009) Adapting to climate change in water resources and water services. Water and climate change adaptation, produced together with the World Water Council, IUCN and IWA, Paper 15, pp 1–15

van Steenbergen F, Tuinhof A (2009) Managing the water buffer for development and climate change adaptation. UNESCO publication, Netherlands