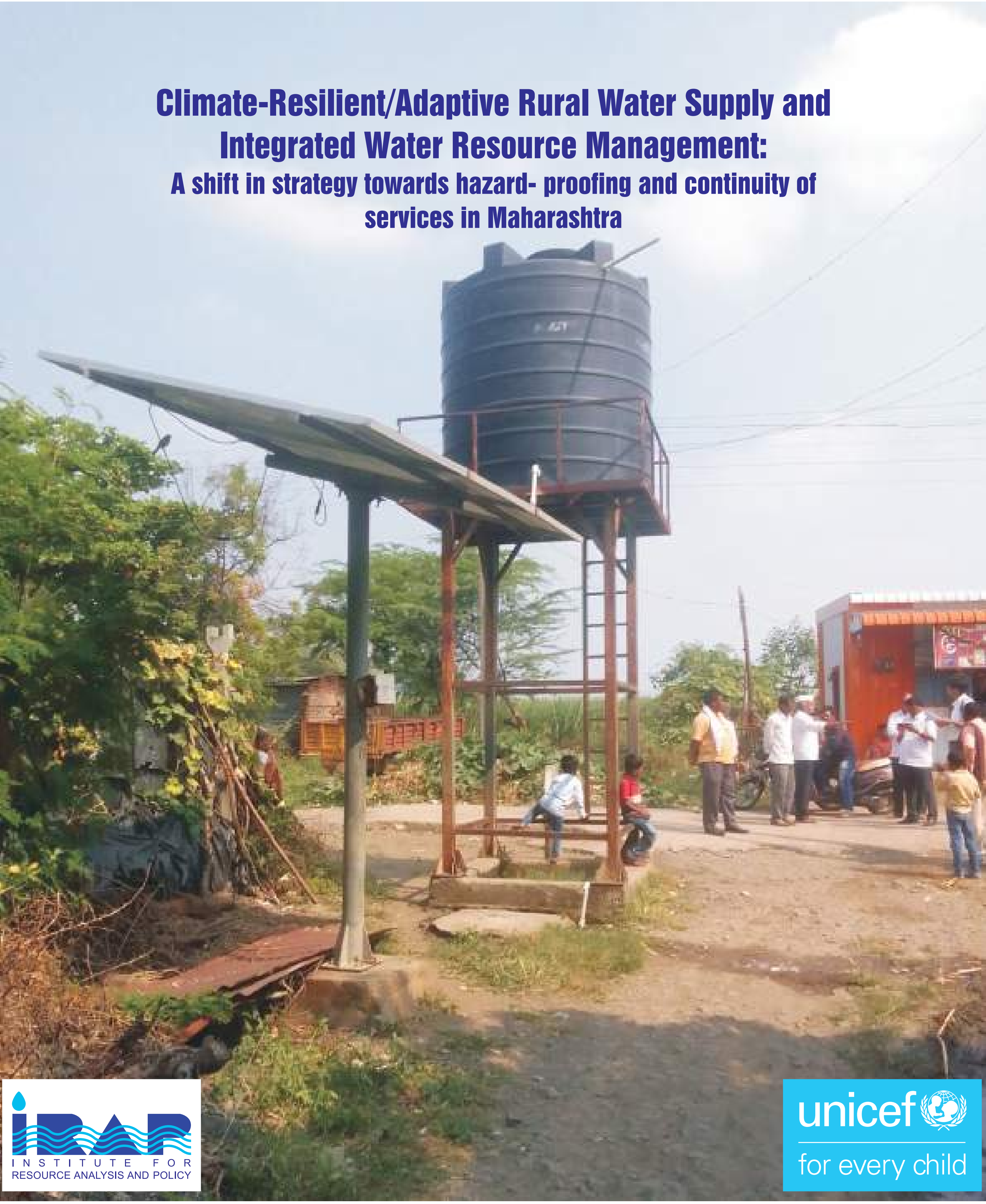
Climate-Resilient/Adaptive Rural Water Supply and Integrated Water Resource Management:

A shift in strategy towards hazard- proofing and continuity of services in Maharashtra



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Contents

List of Abbreviations

ABHY	Atal Bhujal Yojana
ADB	Asian Development Bank
CAPEX	Capital Expenditure
CDRA	Climate and Disaster Risk Assessment
CapManEx	Capital Maintenance Expenditure
CoC	Cost of Capital
DPDC	District Planning & Development Council
ExpDS	Expenditure on Direct Support
ExpIS	Expenditure on Indirect Support
FHTC	Functional Household Tap Connection
GSDA	Groundwater Survey and Development Authority
IWRM	Integrated Water Resource Management
HP	Horse Power
HRD	Human Resource Development
IEC	Information, Education and Communication
JJM	Jal Jeevan Mission
LCCA	Life Cycle Cost Approach
MCM	Million Cubic Meters
MGNREGA	Mahatma Gandhi National Rural Employment Guarantee Act
MEDA	Maharashtra Energy Development Agency
MUWS	Multiple Use Water Services
O & M	Operation and Maintenance
PES	Payment for Environmental Services
RWS	Rural Water Supply
SPI	Standardized Precipitation Index
WASH	Water and Sanitation Hygiene
WQM	Water Quality Management
WRD	Water Related Disaster
WQSI	Water Quality Surveillance Index

Credit Line

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Section I :
General Introduction

Executive Summary

The Government of India had launched the Jal Jeevan Mission (JJM) in the year 2019 to help rural households of the country secure tap water supply within the dwellings by the year 2024, with the ultimate aim of providing safe water supply that can be accessed by every household with ease. One of the biggest challenges in securing tap water supply is ensuring sustainability of the source of water. This is in lieu of the fact that a large proportion of the rural water supply schemes (in terms of the population covered) are dependent on groundwater, and groundwater resources are facing sustainability threats from the point of view of quantity and quality. The problem of well failures becomes rampant with an increase in the incidence of droughts in regions that are known for high climatic variability.

Though schemes such as Atal Bhujal Yojna are launched to improve the sustainability of the use of groundwater resources in regions where they are showing signs of over-exploitation using demand side management, there are several physical and socioeconomic constraints and challenges to achieving the desired outcomes.

Large parts of Maharashtra face these problems of high well failures and 'slip-back' with around 90% of the geographical areas of the state underlain by hard rock aquifers, heavy dependence of the rural communities on groundwater-based schemes for drinking water supply, and high competition that drinking water schemes face from irrigators. As a result, the schemes have a high life cycle cost. The coastal areas of the state face problems from floods and cyclones. There are many areas of the state where groundwater is either contaminated or faces pollution risks. Given this background, it is important to identify regions where the communities dependent on water supply schemes are likely to face problems of limited access to good-quality water for domestic uses, with resultant public health risks.

During the past 12 years, the Water Supply and Sanitation Department of the GoM, UNICEF-Mumbai and IRAP have collaborated on many projects on WASH. They dealt with the following topics: i) multiple water use services to reduce the HH vulnerability to climate variability and change; ii) institutional and policy framework for sustainable water supply in rural areas of Maharashtra; iii) drought predictions; iv) action planning for drinking water safety in rural areas of Maharashtra; v) performance evaluation of rural water supply and sanitation schemes; vi) assessment of climate risk in WASH and design of climate-resilient WASH systems; and vii) strategic techno-institutional models for strengthening functional HH tap connections in rural Maharashtra under JJM.

These projects and assessments have provided great insights into the following: i) the physical factors influencing behaviour of groundwater-the major source of rural water supply-the physical and socioeconomic factors influencing the performance of rural water supply schemes, and the types of water supply systems that can perform well under different conditions; ii) the factors influencing the climate-induced risk in WASH, and the technological and institutional interventions to make the WASH systems climate-resilient; iii) the design of multiple use water services to reduce the vulnerability of the rural HHs to problems associated with a lack of water for domestic and productive uses in different physical and socioeconomic environments; and iv) the planning, design and performance assessment of rural water supply schemes.

There was a need to build on this existing knowledge to fill knowledge gaps in order to meet the challenge of ensuring sustainable rural water supply that is resilient to all types of climate-induced natural hazards, while keeping in view the problems of groundwater depletion and deterioration of water quality. An assignment was therefore conceptualized with the following objectives:

- Mapping of different climate risks in RWS in all the nine agro-climatic zones, considering the rural water supply schemes
- Analysis of the impact of climate variability on the life cycle cost of water supply systems
- Strategies for mitigating the impacts of climate extremes on water supply and climate change impacts on water supply (reducing carbon emissions)
- Developing a handbook on water resources management and WQM for sustainable water supply in Maharashtra in the face of increasing climatic variability

Approach and Methodology

The approach and methodology used to realize the stated objectives of the partnership are discussed below, against each objective.

Objective I

- Develop a climate risk index for water supply that is relevant for the country: The composite index already developed for Maharashtra for climate risk in WASH was updated to make it more specific to water supply risks, considering the effects of hazards such as cyclones and landslides in addition to droughts and floods.

- Compute the climate risk index for water supply and map it for all districts of Maharashtra: the values of the wide range of physical, technical, socioeconomic, institutional and policy variables that are considered for the development of climate risk in water supply were derived for each one of the districts in Maharashtra.

Objective II

- Analyze the life cycle cost of similar types of rural water supply schemes in different environments, characterized by different degrees of climatic variability.

- Assess the impact of climate variability on the life cycle cost of water supply schemes.

Objective III

- Design elements of RWS in flood and cyclone-prone areas for risk reduction.

- Identify interventions for making groundwater-based RWS systems climate-resilient in areas where the resource faces sustainability threats.

- Assess the technical feasibility and cost evaluation of solar power-based water supply schemes in small tribal hamlets.

Objective IV

- Assess the water quality surveillance needs of different areas of Maharashtra using the DWQSI.
- Develop technological and institutional models for building rural water supply systems for multiple uses in different rural typologies of Maharashtra that are climate-resilient and risk-informed.

- Develop an approach and methodologies for conceptualization, planning, technology selection and design of water supply schemes.

- Develop an approach and methodology for water quality surveillance for source protection.

- Document best practices in planning, technology selection and design of water supply schemes, and source protection.

Field Studies and Other Analytical Works

In order to build on the existing body of knowledge on rural water supply schemes in Maharashtra, field studies were done to deepen an understanding of the following: i) life cycle cost of groundwater-based rural water supply schemes in the hard rock areas of Maharashtra; ii) impact of climate-induced hazards such as floods, cyclones and landslides on the rural water supply schemes; and iii) techno-economic feasibility of solar-based drinking water wells in tribal areas.

In addition, desk top research was carried out on the following: 1) developing a composite index for assessing climate-induced risk in rural water supply, as well as computation and mapping of climate-induced water supply risk in different districts of Maharashtra; 2) reviewing international literature to identify the measures required to make rural water supply schemes resilient to floods, cyclones and landslides in terms of changes in the design features of the water supply infrastructure; 3) developing techno-institutional models for multiple use water systems in different agro ecological and socioeconomic settings in Maharashtra, other than those covered in the earlier work with UNICEF; 4) developing an approach and methodologies for conceptualization, planning, technology selection and design of rural water supply schemes; 5) developing an approach and methodology for water quality surveillance for source protection; and 6) documenting best practices in planning, technology selection and design of water supply schemes, and source protection.

Structure of the Report

The report is organized into six major sections. Each section has a summary. The first section of the report deals with the rationale and objectives of the assignment, the field research design and the field survey details. It also discusses the scope and contents of the compendium.

Section II discusses a tool for assessing the risks associated with the rural community's vulnerability to disruptions in water supply caused by natural hazards and assesses the climate-induced water supply risk for each district of Maharashtra. It also discusses the various climate-induced hazards that occur in Maharashtra and their impact on the rural water supply schemes, based on evidence collected from field surveys. While presenting some of the international experiences with the design of rural water supply systems that are resilient to cyclones, landslides and floods, it also suggests some specific measures for improving the resilience of rural water supply systems to climate-induced hazards such as riverine floods, landslides and cyclones.

Section III discusses some of the theoretical perspectives of the life cycle cost analysis of WASH and reviews some of the studies that used this concept internationally. It also discusses some of the field evidence on the effect of climate extremes on the life cycle and the costs associated with operation and maintenance of rural water supply schemes, and then presents an empirical assessment of the life cycle cost of six selected rural water supply schemes that are based on wells in the district of Latur in Maharashtra. The second part of Section III deals with the following: i) the processes that explain the high failure of groundwater-based rural water supply schemes in hard rock regions; ii) the conditions under which groundwater-based schemes perform well; and iii) the measures that can improve the sustainability of rural water supply schemes in different typologies of Maharashtra. The third and last part deals with the concept of multiple use water services in the rural context and the techno-institutional models for improving the performance of rural water supply schemes in different agro-ecological conditions.

Section IV deals with the technical feasibility, cost-effectiveness and carbon emission benefits of solar-powered drinking water supply schemes. It first presents some theoretical aspects of the workings of solar-powered drinking water supply schemes in rural areas. It then presents the evidence collected from the field on the working of solar-powered drinking water schemes in the 13 tribal villages of the Gadchhiroli district of Maharashtra and finally presents the results of the empirical analyses covering the technical feasibility, cost-effectiveness and carbon emission benefits of those schemes.

The first part of Section V deals with a new approach to planning and designing sustainable rural water schemes that can consider the multiple sources of water that are available in rural settings for planning on the principles of physical and environmental sustainability and economic viability. The next part deals with a new approach for water quality surveillance for source protection, covering the concepts underlying the water quality surveillance practices followed internationally; the tool developed by us (details given in Section V of this report) for assessing water quality surveillance needs of rural areas, based on water contamination and pollution risks (covering the various parameters considered); and the results of the mapping of water quality surveillance needs of the state of Maharashtra, done using WQSI at the block level in Maharashtra.

Section VI of the compendium is a handbook that deals with the following: i) best practices in the planning and design of rural water supply schemes that use the concepts of physical, environmental sustainability and economic viability in the technology and source section; ii) various strategies for improving water quality surveillance for source protection in the rural areas of Maharashtra -- including capacity building of various institutions involved in water quality monitoring, data interpretation and initiating local measures, and the changing the staff composition of the water quality testing laboratories; and iii) the best practices that can be followed for source protection in rural areas.

Findings

Mapping Climate Risk in Rural Water supply and Improving Climate Resilience of Water Supply Systems

The first part of this section discusses the development of a composite index for assessing the risks associated with the rural community's vulnerability to disruptions in water supply caused by natural hazards-the various parameters considered for developing the index, and the manner in which these parameters influence the various dimensions of the risk. Then the climate-induced water supply risk of each district is computed and mapped, and the districts facing the highest risk are identified. The development of the index considered several natural, physical, socioeconomic, institutional and policy factors, with each one having the potential to influence one of the three dimensions (i.e., hazard, exposure and vulnerability) of the climate-induced risk in rural water supply through the selection of appropriate indicators for each one of them and the fixing of respective quantitative criteria for assigning values.

The second part discusses the impacts of various climate-induced hazards such as cyclones, landslides and riverine floods, based on the field evidence collected in selected villages during a survey in Kolhapur and Ratnagiri districts. It also discusses some of the international experiences with designing rural water supply systems resilient to cyclones, landslides, and floods and suggests specific methods for improving the resilience of rural water supply systems in the state to these hazards in terms of key design features for the rural water supply infrastructure.

The climate risk mapping exercise for rural water supply systems shows that there are many districts in the state of Maharashtra where rural water supply schemes are prone to climate induced risks. A total of 10 districts had risk values equal to or above 0.27, which indicates moderately high risk. The hazards that cause these risks are droughts, riverine floods, cyclones and landslides. Among all these, the most widespread impacts were from droughts owing to the hard rock geology, the limited surface irrigation and very high dependence on wells, and the heavy dependence on wells for rural water supply.

Though the effects of cyclones and riverine floods are restricted to a few coastal villages, they often damage the water supply infrastructure. The field survey conducted in eight villages from the Kolhapur and Ratnagiri districts of Maharashtra has shown that the local Gram Panchayat had undertaken retrofitting work subsequent to the damages caused to the infrastructure, wherever possible. In cases where the schemes were damaged beyond repair, new water supply schemes were built.

As regards future planning, in order to ensure the drought resilience of the rural water supply schemes, care should be exercised while selecting the sources. The areas where climate-induced risks in water supply are high due to low rainfall, high aridity and a high magnitude of occurrence of droughts are also characterised by intensive groundwater irrigation, and therefore the drinking water bore wells face competition from irrigation. The droughts only add to the problems.

In terms of policy change, the high-risk areas need to gradually shift to reservoir-based water supply schemes where the official agency can exercise control over water allocation. The new Jal Jeevan Mission guidelines provide for funding for multi-village water supply schemes in such areas to find a permanent solution to drinking water shortages.

As regards resource mobilization, the areas that are affected by natural hazards such as cyclones, floods and landslides should tap funds from the State Disaster Management Authority for retrofitting. However, future rural water supply schemes in such areas should consider special features in the system design to proof the infrastructure against damage caused by the hazards, as well as additional materials and equipment to deal with emergency situations. The design of water supply infrastructure in such areas should follow the guidelines framed by the National Disaster Management Authority.

LCC Analysis of Water Supply Schemes and Interventions for Building Climate-Resilient, Multiple Use Rural Water Systems

This section has three parts. The first part of this section analyses the life cycle cost of water supply schemes in an area that is subject to high variability in annual rainfall and that also does not have any groundwater stock that can provide drought resilience. The second part deals with the causes of failure of drinking water wells in rural areas, the determinants of performance of rural water supply schemes, and the measures that are to be adopted for making the water supply scheme in different typologies of Maharashtra climate resilient and sustainable. The third part deals with models of rural water supply for different agro-ecologies in Maharashtra that are capable of providing water to meet domestic and productive needs throughout the year.

As regards the impact of climate variability on the performance of rural water supply schemes, the comparative analysis of groundwater levels during the monsoon for dry and wet years for five districts from Nashik division and six districts from Kongan division of Maharashtra clearly shows that the sustainability of water supply schemes is threatened by droughts, with reduced recharge during the monsoon in the dry years. In the case of Ratnagiri district, where the groundwater condition was better, the incidence of occurrence of droughts was almost nil, and the incidence of well failure was not reported. There was no difference in groundwater level fluctuation during the monsoon between wet and dry years. The LCC analysis carried out for Latur district shows that the real cost of groundwater-based drinking water schemes in such areas will be high. While the life of the schemes varied from four to 35 years, the life cycle cost ranged from Rs. 2.7 per m3 to Rs. 15.7 per m3. This reinforces the argument for either entirely shifting to reservoir based schemes or going for conjunctive use of groundwater and water from surface reservoirs, depending on the gravity of the problems vis-à-vis groundwater scarcity.

As regards the factors influencing the performance of drinking water supply schemes, a recent analysis showed the following: a) the chances of failure of schemes are high if they are groundwater-based; groundwater-based schemes are more likely to fail in areas where the underlying formations are of hard rocks with low aquifer storage space; b) the groundwater-based schemes are also likely to fail in areas with poor effective recharge rate; c) the groundwater-based schemes are also likely to fail in areas where the demand for irrigation water is high, due to the presence of large areas under cultivation and aridity; and d) the groundwater-based schemes are likely to fail in areas where the extent of coverage of surface irrigation is quite low. Conversely, when the aquifer has good storage space, if the effective recharge in the district is good, if the extent of surface irrigation in the district is high, or if the demand for irrigation water is quite low, then the groundwater-based schemes perform well, manifested by the least dependence on tanker water supply during summer months.

Among the four typologies of areas identified in Maharashtra vis-à-vis the probability of success of rural water supply schemes, groundwater-based schemes were found to be sustainable only in one (i.e., typology 4) of the four. The strategies for improving the sustainability of the rural water supply schemes in the remaining three typologies are: 1) groundwater-based schemes requiring augmentation by surface water during the lean season for the districts falling in typology 1; 2) surface water schemes based on nearby sources (small dams in the hills or river lifting schemes serving individual villages and groups of villages) for districts falling in Typology 2; and 3) bulk water transfer for the Regional Water Supply Scheme from the WFRs to the Marathwada region for districts falling in Typology 3.

The high life cycle cost of rural water supply schemes justifies investment to build surface water schemes that involve bulk transfer of water from water-rich areas, despite the high capital cost of building such schemes. The amount of money spent on supplying water through tankers during the lean season alone can justify the investments required for water transfer when building multi-village drinking water schemes. With a conservative estimate of 20 per cent of the rural households in the districts where drinking water wells do not perform well, depending on tanker water for three months in an average year, the additional water to be supplied through tankers comes to 77.75 MCM per annum. At an average price of Rs. 250/m3 for tanker water, the expenditure would be INR 1,943 crore per annum for tanker water supply alone.

Building on an earlier work in Maharashtra that analyzed multiple use water needs of the rural areas and also explored a viable techno-institutional model of a rural water system that can provide water for multiple uses in each situation, we have also proposed techno-institutional models for multiple use water systems in rural areas of the state for different typologies that are capable of providing water for productive as well as domestic uses. Keeping in view the need for multiple use water services, the approach and methodologies for planning, technology selection and design of water supply schemes for rural areas were also discussed.

The high life cycle cost of water supply schemes based on groundwater in hard rock areas with poor resource potential suggests that it is not advisable to invest in bore well-based schemes in such areas, as the cost of supplying water through tankers during the peak summer months increases the real cost of water supply from groundwater in such regions. The analysis makes the case for investing in reservoir-based water supply schemes in such regions, catering to multiple villages. Because reservoir-based multi-village schemes are highly capital intensive, the life cycle cost approach should be used in planning rural water supply schemes if they are to become a government priority. Such a strategic shift will allow the water supply agency to change the norms pertaining to per capita supply levels so as to accommodate water for productive as well as domestic needs.

However, for this to happen, the thinking within the water supply agencies needs to be reoriented, which requires training. Earlier analysis had shown that source strengthening of bore well-based schemes in districts where they do not perform well by augmenting them with surface water supplies during the lean season (for three months) and complete replacement of poorly-performing bore well-based schemes with multi-village schemes based on surface water would require an investment to the tune of INR 9,550 crore for securing additional water supplies to meet a total annual demand of 1,361 MCM of water. However, such investments appear to be cost effective when we consider the high annual expenditure of INR 1943 crore on tanker water supply to tide over the crisis during the summer.

Technical Feasibility and Cost-Effectiveness of Solar-Powered Drinking Water Supply Schemes

The state of Maharashtra has launched a scheme to introduce solar-powered drinking water supply schemes, especially in the remote areas of the tribal-dominated districts of the state, as an attempt to improve the drinking water security of the backward regions by providing reliable energy supplies while reducing the carbon footprint of pumping groundwater. A total of 1830 schemes are already installed in the Gadchhiroli district alone. The solar PV systems are highly capital intensive.

A study undertaken to examine the efficacy and cost effectiveness of the solar-powered schemes, involving six villages from Gadchiroli district, showed that the schemes are working well and are able to provide reliable water supply for drinking and domestic uses in the hamlets in which they were installed. However, they are found to be more expensive than water supply wells powered by electric motors in terms of the cost of water supply per unit volume of water supplied, even after considering the clean energy benefits of such schemes. However, they were found to be a little less expensive than diesel engines. The cost of running the solar PV system was INR 125,408, compared with INR 29,770 for an electric pump and INR 168,929 for a diesel engine.

The analysis involved the following assumptions: 1) the cost of the solar PV system considered was for a panel of size sufficient to generate the amount of solar energy required to pump a total of 30.332 m^3 of water, and the same was compared with the cost of running an electric motor and a diesel engine, which can generate the energy that is required to lift the same volume of water; 2) the life of the solar PV system, the electric motor and the diesel engine considered was 12 years; and 3) the discount rate considered was 6 per cent. This way, the economic value of the benefit from a reduction in carbon emissions through the use of solar power was estimated to be a mere INR 4650 when compared with electric pumps and INR 3881 when compared with diesel pumps. Hence, such schemes will be desirable in very remote villages that do not have reliable power supply and where obtaining diesel for running diesel engines is difficult. They can also be considered for some of the economically most backward tribal areas of the state, where the communities do not have the wherewithal to pay for the cost of operation and maintenance of the conventional schemes run by electricity.

The study concluded that solar-powered drinking water supply schemes will be desirable in very remote villages where the power supply is unreliable and diesel for running diesel engines is difficult to obtain. They can also be considered for some of the economically most backward tribal areas of the state, where the communities do not have the wherewithal to pay for the cost of operation and maintenance of the conventional schemes run by electricity. This was largely the opinion of one of the experts who was at the helm of affairs in GSDA.

Approach & Methodologies for Conceptualization, Planning, Technology Selection and Design of Water Supply Schemes, and Water Quality Surveillance

This section deals with two critical aspects of the management of rural water supply. The first is the planning, technology section and design of rural water supply systems, wherein we discuss an approach and methodology that allows us to consider multiple sources of water in rural areas for water supply planning and then choose source waters and water supply technologies that ensure cost-effectiveness and physical and environmental sustainability.

As part of the overall approach for planning, technology selection and design of RWS schemes, we discuss the method to be used for realistically estimating the requirements for water in rural areas for domestic water supply that includes water for productive needs. As the next step, we discuss a framework for selecting sources for developing rural water supply schemes with a view to achieving physically and environmentally sustainable water supply that uses certain specific indicators to define source sustainability and thresholds for each type of source water. A method of tentatively estimating the unit cost of water supply from each source is then proposed. Then a method of obtaining an optimal combination of sources from a list of all potential water sources available in a rural setting that meets the criterion of overall cost effectiveness is proposed. Analytical procedures for estimating design floods, high flood levels, and negative externalities associated with the use of fossil fuel for pumping water are also discussed. Finally, the procedure for designing non-conventional water supply sources is discussed.

The second part deals with an innovative water quality surveillance approach based on an assessment of the risk associated with source water contamination and pollution. It discusses the philosophy behind the development of a composite index for assessing the water quality surveillance needs of different geographical areas, presents the results of mapping the index for different blocks of Maharashtra, and identifies areas where water quality monitoring needs to be intense in terms of the number of parameters to be covered and the frequency of monitoring.

The water quality surveillance index is a tool for surveillance of drinking water sources aimed at source protection. The tool uses a wide range of natural, physical, socioeconomic and institutional parameters for assessing the pollution risk of an area. The tool assesses the water quality surveillance needs at the block level. The DWQSI values estimated at the block level for all the blocks of Maharashtra help identify the blocks that pose the highest public health risks caused by exposure to contaminated or polluted water for drinking and where frequent and rigorous monitoring and surveillance of water resources and drinking water sources is required to prevent waterborne diseases.

As regards the computed values of the 'risk', Shegaon block in Buldhana district is at the highest risk (DWQSI of 0.090), and Panhala in Kolhapur district is at the lowest risk (DWQSI of 0.582). Overall, 77 blocks are in the high-risk category (DWQSI values ranging from 0.064 to less than 0.216), which constitutes 22% of all the blocks in the state; 273 blocks are in the moderate-risk category (DWQSI values ranging from 0.216 to less than 0.512), and only 4 blocks are in the low-risk category (DWQSI values greater than 0.512). The low-risk blocks are Panhala, Radhanagari, Hatkanangle and Karveer, all in Kolhapur district of Pune division, which is better off in terms of rainfall and surface water availability.

Water Resources Management and WQM for Sustainable Water Supply in Maharashtra in the Face of Increasing Climatic Variability

The problems of water resource depletion and water quality deterioration are increasingly posing major challenges for securing water supply for basic needs in rural areas. This is compounded by the increasing competition for limited water from other competitive user sectors. But the regions with limited water resources also witness high demands for water for irrigated crop production, which is constantly on the rise. Therefore, rural water systems should be designed with due consideration for issues of source sustainability and cost-effectiveness. The current resource scenario demands the use of best practices in planning, technology selection and the design of rural water supply schemes that can overcome some of the challenges with regard to water availability and water quality.

It is also extremely important to protect the quality of the source water to improve the sustainability of the schemes. The risk of pollution of drinking water sources from on-site sanitation is increasing in rural areas owing to the concentration of faecal sludge in a few places, while the capacity to do regular monitoring of water quality remains extremely limited. So it is important to know the best practices that the local institutions need to follow to ensure source protection.

The best practices for planning, technology selection and design of rural water supply systems for ensuring sustainability are: 1) a realistic assessment of the actual domestic and productive water demands; 2) good mapping of all potential water sources that can be tapped from the locality and water that can be obtained from unconventional sources; 3) realistic assessment of the competing water demands from the potential sources mapped; 4) proper quantification of the amount of water that can be supplied by various sources, and the amount of water that will have to be imported; 5) selection of water supply technologies based on a proper evaluation of the comparative cost of various combinations of water supply; 6) consideration of the life cycle cost (LCC) of the technologies; 7) design of systems for the extreme climatic conditions; 8) design of water supply systems for flood-prone areas; and 9) selection of sites for the schemes to prevent pollution of the source water.

In the second part of this section, we discussed the approach to be used for assessing the infrastructure, knowledge and staffing requirements of the laboratories in different areas based on the water quality surveillance needs of those areas. Now for initiating actions for the protection of the water source, we discussed the three types of factors that influence the public health impacts of poor sanitation, viz., physical, socio-economic; and cultural. We have identified specific training needs to build capacities at the local level for analysing the impact of on-site sanitation.

To ensure cost-effective and efficient water quality surveillance, we have also proposed specific capacity-building interventions for improving the analytical capabilities of the officials of the Water Supply and Sanitation Organization (WSSO) and WQ testing laboratories for assessing the pollution risk posed to source water and strategies for improving the surveillance capabilities of the local communities and the role of the Jal Surakshaks.

Now, keeping in view the kind of information that needs to be generated for water quality management and drinking water safety, we have discussed ways to improve the capabilities of GSDA for the processing and interpretation of water quality data. Finally, we also discussed the best practices in planning, technology selection and design of water supply schemes, as well as the best practices for the protection of drinking water sources.

The best practices for source protection proposed for new schemes include: 1) reviewing the situation with respect to water safety; 2) employing a risk reduction strategy; 3) proper siting of the scheme by locating it away from the high-risk areas; 4) capacity ascertainment with respect to WQM and surveillance for regular water sample collection and surveillance. In the case of existing schemes and new schemes, the measures suggested are: a) periodic monitoring of source water quality; b) increasing the frequency of monitoring source water through the collection and testing of water samples during the months of monsoon; c) preventing animal waste disposal; and d) issuing proper warnings on the basis of the degree of risk involved in the event of contamination of the source.

On the 22nd of March, we will be celebrating another World Water Day. This year's World Water Day is about accelerating change to solve the water and sanitation crisis, and because water affects us all, we need everyone to take action. That means you and me. We and our families, the schools and the communities around us can make a difference by changing the way we use, consume and manage water in our lives. Our commitments will be reflected in the Water Action Agenda, to be launched at the UN 2023 Water Conference -the first event of its kind for nearly 50 years. This is a once-in-a-generation moment for the world to unite around water. Let us play our part and do what we can.

1. Rationale

The rural water supply systems in Maharashtra face serious problems of source sustainability owing to their heavy dependence on groundwater sources, leading to malfunctioning, scheme failure during lean periods, increased water contamination, and resultant high life-cycle costs (LCC). The problem is compounded by high climate variability, resulting in droughts and floods. While droughts are frequent in the low to medium rainfall regions, coastal areas face floods and cyclones.

During the past 12 years, the Water Supply and Sanitation Department, GoM, UNICEF and IRAP have collaborated on many projects on WASH. They include studies on: i) multiple water use services to reduce the HH vulnerability to climate variability and change; ii) institutional and policy framework for sustainable water supply in rural areas of Maharashtra; iii) drought predictions; iv) action planning for drinking water safety in rural areas of Maharashtra; v) performance evaluation of rural water supply and sanitation schemes; vi) assessment of climate risk in WASH and design of climate-resilient WASH systems; and, vii) strategic techno-institutional models for strengthening functional HH tap connections in rural Maharashtra under JJM.

These projects and assessments have provided great insights into the following: i) the physical factors influencing the behaviour of groundwater-the major source of rural water supply, the physical and socioeconomic factors influencing the performance of rural water supply schemes, and the types of water supply systems that can perform well under different conditions; ii) the factors influencing the climate-induced risk in WASH, and the technological and institutional interventions to make the WASH systems climate-resilient; iii) the design of multiple use water services to reduce the vulnerability of the rural HHs to problems associated with lack of water for domestic and productive uses in different physical and socioeconomic environments; and iv) planning, design and performance.

2 Objectives of the Programme

The Government of India had launched the Jal Jeevan Mission (JJM) in the year 2019 to help the rural households of the country secure tap water supply within their dwellings by the year 2024, with the ultimate aim of providing safe water supply that can be accessed by every household with ease. One of the biggest challenges in securing tap water supply is ensuring the sustainability of the source of water. This is in lieu of the fact that a large proportion of the rural water supply schemes (in terms of the population covered) are dependent on groundwater, and groundwater resources are facing sustainability threats from the point of view of quantity and quality (with depletion and water quality deterioration). The depletion problems are mainly in semi-arid hard rock regions, owing to the extremely high demand for the resource to meet irrigation needs and the limited potential of the aquifers in these regions, which have poor natural recharge and extremely limited stock. In many regions where resources are available in plenty (like in the coastal alluvial areas and in the Indo-Gangetic plains), there are widespread problems of mineralization/intrusion of groundwater with high levels of salinity, fluoride, nitrate, iron or arsenic on groundwater, making the water unsuitable for drinking and cooking purposes and in many cases even for other domestic uses, which also increase with an increase in groundwater withdrawal and agricultural intensification. The problems of well failures become rampant with the increase in the incidence of extreme climatic events (such as severe droughts) in these regions, which are known for climatic variability such as droughts and floods.

The schemes and programmes such as ABHY (Atal Bhujal Yojna), water-sufficient villages under the localisation of SDGs, are launched to improve the sustainability of groundwater resource use in regions from demand side management where it is showing signs of over-exploitation. However, in the regions where such schemes are absolutely necessary, surplus surface runoff for recharging groundwater is extremely limited, and even when such schemes help augment groundwater resources in certain localities, the extra water that goes into the aquifer is tapped by irrigators, leaving the drinking water wells dry towards the summer months. Large parts of Maharashtra face these problems of high well failures and 'slip-back' with around 90% of the geographical areas of the state underlain by hard rock aquifers, heavy dependence of the rural communities on groundwater-based schemes for drinking water supply, and high competition that drinking water schemes face from irrigators. Given this background, it is important to identify regions where the communities dependent on water supply schemes are likely to face problems of limited access to good quality water for domestic uses, with resultant public health risks. An assignment was therefore conceptualized with the following objectives:

- Mapping of different climate risks in RWS in all the nine agro-climatic zones, considering the rural water supply schemes
- Analysis of the impact of climate variability on the life cycle cost of water supply systems
- Strategies for mitigating the impacts of climate extremes on water supply and climate change impacts on water supply (reducing carbon emissions).
- Developing a handbook on water resources management and WQM for sustainable water supply in Maharashtra in the face of increasing climatic variability

3 Approach, Methodology and Field Research Design

3.1 Approach and Methodology

The approach and methodology used to realize the stated objectives of the partnership are discussed below, against each objective.

Objective I

- Develop a climate risk index for water supply that is relevant for the country: The composite index already developed for Maharashtra for climate risk in WASH was updated to be more specific to water supply risks, considering the effects of hazards such as cyclones and landslides in addition to droughts and floods.
- Compute the climate risk index for water supply and map it for all districts of Maharashtra: The values of the wide range of physical, technical, socioeconomic, institutional and policy variables that are considered for the development of climate risk in water supply were derived for each one of the districts in Maharashtra.

Objective II

- Analyze the life cycle cost of similar types of rural water supply schemes in different environments, characterized by different degrees of climatic variability.
- Assess the impact of climate variability on the life cycle cost of water supply schemes.

Objective III

- Design the elements of RWS in flood and cyclone-prone areas for risk reduction.
- Identify interventions for making groundwater-based RWS systems climate-resilient in areas where the resource faces sustainability threats.
- Assess the technical feasibility and cost evaluation of solar power-based water supply schemes in small tribal hamlets.

Objective IV

- Assess the water quality surveillance needs of different areas of Maharashtra using DWQSI.
- Develop technological and institutional models for building rural water supply systems for multiple uses in different rural typologies of Maharashtra that are climate-resilient and risk-informed.

- Develop an approach and methodologies for conceptualization, planning, technology selection and design of water supply schemes.

- Develop an approach and methodology for water quality surveillance for source protection.

- Document best practices in planning, technology selection and design of water supply schemes, and source protection.

3.2 Field Research Design

3.2.1 Risk to Water Supply Due to Floods, Cyclones and Landslides

The design of rural water supply systems that are resilient to floods and cyclones would require understanding the actual impacts of such climatic phenomena on the water supply systems, particularly identifying the components of the water supply infrastructure that are most subject to damages from the hazard, understanding the nature of repairs and retro-fitting that are required to make the system functional, and understanding the scale of investments that are required for their rehabilitation.

Such an investigation would help us understand the unique technical features that are required in rural water supply systems for them to be resilient against floods, cyclones and landslide-induced damages. Keeping these points in mind, it was decided to undertake field studies in the districts of Ratnagiri and Kolhapur in Maharashtra. The districts are selected in such a way that the rural water supply schemes are subject to floods (Kolhapur) and cyclone-induced (Ratnagiri) hazards, get damaged, but get repaired. Around a dozen water supply systems were selected for the field survey.

3.2.2 Assessment of Life Cycle Cost Assessment (LCCA)

Many rural water supply schemes based on groundwater in hard rock regions are subject to stress due to climate variability. During droughts, the recharge to groundwater becomes negligible. As the water table is generally most likely to be at its lowest during the peak summer months and the rise in water level owing to limited recharge during the monsoon is also likely to be quite low, the schemes fail in the absence of sufficient groundwater stock. The increasing frequency of such climatic extremes means that the schemes in such areas will have a very short life. This phenomenon will increase the cost of the scheme per unit volume of water supplied, though the initial investments for such schemes are quite low. The life cycle cost analysis of such water supply schemes will help in making the right choices on the type of water supply schemes to be invested in. It is important to understand the impact of climatic variability on the life cycle cost of groundwater-based water supply schemes in states like Maharashtra in lieu of the fact that a large proportion of the rural water supply schemes in the state are groundwater-based and that large regions of the state witness high variability in rainfall.

Hence, if we want to understand the impact of climate (especially rainfall) variability on the life cycle cost of the scheme, it is important to compare the scenario in two distinctly different situations: one in which the rainfall variability is high (experiencing severe droughts frequently along with excessively wet years) and where the stock of groundwater is poor or nil, and the other in which either the rainfall variability is quite low (with the frequency of occurrence of droughts being low) or there is a good stock of groundwater, or a region in which both the conditions are satisfied. The advantage of selecting a region with good groundwater stock is that the drought events will not significantly affect the groundwater availability in wells. Hence, two districts from Maharashtra were selected for the primary survey, one (Latur) falling in a drought-prone region underlain by hard rock aquifers and the other (Ratnagiri) falling in a high rainfall region with some groundwater stock owing to the presence of alluvium and laterite. The villages were chosen in such a way that the villages have groundwater-based schemes that have already become dysfunctional. Half a dozen schemes were chosen for the survey from both districts.

3.2.3 Feasibility of Solar-Powered Drinking Water Supply Schemes

The study examined the technical feasibility and economic viability of using solar-powered drinking water schemes in tribal areas of Maharashtra. The tribal areas were chosen because of the poor quality of power supply in those areas, which causes a hindrance to conventional drinking water schemes that are run on grid-connected power supply. The technical feasibility looked at the availability and reliability of power supply from solar PV systems for running the drinking water pumps over the years and across seasons. The economic analysis involved comparing the cost of supplying drinking water through solar-powered pumps with that of pumps powered by conventional electricity supply systems from the grid, with the same levels of supply and the same degree of reliability. In the economic analysis, the clean energy benefits of using solar PV systems for electricity production are considered an additional cost (a positive externality) of the conventional energy source.

The study was carried out in the Gadchiroli district of Maharashtra, which is predominantly a tribal district. Though the water resource situation in the district is good, the grid power supply in the rural areas of the district is quite erratic, as evident from the exploratory field visits conducted. This causes disruptions in water supply services. A large number of solar-powered drinking water schemes are being introduced in the rural areas of the district, and the district has a maximum number of solar powered DW supply schemes promoted by Groundwater Survey and Development Agency (GSDA) of Maharashtra. The primary survey covered 13 solar-powered, single-hamlet drinking water supply schemes in small tribal hamlets. A well-structured questionnaire covering the technical (system performance, operation and maintenance), social, and economic aspects of the use of the system was used.

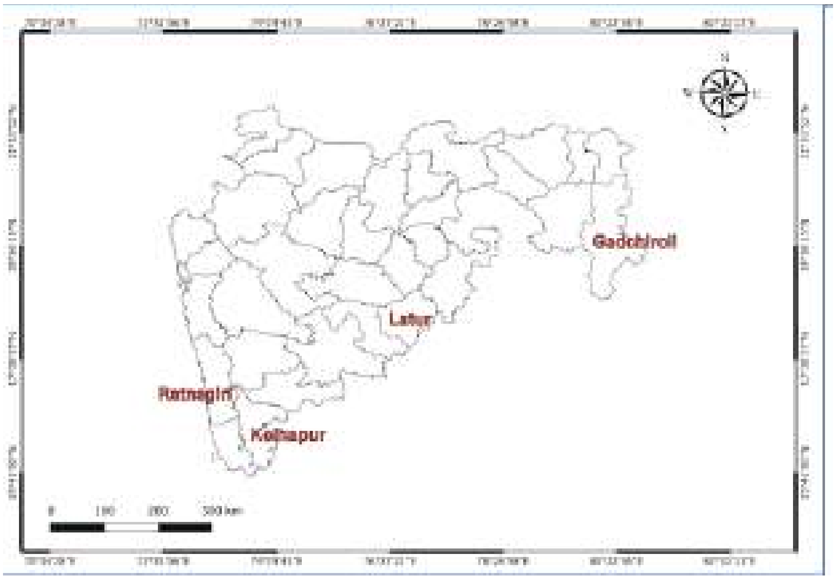
3.3 Field Survey Details

Four districts of Maharashtra were selected for conducting the field study. The names of the districts and the purpose of the field survey are as follows:

1) Latur (hard rock region)-Ratnagiri-alluvium as well as hard rock/laterite (on Life Cycle Cost analysis)
2) Gadchiroli-solar-powered drinking water supply
3) Ratnagiri (cyclone and flash floods)
4) Kolhapur-flood-prone areas

Please refer to Figure 1.1 for the four field survey districts in Maharashtra.

Figure 1.1: Field Survey Locations



The purpose of the field study conducted in Latur was to assess the impact of climate variability on the life cycle cost of rural water supply schemes based on groundwater (bore wells). The types of data collected were both qualitative and quantitative. It involved the collection of both HH level and GP level data. The study covered a total of 6 villages in Latur. The purpose of the study in Gadchiroli was to conduct a technical feasibility assessment and cost evaluation of solar power-based water supply schemes in the small tribal hamlets. The types of data collected were both qualitative and quantitative. The study covered 13 villages from eight blocks. The purpose of the study in Kolhapur and Ratnagiri was to analyse the effect of natural hazards on rural water supply schemes under different environments, characterized by different degrees of climatic variability (flood/cyclones/landslides).

Table 1.1: Details of the Latur Field Survey

Name of the Gram Panchayat/ Village	Taluka	Number of households covered	Focus of survey	Type of survey (HH/GP/Both)
Jewali	Latur	10	Life cycle cost analysis of bore well-based rural water schemes in Maharashtra	Both
Kanadi Borgaon	Latur	10		
Haregaon	Ausa	10		
Matola	Ausa	10		
Nandurga	Ausa	10		
Pangaon	Renapur	10		

Table 1.2: Details of the Gadchiroli Field Survey

Name of the Gram Panchayat/Village	Taluka	Number of villages covered	Focus of survey	Type of survey (HH/GP/Both)
Girola	Dhanora	2	Analysing the working of the Solar-Powered Drinking Scheme in Maharashtra	Gram Panchayat
Bhikar Mausi	Dhanora	3		
Futgaoy	Gadchiroli	1		
Chatgaon	Dhanora	1		
Lekha	Dhanora	1		
Sawela	Gadchiroli	1		
Dhudhumala	Dhanora	3		
Salebhatti	Dhanora	1		

Table 1.3: Details of the Ratnagiri Field Study

Name of the Gram Panchayat/ Village	Taluka	Number of Household Covered	Focus of survey	Type of survey (HH/GP/Bot)
Bhatye	Ratnagiri	6	To study the effects of cyclones/ landslides/floods on the rural water supply	Both
Posare	Khed	5		
Tivare	Chiplun	10		
Talsar	Chiplun	6		
Vetoshi	Ratnagiri	10		
Adare	Chiplun	4		
Owali	Chiplun	6		

Table 1.4: Details of the Kolhapur Survey

Name of the Gram Panchayat/ Village	Taluka	Number of Household Covered	Focus of survey	Type of survey (HH/GP/Both)
Nrusinhawadi	Shirol	5	To study the effects of floods on the rural water supply	Both
Majrewadi	Shirol	7		
Chikali	Karveer	5		
Ambewadi	Karveer	5		
Kabnur	Hatkanangale	0		
Rajapur	Shirol	7		
Rendal	Hatkanangale	6		
Chandur	Hatkanangale	9		

4 The Scope and Contents of the Compendium

Section II of this compendium discusses a tool for assessing the risks faced by rural communities associated with their vulnerability to disruptions in water supply caused by natural hazards in rural areas, as well as assessing the climate-induced risks in water supply for each district in Maharashtra. It also discusses the various climate-induced hazards that occur in Maharashtra, such as cyclones, landslides and riverine floods, and their impacts based on evidence collected from the field in sample villages. While presenting some of the international experiences with the designing of rural water supply systems resilient to cyclones, landslides and floods, it also suggests some specific measures for improving the resilience of rural water supply systems to climate-induced hazards such as riverine floods, landslides and cyclones.

Section III of the compendium discusses some of the theoretical perspectives concerning the life cycle cost analysis of WASH and reviews some studies that have used this concept internationally. It also discusses some of the field evidence to show how climate extremes affect the life cycle and the costs associated with operation and maintenance of rural water supply schemes, and then presents an empirical assessment of the life cycle cost of six selected rural water supply schemes based on groundwater, which fail due to the frequent occurrence of droughts. The next part of Section III of the compendium deals with the following: i) the processes that explain the high failure of groundwater-based rural water supply schemes in hard rock regions (which occupy 90% of Maharashtra's geographical area); ii) the conditions under which groundwater-based schemes perform well; and iii) the measures that can improve the sustainability of rural water supply schemes in different typologies of Maharashtra (defined by the extent to which the groundwater-based schemes succeed in supplying water to meet the needs throughout the year). The last part deals with the concept of multiple use water services in the rural context and the techno-institutional models for improving the performance of rural water supply schemes in different agro-ecological conditions so as to provide water for domestic and productive needs.

Section IV of the compendium deals with the technical feasibility, cost effectiveness and carbon emission benefits of solar-powered drinking water supply schemes. It first presents some theoretical aspects of the working of solar-powered drinking water supply schemes in rural areas, particularly the ideal conditions that make them relevant and also make them perform well. It then presents evidence collected from the field on the working of the solar-powered drinking water schemes in the 13 tribal villages in Maharashtra's Gadchhiroli district, and finally presents the results of empirical analyses covering the technical feasibility (efficiency), cost effectiveness and carbon emission benefits of the schemes studied.

The first part of Section V deals with a new approach to planning and designing sustainable rural water schemes that can consider the multiple sources of water that are available in rural settings and that are based on the principles of physical and environmental sustainability and economic viability. The next part deals with a new approach for water quality surveillance for source protection, covering the concepts underlying the water quality surveillance practices followed internationally, the tool developed by us (details given in Section V of this report) for assessing water quality surveillance needs of rural areas, based on water contamination and pollution risks-covering the various parameters considered-, the results of the mapping of water quality surveillance needs of the state of Maharashtra, done using WQSI at the block level in Maharashtra.

Section VI of the compendium is a handbook that covers the following topics: best practices in the planning and design of rural water supply schemes that incorporate the concepts of physical, environmental sustainability and economic viability in the technology and source sections; various strategies for improving water quality surveillance for source protection in the rural areas of Maharashtra-including capacity building of various institutions involved in water quality monitoring, data interpretation and initiating local measures; changing the staff composition of the water quality testing laboratories; and the best practices that can be followed for source protection in rural areas.

Section II:
Mapping Climate Risk in Rural Water Supply and Improving Climate Resilience of Water Supply Systems

Summary

Some regions and localities of Maharashtra face several climate hazards, such as floods, cyclones and landslides, while many parts of the state also face extreme climatic events, especially droughts. Some of these natural hazards cause damage to rural water supply infrastructure. Some of the hazards also have an impact on the source water in terms of quantity and quality. These hazards, through interruptions in water supply or contamination of the water supplied, cause risks to public health, depending on the degree of vulnerability of the communities.

This section first discusses the development of an index for assessing the risks associated with the rural community's vulnerability to disruptions in water supply caused by natural hazards-the various parameters considered for developing the index, and the manner in which these parameters influence the various dimensions of the risk, i.e., hazard, exposure and vulnerability. Based on the data collected from various sources on these variables at the district level, the climate-induced risks in water supply for each district in Maharashtra were assessed and mapped to identify the districts that are highly prone to climate-induced risks in water supply.

The second part discusses the impacts of various climate-induced hazards, such as cyclones, landslides and riverine floods, based on the field evidence collected in selected villages during a survey. It also discusses some of the international experiences with designing rural water supply systems resilient to cyclones, landslides, and floods and suggests specific methods for improving the resilience of rural water supply systems in the state to these hazards.
As regards the findings, the climate risk mapping exercise carried out with the help of a composite risk assessment index developed for the study shows that there are many districts in the state of Maharashtra where rural water supply schemes are prone to climate-induced risks. A total of 10 districts had risk values equal to or above 0.27, which indicates moderately high risk. The hazards that cause these risks are droughts, riverine floods, cyclones and landslides. Among all these, the most widespread impacts were from droughts owing to the hard rock geology, the limited surface irrigation and very high dependence on wells, and the heavy dependence on wells for rural water supply.

As regards the impact of climate-induced hazards, though the effect of cyclones and riverine floods is restricted to a few coastal villages, they often damage the water supply infrastructure. The field survey conducted in eight villages in the Maharashtra districts of Kolhapur and Ratnagiri revealed that the local Gram Panchayat had undertaken retrofitting work to repair the damages caused to the infrastructure, wherever possible. In cases where the schemes were damaged beyond repair, new water supply schemes were built.

As regards future planning, in order to ensure the drought resilience of the rural water supply schemes, care should be exercised while selecting the sources. The areas where climate induced risks in water supply are high due to low rainfall, high aridity and a high magnitude of occurrence of droughts are also characterised by intensive groundwater irrigation, and therefore the drinking water bore wells face competition from irrigation. The droughts only add to the problems. As a policy measure, such high-risk areas need to gradually shift to reservoir-based water supply schemes where the official agency can exercise control over water allocation. The new JJM (Jal Jeevan Mission) guidelines provide for funding for multi-village water supply schemes in such areas to find a permanent solution to drinking water shortages.

As regards resource mobilization, the areas that are affected by natural hazards, such as cyclones, floods and landslides, should tap funds from the State Disaster Management Authority for retrofitting. However, the future building rural water supply schemes in such areas should be accompanied by considerations of special features in the system design to protect the infrastructure against the damages caused by the hazards and additional materials and equipment to deal with emergency situations. The design of water supply infrastructure in such areas should follow the guidelines framed by the National Disaster Management Authority.

1. Introduction

Some regions and localities of Maharashtra face several climate hazards, such as floods, cyclones and landslides. Many regions of Maharashtra also face extreme climatic events, especially droughts and abnormally wet years. Some of these natural hazards can and do cause damage to rural water supply infrastructure. Some of the hazards also have an impact on the source water in terms of quantity and quality. Depending on how vulnerable the community is to the disruptions in water supply services caused by the hazard, they face public health risks due to interruptions in water supply or contamination of the water supplied to them.

In this section, we first discuss the development of a tool for assessing the risks faced by rural communities associated with their vulnerability to disruptions in water supply caused by natural hazards-the various parameters considered for developing the index and the manner in which these parameters influence the various dimensions of the risk, i.e., hazard, exposure and vulnerability. Based on the data collected from various sources on these variables at the district level, we assess the climate-induced risks in water supply for each district in Maharashtra, map them and identify the districts that are highly prone to climate-induced risks in water supply.

In the second part, we will also discuss the impacts of various climate-induced hazards that occur in Maharashtra, such as cyclones, landslides and riverine floods, based on the evidence collected from the field in selected villages during a sample survey. We will also discuss some of the international experiences with designing rural water supply systems resilient to cyclones, landslides and floods, and finally suggest specific methods for improving the resilience of rural water supply systems in the state to these climate-induced hazards.

2 Climate Risk Assessment in Rural Water Supply

2.1 Development of Climate Risk Index for Water Supply

For the development of the index to assess climate-induced risk in water supply, the factors influencing the three different dimensions of risk, i.e., hazard, exposure and vulnerability in the rural water supply sector are identified and grouped as natural, physical, socio-economic, and institutional factors. These factors and relevant variables are identified based on the literature review, expert knowledge, and understanding of the study regions. The various factors and the ways in which they can influence climate-induced hazards as well as the exposure and vulnerability of the communities to these hazards, are discussed in the subsequent sub-sections. A summary of the discussion is also presented in Table 1.

1) Factors Influencing Climate-Induced Hazard in Water Supply

The occurrence of natural hazards such as droughts, floods, landslides and cyclones, is mainly influenced by natural factors. These include rainfall and its variability, flood proneness, aridity, and overall renewable water availability. Above-normal rainfall usually reduces the probability of drought occurrence and helps relieve water scarcity, and vice versa. As pointed out by Maliva and Missimer (2012), areas that receive low annual rainfall are at greater risk of having frequent droughts. In India, inter-annual variability in rainfall is found to be higher in regions with lower magnitudes of (mean) annual rainfall (Sharma, 2012). Hence, such regions are likely to experience droughts more frequently as compared to those with lower variability (Kumar et al., 2006; Kumar et al., 2008).

Further, given the nature of the relationship between rainfall and runoff in the semi-arid and arid tropics, the impact of meteorological droughts in terms of hydrological stress is greater in areas experiencing low (mean) annual rainfall compared to their counterparts receiving higher (mean) annual rainfall for the same intensity of drought (in terms of the Standard Precipitation Index (SPI) (source: Deshpande et al., 2016; James et al., 2015).

Flood-prone areas are at a greater risk of recurring floods due to excessively high rainfall (Brouwer et al., 2007). Heavy rainfalls in the area can have an adverse effect on surface water quality and groundwater, which can contaminate water supply (Zimmerman et al., 2008; Brouwer et al., 2007). Another factor that influences water scarcity (during droughts) is the overall availability of annual renewable water in a region (Rijsberman, 2006). Renewable water availability of more than 1700 cu m/capita/year is considered secure (Falkenmark et al., 1989).

2) Factors Influencing Community's Exposure to Hazards

Community exposure to any hazard is influenced by several factors. Natural factors include the occurrence of cyclones, the depth to water table, climate, and the groundwater stock. Cyclones can cause strong winds that can damage power lines, thereby disrupting the water supply. Groundwater at shallow depths will be susceptible to biological contamination during floods. A high groundwater stock can play a vital role in buffering the effects of the risks posed during droughts (Calow et al., 2010). In areas with a cold climate, exposure of the community to the risks posed during a bad rainfall year will be low as overall water requirements will be lower (Kabir et al., 2016a, 2016b). Areas with a humid climate have a greater chance of an outbreak of water-borne diseases during floods (Githeko et al., 2016).

There are several physical factors influencing community exposure to hazards, and they include characteristics of the water source, age of the water supply system, provision of buffer storage of water in reservoirs per capita, proportion of HHs covered by tap water supply, resource depletion due to over-exploitation, and flood control measures such as dams and water pumping facilities. A perennial water source would significantly reduce community exposure to droughts. Further, an ageing water supply system is at a greater risk of damage and disruption during natural calamities such as floods and cyclones. Adequate provision of buffer water storage in reservoirs is one other important factor that can reduce exposure to water scarcity conditions during droughts (Kumar, 2010, 2016; McCartney & Smakhtin, 2010). While the chances of such practices occurring would depend a lot on the frequency and intensity of droughts.

Similarly, HHs' access to tap water supply will help in counteracting prolonged exposure to climate-induced risks (Hunter et al., 2010; Montgomery & Elimelech, 2007; WHO, 2002). Further, flood control measures such as embankments, dykes, dams and water pumping infrastructure will help in reducing the severity of floods. Pumping stations and transformers kept in low-lying areas also increase the exposure to flood hazards.

Socio-economic factors in the context include the proportion of people living in low-lying areas and the proportion of people having access to a water supply source within the dwelling premises. Low-lying areas, due to their topographical disadvantage, will be more prone to floods (Patz & Kovats, 2002). Nevertheless, people who have access to a water supply within their premises will have less exposure to the risk posed by droughts or floods, owing to the fact that there will be a lesser chance of water contamination that normally happens during collection, conveyance, and storage if the source is available (WHO, 2002).

Institutional and policy factors also play an important role in regulating community exposure to climate-induced risks in water supply. A policy to hire private tankers for emergency water supply in rural areas and an increase in the number of such tankers being made available will help the community face water stress induced by droughts. Further, the provision of disaster risk reduction measures such as flood and cyclone warning, drought prediction, and evacuation measures will help the community prepare better for any adverse eventuality (Pollner et al., 2010).

3) Factors Influencing Community Vulnerability to Hazards

Community vulnerability disruptions in water supply due to hazards are mainly socio-economic and institutional in nature. Climate is the single most important natural factor that influences in this context. For instance, a cold climate and humidity increase flood-related health risks such as diarrhoea caused by bacteriological contamination of water and food (Haines et al., 2006; Githeko et al., 2016). Inadequate personal and community hygiene resulting from water shortages can result in diseases such as diarrhoea (Esrey et al., 1985; Howard, 2005). But in hot, arid, and semi-arid climates, the breeding of water-related insect vectors that can cause such diseases would be less common (Hunter, 2003). Hot and arid areas are more prone to drought-related health risks such as dehydration (Haines et al., 2006).

Population density is a key socio-economic variable that affects community vulnerability to the health risks associated with climate related hazards. More densely populated areas have greater faecal loadings within the environment, and these are associated with greater vulnerability to infectious disease (Woodward et al., 2000).

The burden of waterborne diseases is often closely linked to poverty (Fass, 1993; Stephens et al., 1997) and malnutrition. The poor tend to be more vulnerable to diseases and have the least access to basic services (WHO & UNICEF, 2000). This could be because a high proportion of those living in poverty lack the wherewithal to have access to alternate sources of water and are also generally unhealthy. There is a greater prevalence of undernourishment in general and malnutrition among children. Nevertheless, better access to primary health services will make them less vulnerable. People with malnutrition are more vulnerable to water-borne diseases.

Age is also an important factor affecting the vulnerability of the population to health problems caused by disruptions in water supply services in terms of quantity and quality of the supplied water. The elderly are more vulnerable to diseases, including water-borne diseases. Communities with a higher proportion of people in the old age category can be highly prone to disease risks, even if they score highly on social and economic development indicators such as health and per capita income. A study carried out by IRAP explaining the inter-state variations in COVID-19 infections and COVID-19 deaths in India showed a high influence of the aged population (expressed in terms of the percentage population above the age of 60) on both the dependent variables (Kumar et al., 2022).

Institutional and policy factors such as the availability of a greater number of institutions with the ability to provide relief and rehabilitation measures to people affected during floods and cyclones (including government, private and nongovernmental organizations) in terms of required equipment and budgetary allocations and preparedness improve community adaptive capacity against climate-induced vulnerabilities. Similarly, the presence of an adequate number of public health infrastructures decreases population vulnerability to the severity of diseases caused during hazards (Haines et al., 2006). Finally, social ingenuity also matters in adapting to natural disasters and reducing vulnerability. Social cohesion, which is characteristic of homogeneous communities, also helps in adaptation, building resilience and vulnerability reduction (IRAP, GSDA & UNICEF, 2013).

4) Climate-Induced Risk in Water Supply

Table 2.1 identifies the various factors that influence the climate-induced water related hazards, the exposure of the water supply systems to these hazards, and the vulnerability of the communities to the disruptions in water supply caused by the hazard, as well as the different variables that define them. They were identified through a systematic search of the scientific literature that deals with climate hazards related to water, the impacts of such hazards on the water supply systems in terms of quantity and quality of water available from the sources and the systems, and the vulnerability of the communities to problems associated with the lack of water for domestic needs and the factors that determine the degree of these hazards, exposure and vulnerability. A total of six factors are identified as key to influencing climate risk in water supply through their effect on hazards or exposure or vulnerability. They are: only natural factors influencing the degree of hazard; natural, physical, socioeconomic, and institutional and policy factors influencing the degree of exposure of the water supply system to the hazard; and socioeconomic, and institutional and policy factors influencing community vulnerability. Totally, there are four variables (all natural) influencing the hazard; 15 variables (four natural, six physical, two socioeconomic, and three institutional and policy-related) influencing exposure; and eight variables (five socioeconomic and three institutional and policy-related) influencing vulnerability. Table 2.2 discusses the quantitative criteria used for assigning values to different variables. Table 2.3 discusses the data sources and estimation procedure.

Table 2.1: Factors influencing climate-induced hazard

Sub-Index (Factors)	Variable (Indicators)	Rationale	Impact on severity of Risk (Negative or Positive) [1]
Hazard Sub-Index			
Natural	Rainfall	In high rainfall areas, the drought impacts on hydrology will be less as compared to low rainfall areas, and vice versa in low rainfall areas.	Negative
	Rainfall Variability	In areas with high rainfall variability, the frequency of occurrence of severe droughts will be higher .	Positive
	Aridity	Impact of droughts in areas with high aridity in terms of hydrological changes will be greater as compared to ar eas of low aridity .	Positive
	Annual Renewable Water Availability	Renewable water availability of more than 1700 cu m/capita/year is considered secure.	Negative
	Flood Proneness	'Flood Prone' areas are more susceptible to hazards associated with high rainfall.	Positive
Exposure Sub-Index			
Natural	Depth to ground water table	Groundwater at a shallow depth will be susceptible to biological contamination during floods.	Negative
	Temperature and Humidity	In areas with a cold and humid climate , there is a high chance of water and food contamination due to unhygienic conditions and the spreading of insect vectors .	Positive
	Groundwaterstock	Act as buffer during droughts. Normally available in alluvial areas and as valley fills along rivers	Negative
	Occurrence of cyclones with high-speed winds along the coastal districts	Cyclones with high-speed winds may damage the WSS or affect the power supply, thus interrupting the supply of water from an electrically operated WSS.	Positive

[1] 'Positive' sign suggests that if the value of the variable increases, the effect on the particular dimension of risk (i.e., hazard or exposure or vulnerability) will be higher. Conversely, 'negative' sign suggests that if the value of the variable increases, the effect on the particular dimension of risk will be lower.

Sub-Index (Factors)	Variable (Indicators)	Rationale	Impact on severity of Risk (Negative or Positive) [1]
Physical	Characteristics of natural water resources	Perennial water source would significantly reduce community exposure to droughts	Negative
	Condition of the water system	Older water supply systems are more susceptible to disruption and damage during floods and cyclones.	Negative
	Provision of buffer storage of water in reservoirs per capita	Reduces exposure to water scarcity conditions during droughts	Negative
	Proportion ofHHs covered by tap water supply	Reduces the chances of contamination of water during collection and storage	Negative
	Flood control measures such as embankments, dykes, dams and water pumping facilities	Reduces severity of floods	Negative
	Availability of skilled labour for immediate repair and maintenance of water supply system	Non availability of skilled labour for immediate repair of the WSS may cause interruptions in the water supply	Negative
Socio-Economic	Proportion of people living in low-lying areas	Relatively more exposed to flood hazards	Positive
	Proportion of people having access to a water supply source within the dwelling premises	Less exposure to risk posed by droughts or floods	Negative
Institutional& Policy	Disaster risk reduction measures available; preparedness and ability to respond	Helps the community prepare better for any adverse eventuality	Negative
	Existence of a policy to hire private tankers for emergency water supply	Help the community face water stress induced by droughts	Negative
	Provision for tanker water supply in rural areas in terms of the number of tankers	Increases the community's ability to tide over the crisis caused by reduced water supply from public systems.	Negative

Sub-Index (Factors)	Variable (Indicators)	Rationale	Impact on severity of Risk (Negative or Positive) [1]
Vulnerability Sub -Index			
Socio-Economic	Populationdensity	High population density increases vulnerability .	Positive
	Proportion of people living in poverty	Vulnerability will be high for those who lack the wherewithal to have access to alternate sources of water , including purchased water	Positive
	Proportion of people who are unhealthy	Undernourishment in general and malnourishment, especially among children, make the community more vulnerable	Positive
	Access to primary health services	Good access to primary health facilities makes the community less vulnerable	Negative
	Percentage of children under the age of 5 with stunting (height-for-age)	Physical growth of children (under the age of 5), an indicator of the nutritional well-being of the population, influences vulnerability to diseases	Negative
	Proportion of aged population (above 65 years)	Proportion of elderly people in the community increases the vulnerability to hazards	Positive
Institutions and Policy	Ability to provide relief and rehabilitation measures for floods and cyclones (number of agencies, including government, private and NGOs)	Improve community ada ptive capacity	Negative
	Social ingenuity and cohesion	Improves community adaptive capacity and resilience	Negative
	Adequate number of primary and other health infrastructure	Decreases community vulnerability to diseases	Negative

Table 2.2: Quantitative criteria for assigning values for different variables

Sub-Index (Factors)	Variable (Indicators)	Impact on severity of Risk (Negative or Positive)	Score			Score Given	Remarks
			1 = Low	2 = Moderate	3 = High		
A. Hazard Sub-Index							
Natural	Rainfall	Negative	Average annual rainfall greater than or equal to 1000 mm	Average annual rainfall between 500-1000 mm.	Average annual rainfall less thanequal to 500 mm.		The hazard is drought.
	Rainfall Variability	Positive	Coefficient of variation inrainfall is less than 17%	Coefficient of variation in rainfall is equal to/between 17% and 40%	Coefficient of variation in rainfall is greater than 40%		As per the guidelines of IMD
	Aridity	Positive	Humid to SubHumid	Semi-arid	Arid to Hyper Arid		As per the guidelines of IMD
	Annual Renewable Water Availability	Negative	Renewable water availability of more than equal to 1700 cum/capita/year	Renewable water availability of between 1000-1700 cum/capita/year	Renewable water availability of less than equal to 1000 cum/ capita/year		
	Flood Proneness	Positive	Probability of occurrence of flood less than 10%	Probability of occurrence of flood is between 10% and 33%	Probability of occurrence of flood greater than 33%		
B. Exposure Sub-Index							
Natural	Depth to ground water table	Negative	Depth to groundwater table is greater than or equal to 30 m	Depth to ground water table is between 5 m and 30m	Depth to groundwater table is less than equal to 5 m		The exposure is in the form of bacteriological contamination
	Temperature and Humidity	Positive	Temperatures ranging between 30°C and 35°C and Humidity ranging from 30±5% to 50±3%	Temperatures ranging between 27°C and 30°C and Humidity ranging from 30±5% to 50±3%	Temperature ranging between 23 and 27°C; Humidityranging from 60±8% to 80±6% most favorable condition for unhygienic conditions		

Sub-Index (Factors)	Variable (Indicators)	Impact on severity of Risk (Negative or Positive)	Score			Score Given	Remarks
			1 = Low	1 = Low	1 = Low		
	Groundwaterstock	Negative	Groundwater stock is five times more thanthe annual recharge	Groundwater stock is two times more than the annualrecharge	Groundwater stock is equal toor less than the annual recharge		As per the guidelines of CGWB
	Occurrence of cyclone with high-speed winds	Positive	No cyclones with high-speed winds		Cyclones with high-speed winds		
Physical	Characteristics of natural water resources	Negative	Perennial watersource with low inter-annual variability (example: river)	Perennial sourcewith high inter-annualvariability (coefficient of variation in the annual flows)	Seasonal water sources (ephemeral rivers, lakes, ponds, etc.)		
	Condition of the water supply system	Negative	New water supply pipelinesystems (less than 5 years)	Medium-aged water supply pipeline systems(between 5 and 15 years)	Old water supply pipeline systems (older than 15 years)		
	Provision of buffer storage of water in reservoirs per capita	Negative	Provision of buffer storage in a reservoir with a minimum 36 m^3/capita/year	Provision of buffer storage in a reservoir between 15 m^3/capita/year	Provision of buffer storage ina reservoir less than 9 m^3/capita/year		
	Proportion of HHs covered by tap water supply	Negative	More than 75% of HHs are covered by tap water supply	40-60% of HHs are covered by tap water supply	Less than or equal to 40% of HHs are covered by tap water supply		
	Flood control measures such as embankments, dykes, dams and water pumping facilities	Negative	Flood control measures available	Significant damage reported due to floods despite the availability of flood control measures	No flood control measures available		
	Availability of skilled labour for immediate repair and maintenance of water supply system	Negative	Available		Not available		

Sub-Index (Factors)	Variable (Indicators)	Impact on severity of Risk (Negative or Positive)	Score			Score Given	Remarks
			1 = Low	1 = Low	1 = Low		
Socio-Economic	Proportion of people living in low-lying areas	Positive	Less than or equal to 25% of people living in low-lying areas	25-50% of people living in low-lying areas	Greater than or equal to 50% of people living in low-lying areas		
	Proportion of people having access to a water supply source within the dwelling premises	Negative	More than 75% of people having access to a water supply source within the dwelling premises	40-75% of people having access to a water supply source within the dwelling premises	Less than 25% of people having access to a water supply source within the dwelling premises		
Institutional & Policy	Disaster risk reduction measures available	Negative	Disaster risk reduction force available within a radius of 100 km	Disaster risk reduction force available within a radius of 100-500 km	Disaster risk reduction force available outside a 500 km radius		
	Existence of policy to hire private tankers for emergency water supply	Negative	Policy exists to hire private tankers for emergency water supply		No policy exists to hire private tankers for emergency water supply		
	Provision for tanker water supply in rural areas in terms of the number of tankers	Negative	More than 1 tanker for 20 households	1 tanker for 20 to 50 households	Less than 1 tanker for 50 households		
C. Vulnerability Sub-Index							
Socio-Economic	Population Density	Positive	Population density less than 200 persons/sq. km	Population density in the range of 200-500 person/sq. km	More than 500 persons/sq. km		
	Proportion of people living in poverty	Positive	Less than or equal to 25% of people living in poverty	25-60% of people living in poverty	Greater than 60% of people living in poverty		
	Access to primary health services	Negative	More than 60% people having access to primary health services	25-60% of people havingaccess to primary health services	Less than 25% of people having access to primary health services		

Sub-Index (Factors)	Variable (Indicators)	Impact on severity of Risk (Negative or Positive)	Score			Score Given	Remarks
			1 = Low	1 = Low	1 = Low		
Socio-Economic	Proportion of people who are unhealthy	Positive	Infant mortality rate less than or equal to 12.0 (per 1000 people)	Infant mortality rate between 12.0 and 60.0 (per 1000 people)	Infant mortality rate greater than 60.0 (per 1000 people)		
	Percentage of children under the age of 5 with stunting (low height-for-age ratio)	Negative	Average height of children below the age of 5 as a % of the median is 95 to 110	Average height of children below the age of 5 as a % of the median is 85 to 89	Average height of children below the age of 5 as a % of the median is less than 85		
	Proportion of people above the age of 65	Positive	Proportion of aged pop. < 5 per cent	Proportion of aged population 5-8 per cent	Proportion of aged pop. above 8%		
Institutions and Policy	Ability to provide relief and rehabilitation measures for floods and cyclones (no. of agencies, including government, private and NGOs)	Negative	More than one NGO for every 1,000 people	One NGO for 1,000-2000 people	Less than one NGO for every 2000 people		
	Social ingenuity and cohesion	Negative	Settled and homogenous communities, exposed to natural disasters	Settled, but heterogeneous communities exposed to natural disasters	Settled, but heterogeneous communities not exposed to natural disasters		
	Adequate number of primary and other health infrastructure	Negative	One Sub Health Centre covered 3000 to 5000 of the rural population	One Sub Health Centre covered 6000 to 8000 of the rural population	One Sub Health Centre covered more than 8000 of the rural population		

Table 2.3: Data source and estimation procedures

		Variable	Estimation Procedure	Data Sources	Remarks
HAZARDS	**Natural**	Rainfall	Based on data analysis.	India-WRIS	
		Rainfall Variability	Based on data analysis.	India-WRIS	
		Aridity	Extracted from available Secondary Data	CGWB Report	
		Annual Renewable Water Availability	Based on data analysis.	NAQUIM CGWB Report	
		Flood Proneness	Based on data analysis.	India-WRIS	
EXPOSURE	**Natural**	Depth to ground water table	Based on data analysis.	India-WRIS	Past 10 years' (2010-19) data
		Temperature and Humidity	Extracted from available Secondary Data	IMD Report, Maharashtra, en.climate.org	
		Groundwater stock	Based on data analysis.	Report of the Expert group on "Groundwater Management and Ownership", GOI and CGWB, GOI	
		Occurrence of cyclone with high-speed winds	Extracted from available Secondary Data		
	Physical	Characteristics of natural water resources	Extracted from available Secondary Data	CWC Basin Report	
		Condition of the water supply system	Extracted from available Secondary Data	JJM, Dashboard	(As of date, i.e., 18th Nov, 2022)
		Provision of buffer storage of water in reservoirs per capita	Based on data analysis.	Capacity Assessment of Reservoirs in Maharashtra, Govt. of Maharashtra	
		Proportion of HHs covered by tap water supply	Extracted from available Secondary Data	JJM, Dashboard	(As of date, i.e., 18th Nov, 2022)
		Flood control measures such as embankments, dykes, dams and water pumping facilities	Extracted from available Secondary Data		

		Variable	Estimation Procedure	Data Sources	Remarks
EXPOSURE	Socio-Economic	Proportion of people living in low-lying areas	Based on data analysis.	Primary Data Available	
		Proportion of people having access to a water supply source within the dwelling premises	Extracted from available Secondary Data	NFHS-5 District Report	
	Institutional & Policy	Disaster risk reduction measures available	Extracted from available Secondary Data	DDMP	
		Existence of policy to hire private tankers for emergency water supply	Extracted from available Secondary Data	Secondary Data used in earlier study	
		Provision for tanker water supply in rural areas in terms of the number of tankers	Extracted from available Secondary Data	Secondary Data used in earlier study	
VULNERABILITY	Socio-Economic	Population Density	Extracted from available Secondary Data	Census, 2011	
		Proportion of people living below the poverty line	Extracted from available Secondary Data	MPI Report, NITI-Aayog	
		Access to primary health services	Based on data analysis.	Rural Health Statistics, 2019-2020, GOI	
		Proportion of people who are unhealthy (use infant mortality per 1000 live births)	Extracted from available Secondary Data	NHSRC Report	
		Percentage of children under the age of 5 with stunting (low height-for-age ratio)	Extracted from available Secondary Data	NFHS-5, Maharashtra State Report	
		Proportion of aged population (above 65 years)	Extracted from available Secondary Data	Census, 2011	
	Institutions and Policy	Ability to provide relief and rehabilitation measures for floods and cyclones (number of agencies, including government, private and NGOs)	Extracted from available Secondary Data	giveindia.org	
		Social ingenuity and cohesion	Based on data analysis.	Census, 2011,	
		Adequate number of primary and other health infrastructure	Based on data analysis.	Rural Health Statistics, 2019-2020, GOI	

2.2 Mapping of Climate Risk in Water Supply for Maharashtra Districts

Data pertaining to the different variables considered in the assessment of climate risk in water supply were collected from a wide range of secondary sources of the state government of Maharashtra and central agencies (such as India-WRIS and IMD), and deduced for each of the districts of the state. The normative criteria already defined were used to assign values to each of the variables, which were then normalized as 1, 2 and 3. Based on these values, the final assessment of hazard, exposure and vulnerability was done and further normalized to bring the value of each sub-index into the range of 0.0 and 1.0.

The values assigned to each variable, considered for computation of the sub-indices and the computed values of hazard, exposure and vulnerability, as well as the final risk for different districts, are presented in Annexure 3.

The computation shows that the value of the hazard ranges from a low of 0.46 for Jalna to a high of 0.67 in four districts, viz., Ahmednagar, Dhule, Nashik and Pune. The second highest value of hazard (0.60) was found in the case of 18 districts. The lowest value of hazard was in the case of Ratnagiri and Sindhudurg (0.47). The results are presented in a graphical form in Figure 2.1.

As regards exposure to the WASH systems, it was found to be highest for Mumbai, with a value of 0.72. The second highest exposure was found for Bid district, with a value of 0.67. The lowest exposure was in the case of Jalna district, with a value of 0.46. It can be seen that the variation in the degree of exposure amongst districts is higher than that of hazard. The results are presented in a graphical form in Figure 2.2.

As regards the vulnerability of the communities, six of the districts were found to have the highest value, i.e., 0.81. The districts are Thane, Palghar, Gondiya, Nanded, Buldana, Hingoli, Dhule and Jalna. The vulnerability was found to be lowest in the case of Mumbai (0.63), which faces the highest degree of hazard. The second-lowest vulnerability was found in the case of three districts, viz., Gadchhiroli, Chandrapur and Sindhudurg. In the case of vulnerability, the variation in the values amongst districts (0.81 to 0.63) is much lower as compared to hazard and exposure. The vulnerability values are generally quite high for most districts. The results are presented in a graphical form in Figure 2.3.

The final risk in water supply induced by climate ranged from a low of 0.16 in the case of Sindhudurg to a high of 0.31 for Bid. The second-highest value of risk was for Nanded and Parbhani (0.30 each). Seven districts have a high value of risk (0.27 and above). They are: Thane (0.28), Palghar (0.29) and Gondiya (0.28), and Ahmednagar, Amaravathi, Buldhana, Mumbai and Pune (0.27 each). In order to make the rural water supply systems resilient, we need to focus on reducing the exposure of the systems to hazards and the vulnerability of the communities.

Figure 2.1: Mapping of Hazard in rural water supply in Maharashtra

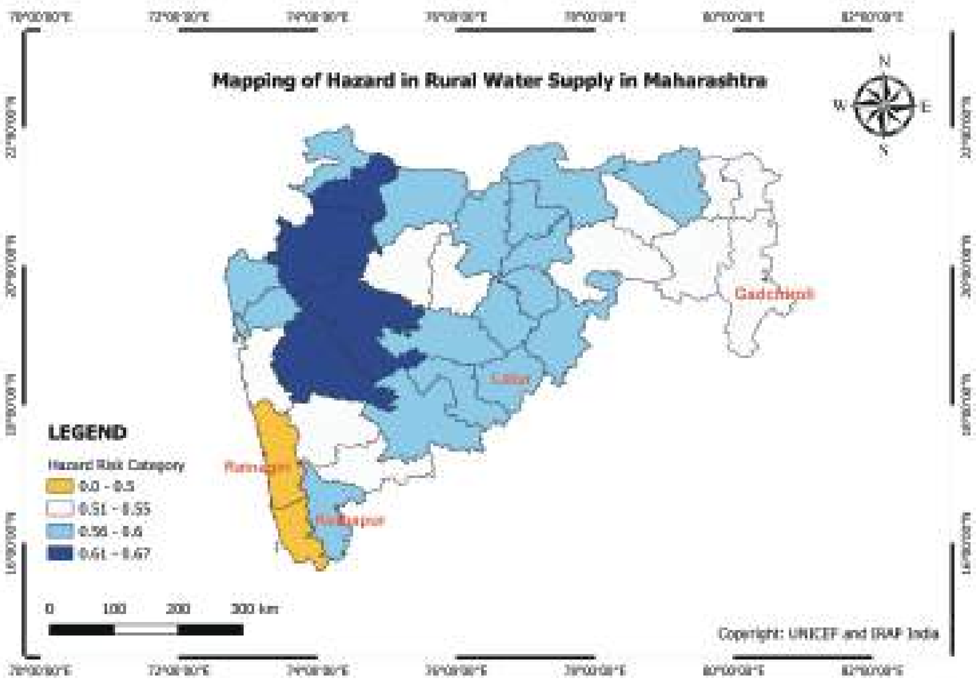


Figure 2.2: Mapping of Exposure in rural water supply in Maharashtra

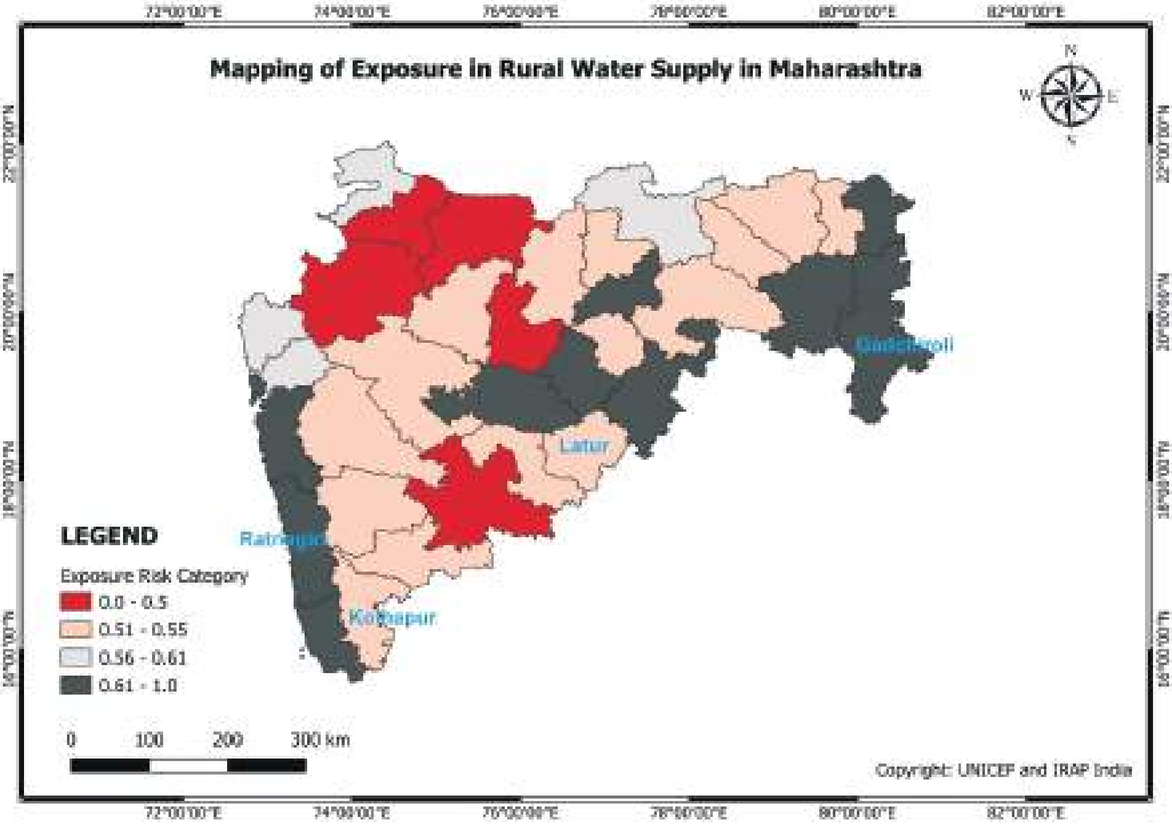


Figure 2.3: Mapping of Vulnerability in rural water supply in Maharashtra

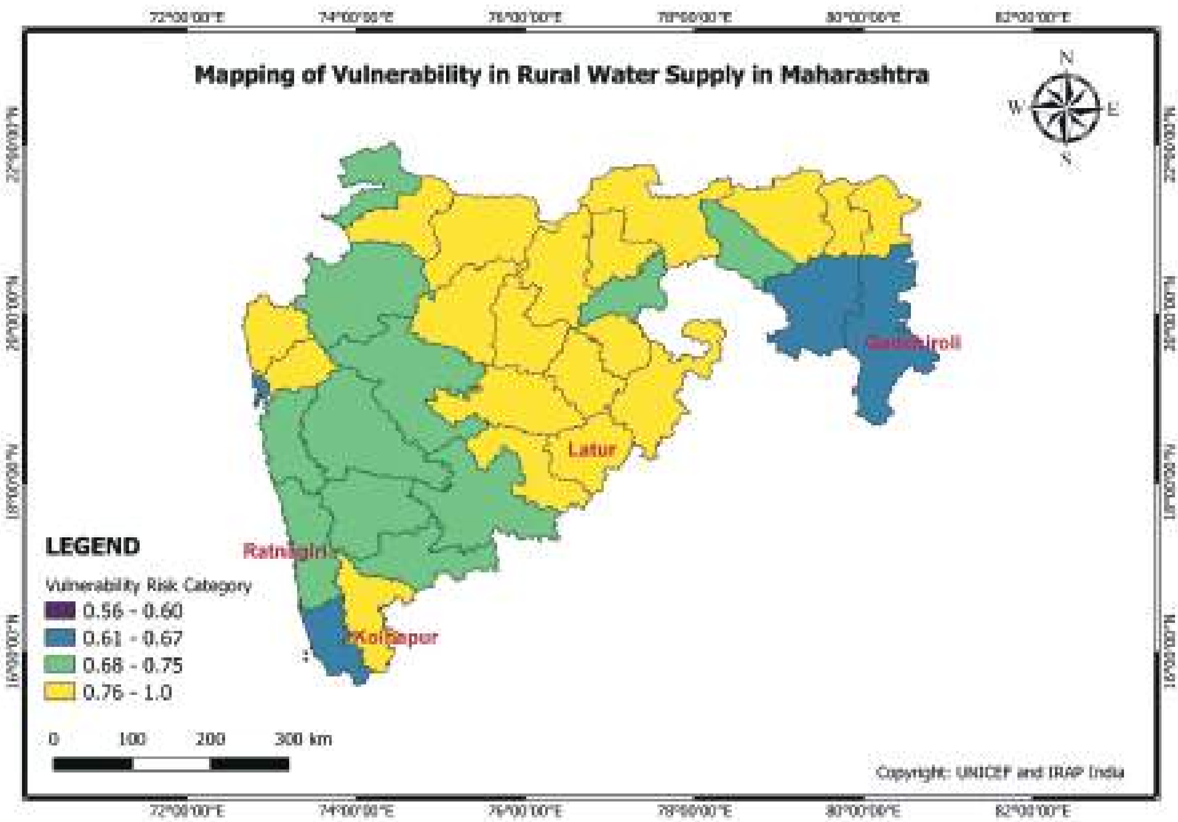


Figure 2.4: Mapping of Climate Risk in rural water supply in Maharashtra

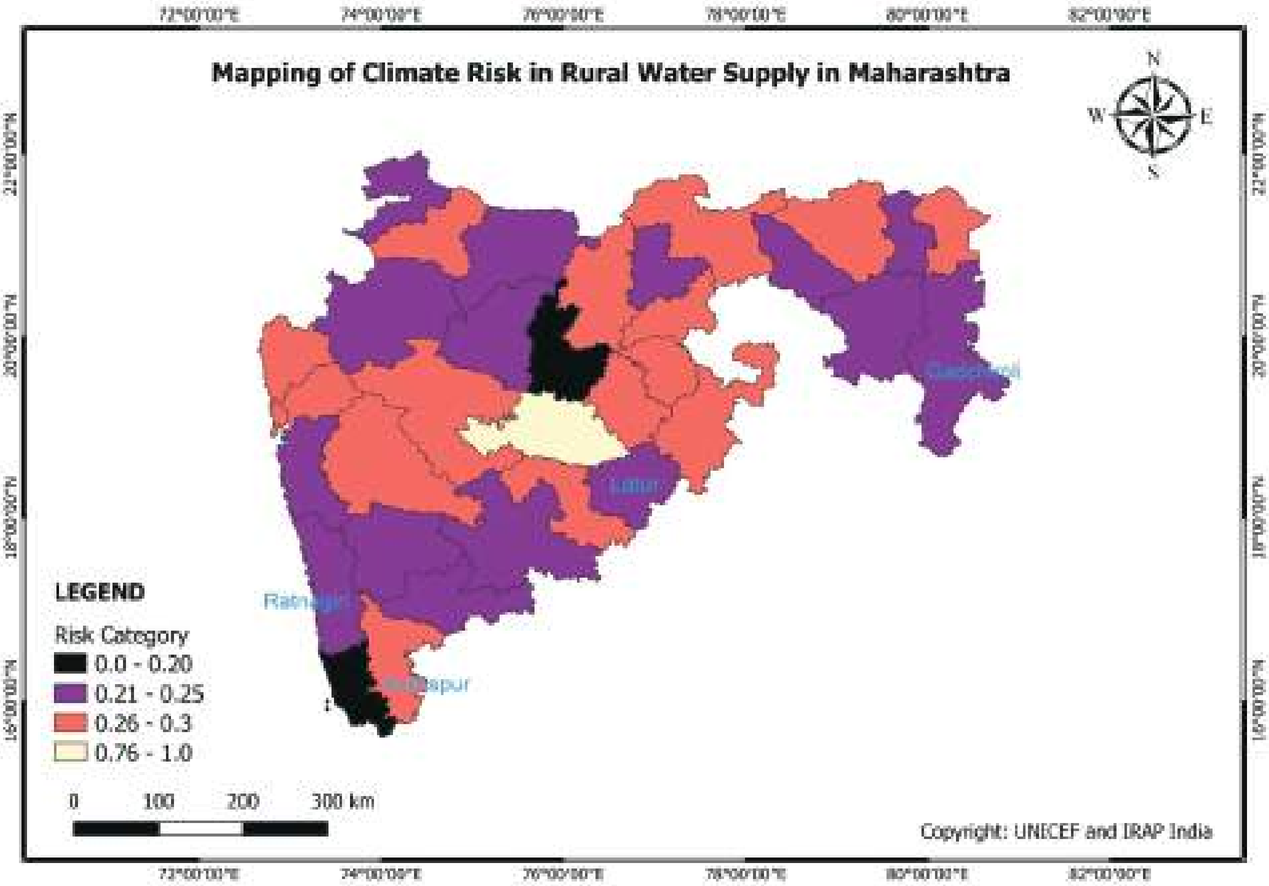


Figure 2.5: Hazard mapping of rural water supply in Maharashtra

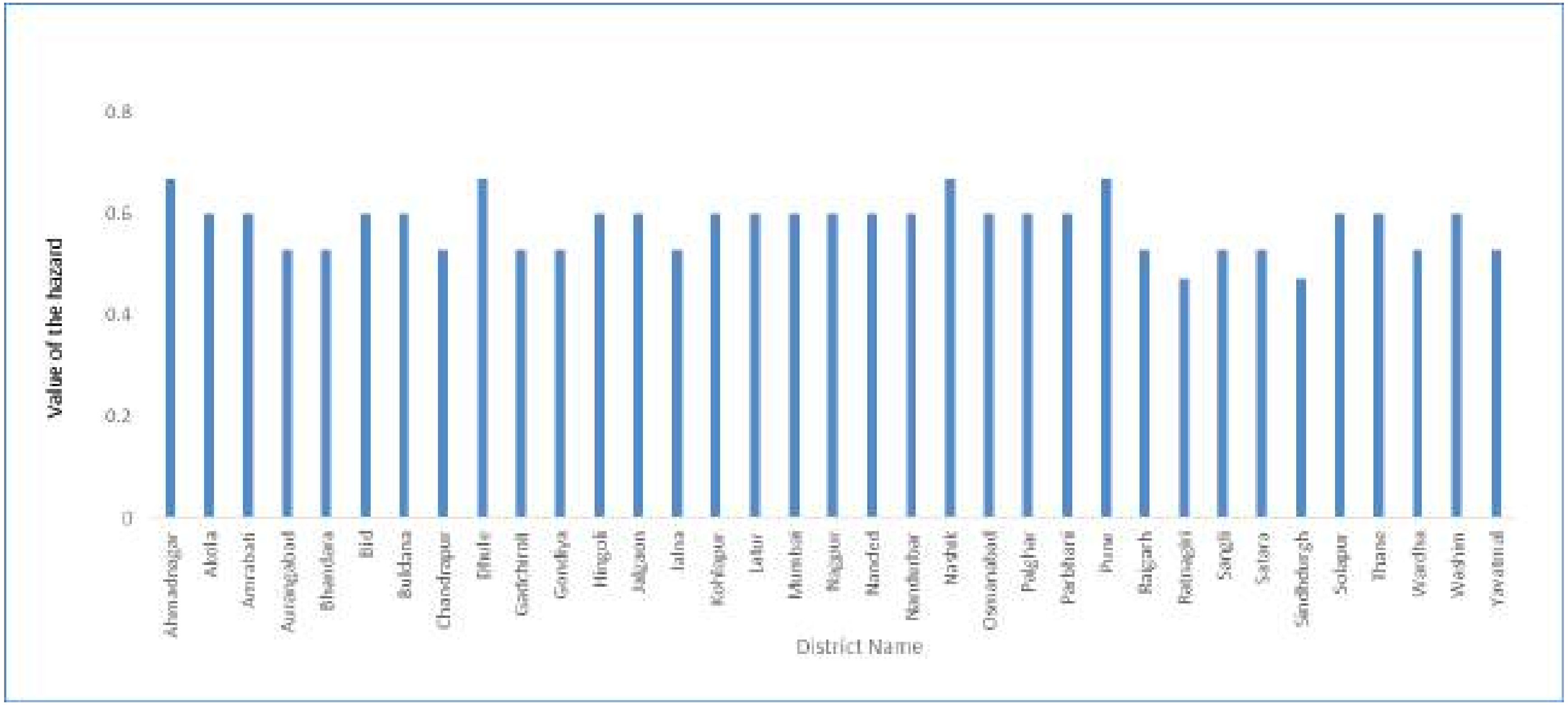
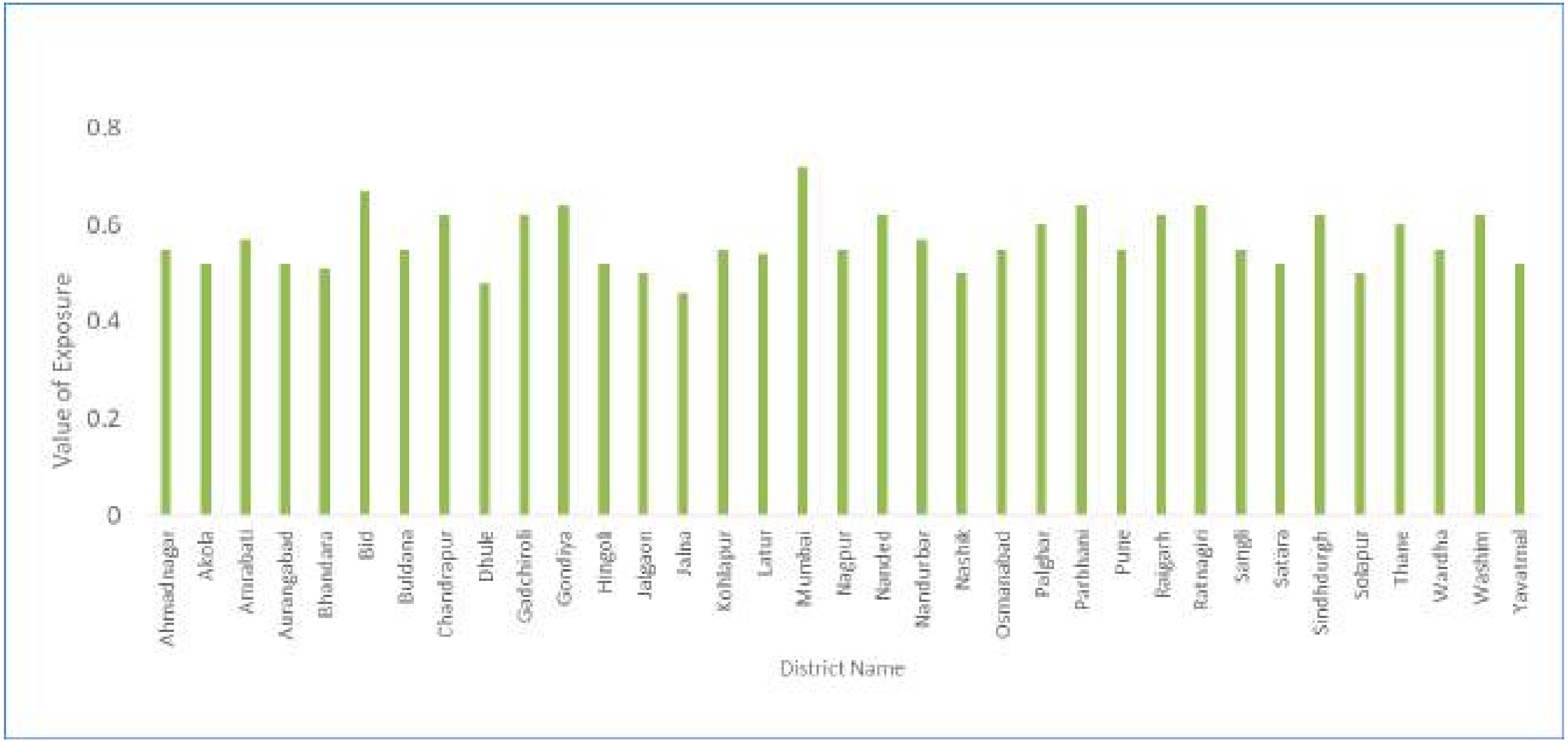


Figure 2.6: Mapping of Exposure in different districts of Maharashtra Figure



2.7: Vulnerability mapping of water supply in different districts of Maharashtra

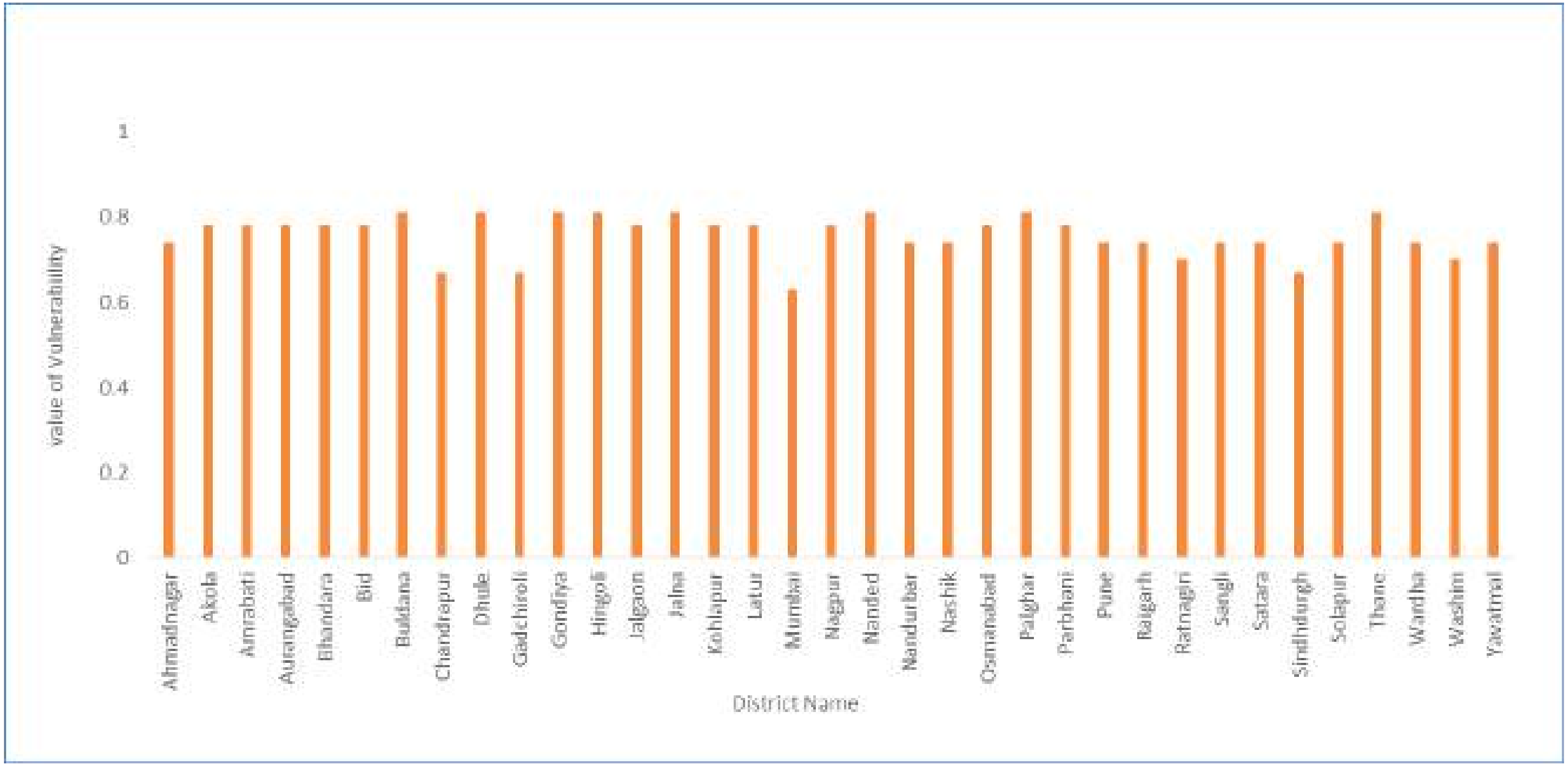
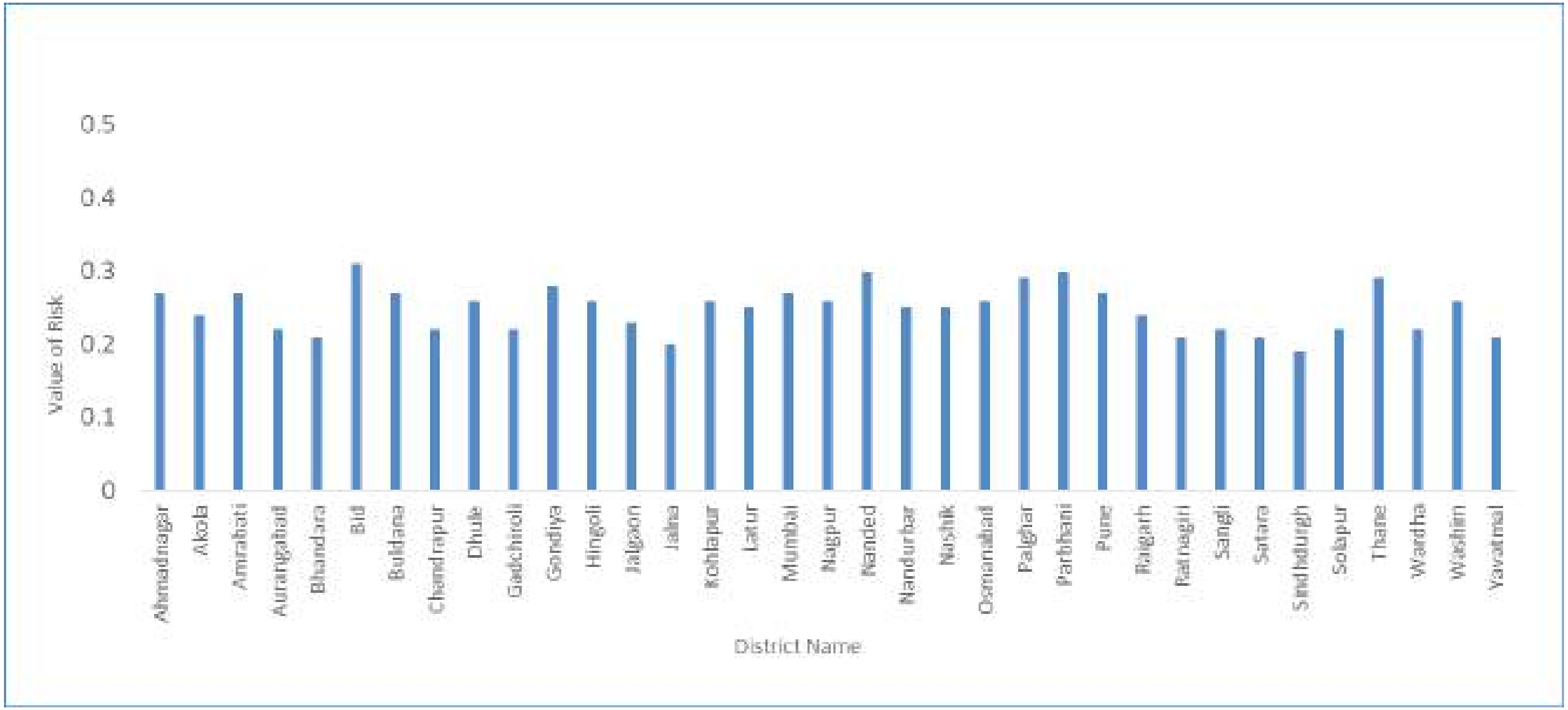


Figure 2.8: Climate Risk Index in water supply of different districts of Maharashtra



2.3 Which Regions in Maharashtra Face a High Risk in Rural Water Supply?

In this study, we first refined the climate-induced WASH risk index developed for the state to look at rural water supply alone, and the mapping of climate-induced water supply risk was carried out for all the districts of the state. Data pertaining to the different variables considered in the assessment of climate risk in water supply were collected from a wide range of secondary sources of the state government of Maharashtra and central agencies (such as India-WRIS and IMD), and deduced for each of the districts of the state. The normative criteria already defined were used to assign values to each of the variables, and normalized as 1, 2 and 3. Based on these values, the final assessment of hazard, exposure and vulnerability was done and further normalized to bring the value of each sub-index into the range of 0.0 and 1.0.

The computation shows that the value of the hazard ranges from a low of 0.46 for Jalna to a high of 0.67 in four districts, viz., Ahmednagar, Dhule, Nashik and Pune. As regards exposure of the WASH systems, it was found to be highest for Mumbai, with a value of 0.72. The lowest exposure was in the case of Jalna district, with a value of 0.46. The variation in the degree of exposure amongst districts is greater than that of hazard. As regards the vulnerability of the communities, six of the districts were found to have the highest value, i.e., 0.81. The districts are Thane, Palghar, Gondiya, Nanded, Buldana, Hingoli, Dhule and Jalna. The vulnerability was found to be lowest in the case of Mumbai (0.63), which faces the highest degree of hazard. In the case of vulnerability, the variation in the values amongst districts (0.81 to 0.63) is much lower as compared to hazard and exposure. As regards the water supply risk, a total of 10 districts had risk values equal to or above 0.27. They are Amravati, Ahmednagar, Bid, Buldana, Gondiya, Mumbai, Nanded, Palghar, Parbhani, Pune and Thane. These are districts where communities are expected to face problems due to disruptions in water supply services caused by hazards such as floods, droughts, cyclones and landslides.

Most of the high-risk districts are in the western Maharashtra, Aurangabad and Nashik divisions. The major source of risk is overall water scarcity and the high frequency of occurrence of meteorological droughts. The dependence on wells (bore wells and handpumps) for rural water supply is very high in these divisions, in spite of the limited groundwater potential of the underground hard rock formations.

One way to reduce the exposure is to switch to more dependable surface water-based systems or to create buffer storage in the local reservoirs that can be tapped during droughts and lean seasons. In regions like Aurangabad, switching to surface water-based schemes would require importing of water from water-abundant Kongan region. The imported surface water can also be stored in the reservoirs of the region during drought years when they are not full. The water stored in reservoirs can be used as buffer during droughts. In western Maharashtra, there is scope for building small reservoirs to create local surface storages using small dams for mini water supply schemes.

The access to good quality surface water (which is free from minerals) from reservoirs for domestic uses and the enhanced dependability of the supplies from such sources would also encourage rural households to go for piped water supply schemes with a tap connection within the dwelling. This would further reduce the exposure of the communities to the disruptions in water supply caused by droughts and reduced rainfall.

3 Effect of Coastal and Riverine Floods, Cyclones and Landslides on Rural Water Supply Schemes and Approach

3.1 Risk to Water Supply Due to Floods, Cyclones and Landslides: Some Theoretical Perspectives

Floods can cause water supply risks through damage to the supply infrastructure, such as pumping machinery, pipeline networks and the protection walls of wells (permanent or temporary), or they can restrict access to water supply sources such as stand posts, handpumps or wells. Floods can also cause contamination of the source water, especially in the case of open wells, ponds and lakes, and sources that tap shallow aquifers. This happens through the entry of contaminated flood waters. The degree of risk associated with poor water supply services due to floods depends on the type of water source and the water supply infrastructure, the age of the infrastructure, what proportion of the population lives in low-lying areas, the community's access to alternate sources of water, and their overall socioeconomic status. The risk will also be dependent on the ability of the local government to issue flood warnings, do flood fighting, and carry out relief and rehabilitation.

Similarly, cyclones can cause damage to water supply infrastructure, mainly due to the excessively heavy rainfall that follows the landfall of the cyclonic storm. The damage can be breakage of infrastructure such as pipelines, damage due to floods that occur as a result of heavy precipitation (as indicated above), power outages, displacement of the local population in the coastal areas affected by floods, and their subsequent relocation to areas that do not have formal water supply and medical services. Here also, the degree of risk associated with poor water supply due to cyclones depends on the characteristics of the water supply sources, the dependence of the source on electricity supply for running, and the socioeconomic conditions of the people who live in the cyclone-prone areas (type of housing, overall economic conditions, degree of poverty, etc.), which affect the exposure of the water supply system and the vulnerability of the communities. The vulnerability will also depend on the local government's ability to respond to the situation by carrying out repairs of the systems and resuming power supply, as well as rescue and rehabilitation work.

In the case of landslides, the damage to water supply sources can be highly localized, though it can at times be permanent. In some cases, the entire source can be permanently damaged, like when an open well used for water supply gets fully filled with slush and mud coming from the slopes. In some cases, there can be a temporary obstruction in accessing the sources, such as wells and handpumps. Piped water supply networks are less likely to be damaged due to landslides. Unlike floods and cyclones, in the case of landslides, the speed with which the local agencies respond to do rescue and rehabilitation work and resume basic services will greatly determine the risks associated with the disruptions in water supply.

3.2 The Effect of Floods and Other Natural Hazards on Water Supply Schemes and Resilience Building: Field Evidence

3.2.1 Ratnagiri Case

Out of the eight GPs covered by the survey, one was affected by a cyclone, three were affected by riverine floods, and four were affected by landslides. The total loss in monetary terms was INR 5000 in the case of the cyclone, INR 2150000 in the case of the riverine floods, and INR 1000000 in the case of the landslides.

3.2.1.1 Impact and Interventions Related to Water Supply During Natural Hazards

In Ratnagiri, during the natural hazards, most of the water sources (mainly wells) become inaccessible; as a result, safe water becomes scarce. Water becomes contaminated and unfit for human consumption. The impacts of different types of natural hazards on the water scheme and source water, as observed during the field study, are as follows:

A) Riverine Floods

In some cases, the drinking water well was completely destroyed and became inaccessible. Steining wall was damaged and the water quality was decorated. Access to safe drinking water was disrupted. The entire supply infrastructure, such as the pump, pump house, main pipeline and in some cases, the distribution pipeline, was damaged. To ensure uninterrupted supply tankers were arranged by Zilla Parishad to reach those villages where no other alternative source of water was present. Retrofitting, like increasing the height of the main supply line up to 12 feet above the maximum flood level or installing the pipeline three feet below the riverbed, has been done by Zilla Parishad. The height of the new well was increased by 4 meters as well.

B) Landslide (Due to and Flash Floods)

In a village, the drinking water well got filled with soil and became inaccessible due to the landslide. The main supply pipeline was broken. Retrofitting of the damaged well was done by clearing all the debris. The height of the protection wall of the well has been increased so that it can be protected from further landslides in the future. After the landslide, a new well was constructed under DPDC funds, and the estimated cost of the new well construction is Rs.100,000. The villagers were shifted to an alternative well.

C) Landslide

In some cases, the source was either partially affected or unaffected. The main water supply infrastructure pipeline of approx. 213 meters was completely destroyed, and a portion of the distribution line was damaged. The main pipeline has been replaced. The well was repaired by the villagers voluntarily, and funds received by the Zilla Parishad were utilized to revive some parts of the scheme, including the pump house and part of the distribution pipeline. The Zilla Parishad funds were not sufficient to completely revive the system, and there are still some contamination issues with the water supplied to the villagers.

D) Cyclones

In a village, the drinking water source was unaffected. The water supply infrastructure was also not affected. But due to cyclones, the water supply service was affected due to the absence of electricity. Tanker water supply was provided for 4-5 days until electricity was restored.

3.2.1.2 Fund Allocation

Except for Bhatye and Ovali, all other Gram Panchayats received funds from the Zilla Parishad. Two Gram Panchayats, Khed and Talsar, have applied for the new water scheme under the Jal Jeevan Mission. Bhatye and Ovali utilized their collected funds for the revival of the scheme. According to the field investigation, the Zilla Parishad was the institution that took on the responsibility of reviving the scheme. However, in two Gram Panchayats took on this responsibility and made every effort to revive the scheme. The time taken to revive the scheme varied from five days to one year.

3.2.1.3 Management of Drinking Water during Floods

During the time of the natural hazards, 75% of the households in the surveyed villages used an alternate well as a source for drinking water. Water collection became a severe problem. 12.5% of the households in the village fetched water from handpumps. Among the households that needed to seek alternative water sources, 2.5% of them were dependent on alternate wells and the tanker well supply. 7.5% of the household population was dependent on aid, as they were relocated to a safer place during floods. Only about 2.5% of households took water from their neighbour's house due to the neighbour having their own private bore well that was unaffected by natural disasters.

3.2.1.4 Impact of the Hazards on Women

Women are especially affected by natural hazards. 34.78% of household women reported that their household workload and time increased after natural hazards. It was very difficult for them to collect water repeatedly and in adequate amounts for drinking and household activities. Only 2.17% of the household population could afford to hire "helpers" to fetch water at the rate of Rs 100/day. 13.04% of the household faced problems only for a few days as the damage caused by natural hazards was less and retrofitting did not take much time. However, 19.57% of the household population faced problems for several months as the damaged caused by natural hazards was higher and retrofitting took time. An estimated 13.04% of households faced no problems even after natural hazards as they had their own private bore well or wells.

Natural hazards can have a major impact on human safety and livelihood. Understanding how villagers' perceptions change towards the usage of water after natural hazards can assist in developing more effective strategies for building resilience against climate change-induced natural hazards. However, field investigations reveal that 80% of the household population had not learnt their lesson even after being exposed to a natural hazard. Only 15% of them have begun to use water wisely, and only 4% have begun to store rainwater for some household purposes. Hence, capacity building and climate resilience communication strategies are key to sensitising communities.

3.2.1.5 Summary of Field Survey

A review of the experience of eight villages that were affected by floods, landslides and cyclones that affected the village water supply system shows that the effects of the hazards were different in different situations, even though the source was the same type. In the case of floods, the contamination of the source with mud and damage to water distribution pipelines occurred. In many cases, the source structure (in this case, the Steining wall of the open well) was also damaged. In the case of landslides, the source became inaccessible or got filled with mud. In one or two cases, the damage extended to the pump house and the pump. In the event of a cyclone, where there was no damage to the source or the water distribution system, a power outage affected the water supply for a few days. The retrofitting of the water supply infrastructure after the occurrence of the hazard included repair of the damaged Steining wall, construction of a new well (when the source was fully damaged) away from the flood-prone areas (away from the river), removal of the debris from inside and surrounding the well, raising the height of the protection well, replacement of the damaged pipelines, rebuilding of the pump house, installation of a new pump, and installing the main pipeline below the river bed or above the high flood level to protect it from floods in the future. In situations where the supply was interrupted for a few days due to a power outage, tanker water supply was arranged.

The findings of the field survey with regard to the impacts of the hazards and the actions taken by the local agencies to restore the water supply services are summarized in Table 2.4. The interventions made by the GP to supply water are presented in a graphical form in Figure 2.9.

From Table 2.4 it is evident that the nature of responses to the natural hazards to revive the working of water supply systems varied from situation to situation, depending on the nature of damage (i.e., whether to the source or the physical infrastructure for tapping water from the source) and the extent of damage. In cases where parts of the infrastructure were damaged (such as pumping machinery, pump house, Steining walls of wells, water distribution pipes), the GPs could undertake the necessary repair. Wherever the chances of recurrence of the hazard exist (as in the case of floods in the rivers, or landslides), retrofitting was done (for example, raising the height of the pipeline above the high flood level in the river or building a Steining wall for the drinking water well). In cases where the entire source was damaged, the local institution (here, GP) went for a new source. In the case of floods and cyclones, the dissemination of vital information (like the flood and cyclone warnings) was also issued by the GP.

Figure 2.9: The Interventions Made by the Gram Panchayat

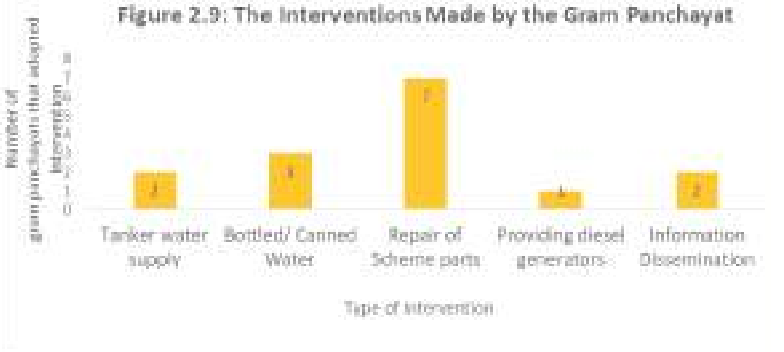


Table 2.4: Types of natural hazards and retrofitting/alternate arrangements made

Sr. No	Name of the Village	Type of Natural Hazard	Type of Water Supply Source	Effect of Flood/ Landslide/Cyclone Hazard on the Source	Effect of Flood/ Landslide/ Cyclone on the Water Supply Infrastructure	Component of the source / scheme that is damaged	Retrofitting Done / Alternate Arrangement
1	Vetoshi	Landslide	Open well	The entire well got filled with soil and became inaccessible due to the landslide.	The main supply pipeline was broken	*Source*: entire well damaged *Supply*: main supply pipeline	Villagers shifted to an alternate functional well for drinking and domestic purposes. Retrofitting of the damaged well was done by clearing all the debris. The height of the protection wall of the well has been increased so that it can be protected from further landslides in the future.
2	Tavsal	Landslide	Open well	The entire well got filled with soil and became inaccessible due to the landslide.	Water supply infrastructure was unaffected	*Source*: entire well damaged *Supply*: unaffected	After landslide, a new well was constructed with DPDC funds, with an estimated cost of Rs. 10,0000.
3	Bhatye	During cyclones, water supply was affected due to the absence of electricity	Open well	Not-affected	Water supply infrastructure was not affected	Due to the power outage, water supply was affected for 4-5 days. No direct impact on the water source/scheme.	Tanker water supply was provided for 4-5 days.
4	Posare	Flood	Open well	The flood completely destroyed the drinking water well, which became filled with rocks. The villagers did not repair the damaged well as it became inaccessible due to a shift in river course.	Entire supply infrastructure, such as the pump, pump house, main supply pipeline, and the distribution pipeline, was damaged.	Both the source and supply infrastructures were completely destroyed.	Tankers were provided to the villagers for 2 months. A new well is being constructed, and the distance between the new well and the river has been increased to 150 m.
5	Tiware	Flood	Open well	Steining wall of the well was damaged, and the source became inaccessible, and the water was also contaminated	Supply infrastructure such as the pump house, pump and the main supply pipeline were damaged.	*Source*: damaged *Supply infrastructure*: damaged	After the flood, the Zilla Parishad raised the height of the main supply pipeline up to 12 feet above the river bed with the help of columns.

Sr. No	Name of the Village	Type of Natural Hazard	Type of Water Supply Source	Effect of Flood/ Landslide/Cyclone Hazard on the Source	Effect of Flood/ Landslide/ Cyclone on the Water Supply Infrastructure	Component of the source / scheme that is damaged	Retrofitting Done / Alternate Arrangement
6	Talsar	Flood	Open well	Steining wall of the well was damaged and the source was contaminated	Supply infrastructure pump house and main supply pump were damaged	*Steining* wall of the well was damaged *Supply*: infrastructure damaged	The village shifted to an alternate community well for 2-3 months. A new pump was installed, and a new pump house was built. Also, the Steining wall was rebuilt. A new main pipeline was installed 3 feet below the river bed. The height of the well wall was increased by 4 meters.
7	Owali	Landslide	Open well	Source infrastructure was unaffected	Supply infrastructure main pipeline of approx. 213 meters was completely destroyed.	*Source*: unaffected *Supply*: main pipeline damaged	Villagers were shifted to an alternate community well, a private bore well and a well for 2-3 months. The main pipeline has been replaced.
8	Adare	Landslide	Open well	Well and the Steining wall was partially damaged.	Supply infrastructure, including the main supply pipe line and a portion of the distribution line, was damaged.	*Source*: partial infrastructure was damaged *Supply*: main supply pipeline and part of distribution pipeline damaged	This village provides an example of a participatory approach to building resilience against the impact of extreme weather events on rural water supply. The well was repaired by the villagers voluntarily, and funds received by the Zilla Parishad were utilized to revive some parts of the scheme, including the pump house and part of the distribution pipeline. The Zilla Parishad funds were not sufficient to completely revive the system, and there are still some contamination issues with the water supplied to the villagers.

3.2.2 The Kolhapur Case

3.2.2.1 Places Where People Were Relocated During the Floods

Relocation after the floods was temporary in Kolhapur. Nearly, 35 per cent of the families were relocated to relative's house living in the nearby areas during floods. Around 33 per cent of the population was shifted to local schools. Two per cent of the population moved to nearby villages or their neighbours' houses and some of them moved to the second floor of the house. Four per cent of the total population moved to neighbouring states like Karnataka, and agriculture farms, and another four per cent did not relocate themselves to any other place.

3.2.2.2 Fund Allocation

In Kolhapur, the Gram Panchayat mainly took on the responsibility to revive the scheme in five villages. In Chikali Gram Panchayat, the Zilla Parishad took on the sole responsibility of scheme revival by covering the costs. However, in two Gram Panchayats, Nursinhwadi and Majrewadi, both the Zilla Parishad and Gram Panchayat shared financial responsibility.

3.2.2.3 Challenges Faced During Floods

About 38 per cent of the schemes (i.e., three out of the eight schemes) faced issues regarding the removal and repair of the motor. The rest of the Gram Panchayat faced issues such as difficulty in repairing and restoring electricity supply, absence of spare motors (one scheme), scarcity of funds (one scheme), submergence of the jack well (one scheme), and inaccessibility of the supply infrastructure (one scheme).

3.2.2.4 Challenges Related with Drinking Water after Floods

During the floods, 47 per cent of the sample households that were relocated to various locations stated that the waiting time was very high and the quantity of water was insufficient for the entire family. Only nine per cent of the sample households reported managing to get the water on time, but the quantity was not sufficient. Two per cent of the households used stored water and did not collect water from anywhere else. However, 42 per cent of the households did not face any challenges.

3.2.2.5 Alternate Source of Water

During the floods, 44 per cent of the sample households were dependent on tanker water and bottled water provided by the Zilla Parishad and NGOs, as they were relocated to a safer place at the time of the floods. Water collection became a severe problem. Around 4% of the sample households in the village fetched water from handpumps. Among the households that needed to seek alternative water sources, 4% and 2% of them were dependent on agriculture bore well and well, respectively. Eight percent of the sample households were dependent on a private bore well. Very few households (around 4%) could manage to obtain water from a tap connection that was unaffected during the flood.

3.2.2.6 Behavioural Change Issues

Natural hazards can have a major impact on human safety and livelihood. Understanding how villagers' perceptions changed towards the usage of water after natural hazards can assist in developing more effective strategies for building resilience against climate change-induced natural hazards. However, field investigations reveal that 92 per cent of the household population has not learnt any lesson, even after being exposed to a natural hazard. Only 2 per cent of them have started using alum to improve the water quality.

3.2.2.7 Summary of the Field Survey Results

The survey in Kolhapur covered eight villages, all of which were affected by floods. In all the villages, the water supply source was a river. In all cases, the effect of flood hazards was on both the source water and the water supply system. The source (river water) was contaminated. The supply system, including the pumping machinery, the switch room and the panel boards, was damaged in most cases. The impact on the communities includes their relocation to temporary relief camps (schools, colleges, sugar factories, etc.). During this time, drinking water was supplied to the relief camps through tankers by the Zilla Panchayat, and in some cases, water bottles were also supplied. The systems were repaired wherever the damage was severe, like in the case of Chikali, where the silt from the jack well had to be removed and the equipment had to be reinstalled at a higher level than the maximum observed floods. The average loss caused by flooding in Kolhapur is about Rs. 421750. On an average, it took 9 days to revive the scheme. Tanker water was provided as an alternate source of water during the period.

The findings of the field survey with regard to the impacts of the hazards and the actions taken by the local agencies to restore the water supply services are summarized in Table 2.5. The interventions adopted by the GPs to supply water are presented in a graphical form in Figure 2.10.

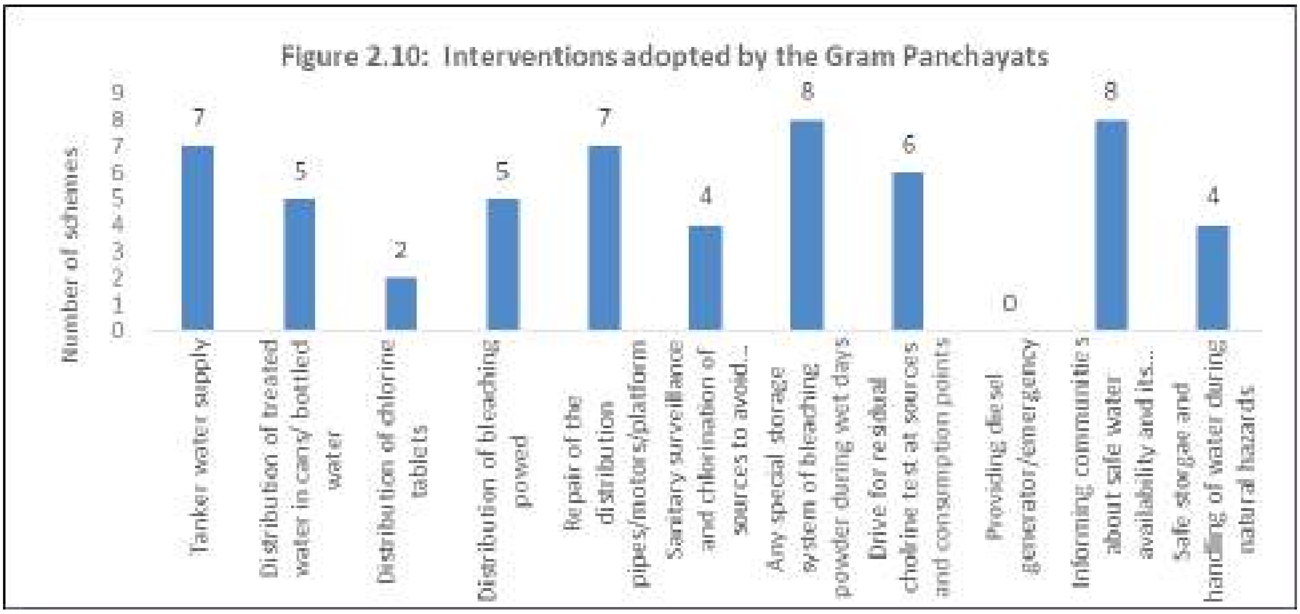


Figure 2.10: Interventions adopted by the Gram Panchayats
Number of schemes
0
1
2
3
4
5
6
7
8
9
7
5
2
5
7
4
8
6
0
8
4
Tanker water supply
Distribution of treated water in cans/ bottled water
Distribution of chlorine tablets
Distribution of bleaching powed
Repair of the distribution pipes/motors/platform
Sanitary surveillance and chlorination of sources to avoid...
Any special storage system of bleaching powder during wet days
Drive for residual choline test at sources and consumption points
Providing diesel generator/emergency
Informing communities about safe water availability and its...
Safe storgae and handling of water during natural hazards

Table 2.5: Natural hazards and retrofitting/alternate arrangements

Sr. No	Name of the Village	Type of Natural Hazard Occurred	Type of Source	Effect on Source	Effect on Supply system	Component of Source/ Scheme That is Damaged	Retrofitting Done/ Alternate Arrangement
1	Ambewadi	Flood	River	River was flooded and contaminated	Supply system: The entire supply system was damaged	Source: The river was flooded and contaminated The panel boards, switches and the pump house got damaged. The pump house, which is about 50 meters away from the river and at an elevation of 20 meter above the river bed, was submerged during the floods.	District administration warned the locals and relocated them to safer places in Kolhapur city, like schools and colleges. For 15 days, tanker water and bottled water were supplied by the Zilla Parishad and some NGOs.
2	Chikali	Flood	River	River was flooded and contaminated	The entire supply system was damaged.	Source: The river was flooded and contaminated. The jack well was submerged in the flood water. Motors and starters were damaged. There was an interruption in the water supply for 8 days.	Tankers and water bottles were provided by the Zilla Parishad for a few days. The Gram Panchayat hired 3 generator sets. Silt from the jack well was removed. All the equipment has been installed 2 meters above the 2021 flood level. Multi-storied houses have been constructed so that, during a flood situation, the 2nd or 3rd floor could be used.
3	Nrusinhawadi	Flood	River	River was flooded and contaminated	Supply system: The supply system was damaged.	Source: The river was flooded and contaminated. The switch room, which is 50 meters away from the river and at an elevation of 6 meters, got submerged during the floods.	Tanker water was supplied for four days. The villagers also fetched water from private bore wells.
4	Majrewadi	Flood	River	River was flooded and contaminated	Supply system: The supply system was partially damaged.	Source: The river was flooded. 10 HP pumps and starter were damaged.	The villagers migrated to their relatives' place and took shelter in the sugar factory in the nearby area. Tanker water was supplied for 1 month.

Sr. No	Name of the Village	Type of Natural Hazard Occurred	Type of Source	Effect on Source	Effect on Supply system	Component of Source/ Scheme That is Damaged	Retrofitting Done/ Alternate Arrangement
5	Rajapur	Flood	River	River was flooded and contaminated	Supply system: The supply system was partially damaged, and electricity lines were submerged.	Source: The river was flooded The electricity line was submerged, affecting the water supply. The starter was also damaged	It took 10 days to repair and restore the system.
6	Rendel	Flood	River	River was flooded and contaminated	Supply system: The supply system was damaged.	Source: The river was flooded. The jack well was totally submerged in the flood water. Two 75 HP pumps were damaged	The village was partially affected. Families in low-lying areas were shifted to safer places. Water was supplied to the camp by 6 tankers, of which 4 were hired and 2 were owned by the Gram Panchayat. NGOs provided packaged drinking water.
7	Kabnur	Flood	River	River was flooded and contaminated	Supply system: The supply system was damaged.	Source: The river was flooded. Water supply was disrupted due to damage to the pumping machinery and panel board.	The Gram Panchayat has proposed a Water Supply Scheme under the Jal Jeevan Mission.
8	Chandur	Flood	River	River was flooded and contaminated	Supply system: The supply system was damaged.	Source: The river was flooded. The jack well was submerged, and the motor and panel board were damaged.	Families were shifted to a nearby school in the village. Water was provided to the relief camp with the help of tankers. Water was brought from private bore wells free of cost.

3.3 Review of International Experience with Hazard Resilient Water Supply Schemes

Extreme weather events, including floods and droughts, affect the operational efficiency and sustainability of water supply, drainage and sewerage infrastructure, and wastewater treatment services and threaten their protection of public health and the environment (WHO, 2011). Adverse effects of climate risks on access to potable water are being increasingly acknowledged in Sub-Saharan Africa. Resilient infrastructure supported by appropriate governance arrangements is therefore central to water security during these extreme weather events. Water legislation and infrastructure designs do not adequately take into consideration the effects of extreme events on access to potable water, making water security a challenge in rural Malawi (Joshua et. al., 2022).

Recent extreme weather events and linked natural disasters in Himachal Pradesh, India (impact exacerbated by anthropogenic activities) appear to be consistent with climate change-driven increase in temperatures and varying distribution and intensity of precipitation. Therefore, enhanced resilience to climate change-linked and natural disasters, including risk-informed system operations and maintenance, is critical for ensuring proper service delivery in rural water and sanitation. The Climate Resilience approach will result in improved rural water supply and sanitation. Also, institutions and the capacity of stakeholders for rural water supply and sanitation services will be strengthened (CDRA, 2022).

The new systems are designed to increase resilience and water security in the face of climate change while also minimizing negative environmental impacts (MACS Energy & Water, 2022). This is achieved, for instance, by using more reliable water sources, avoiding water over-abstraction and safeguarding minimal environmental river flows while also considering the changing water availability and demands (MACS Energy & Water, 2022).

Water infrastructure systems are vulnerable to different natural disasters such as earthquakes, landslides, etc. (Soliman et al., 2019). It is recommended that developing countries focus on building resilient water supply systems to enhance the sustainability of water resource usage (Soliman et al., 2019). Water supply must be characterized by its reliability and effectiveness in supplying high-quality water for 24 hours on a daily basis. External distractions forces can act on a water supply system, reducing the supply reliability (Soliman et al., 2019).

Climate change presents a major threat to water and sanitation services. There is an urgent need to understand and improve resilience, particularly in rural communities and small towns in low- and middle-income countries that already struggle to provide universal access to services and face increasing threats from climate change (Howard et al., 2021).

More frequent and extreme droughts were experienced in rural African Communities (MacAllister et al., 2020). Boreholes accessing deep (>30 m) groundwater performed best during the drought (MacAllister et al., 2020). Prioritizing access to groundwater via multiple improved sources and a portfolio of technologies, such as hand-pumped and motorised boreholes, supported by responsive and proactive operation and maintenance, increases rural water supply resilience (MacAllister et al., 2020).

Climate change threatens drinking water safety in rural areas in multi-dimensional ways (Kohlitz et al., 2020). In applying adaptation, vulnerability, and resilience analyses side-by-side in a case study in Vanuatu, the contributions were demonstrated that different approaches can make to problematizing climate variability and change for rural drinking water safety in developing countries (Kohlitz et al., 2020). The adaptation approach raises the importance of recognizing water quality risks created by present and future climate hazards (Kohlitz et al., 2020). The vulnerability approach points out how social processes cause climate-induced water safety issues more for some than others (Kohlitz et al., 2020). The resilience approach highlights the value of enabling people to have flexibility in how they access safe water under unpredictable climate conditions and the need to sustain water resources (Kohlitz et al., 2020). These complementary approaches can and should be employed together when considering drinking water safety management under climate change (Kohlitz et al., 2020).

There is a growing consensus around the need to build the resilience of water supplies to protect public health from the effects of climate change. The HTIW (How Tough is WASH framework) was applied to community-managed water supplies in Ethiopia and Nepal and was found to be quite effective. The application of the framework to 35 water supplies revealed critical weaknesses in service delivery and low to moderate resilience in most systems. The factors that contributed to the low resilience of these systems were a lack of financial and technical support for water supply managers and inadequate source protection measures (Nijhawan et al., 2022).

3.4 Methods of Improving Resilience of Water Supply Systems to Floods and Other Hazards in Maharashtra

Based on a review of international literature dealing with climate-resilient water supply and wastewater treatment systems, a few measures for improving the climate resilience of rural water supply schemes in

Maharashtra are proposed here, while keeping in view the types of water supply systems that exist, the overall socioeconomic conditions in the rural areas and the institutional set-up that exists for governing and managing the rural water supply schemes.

3.4.1 Making Water Supply Systems Resilient to Floods

Following are some of the techniques recommended depending on the type of water supply system:

Water Storage Tanks: Floods may cause damage to the tanks, which generally happens at unsuitable sites for tanks. Inadequate construction techniques may also lead to the damage of storage tanks. Good concreting techniques will surely increase the resilience of the storage tanks during the floods. Before constructing the storage tanks, natural drainages and flood detention areas must be avoided.

Hand pumps: By constructing a raised slab above floodwater level, flooding can be avoided. Where flooding is inevitable, the risk may be reduced by sealing the manhole, fixing the hand pump securely to a slab that has been properly cured, choosing a hand pump with spout above the maximum water level, and using a closed rather than an open system. Training local people to repair and maintain hand pumps as well as keep spare parts will reduce dependence on external expertise and resources, which will be limited.

Boreholes: In order to have a resilient bore well system, the site for the same should be correctly selected. By having a deeper foundation, erosion of aprons may be avoided. The construction of raised slabs and a mound above floodwater level will also lead to better resilience in the system during floods. Watertight casing should also be constructed above the water table.

3.4.2 Making Water Supply Systems Land-Slide Resilient

Landslides represent a major threat to human life, property and constructed facilities, infrastructure and the natural environment in most mountainous and hilly regions of the world. Aizawl and Shimla face an elevated threat of landslides due to specific geologic, seismic, climatic, and development conditions that exacerbate landslide hazard conditions. (GeoHazards, 2020). Table 2.6 provides a list of specific hazards posed to different types of water supply and wastewater infrastructure by earthquakes and landslides, as well as the challenges and potential solutions and actions that can make the water supply systems, which are exposed to the hazards, resilient.

[2] Good concreting involves: Proper mixing of concrete, compacted properly to prevent it from being porous, and sufficient curing of concrete to develop its full strength.

Table 2.6: Water supply challenges during natural hazards and resilient action

S. No	Description	Challenges	Solutions/Resilient Actions
1	Numerous pipe breaks all at once in the distribution network (i.e., from shaking, settlement, and landslides)	100s to 1000s of pipe breaks are anticipated based on the experience of the GHI/GHS team, given the water systems' piping and the terrain exposed to a magnitude 7-8 earthquake. This number of pipe repairs was observed in the 1994 Northridge, 2008 Wenchuan, and 2015 Nepal earthquakes where similar pipeline materials were used, just as examples.	a) Stockpile materials (pipes, clamps, e tc.) that can be used for rapid repairs (it is best if the type and number of materials are based on an analysis of expected damages). This allows water systems to have materials on hand after a damaging earthquake to potentially initiate repair work right away; b) Develop plans and include them in an emergency response plan for wetting the network, identifying leaks, making repairs, and disinfecting pipelines; c) Perform a landslide hazard assessment to know where landslides are located and most likely t o occur. Use the finding s to preliminarily mitigate or plan how to repair the water system in these places (sufficient mitigation designs). These plans should be included in the emergency response plan; d) Add automatic isolation valves that sense rapid f low and a lowering of pressure (this may have the most impact on transmission lines, see the following section, and may be limited in use in distribution areas that do not provide a continuous water supply); e) Add flexible connections at interfaces to ta nks, reservoirs, and pump stations. Rigid connections can break during earthquake shaking; f) Add instrumentation and monitoring to help identify damage; g) Utilize seismic resilient pipelines. Examples include butt-welded steel, high- and medium -density polyethylene with electro -fused joints, and earthquake-resistant ductile iron.
2	Transmission Pipeline exposed to landslide movements	Of the numerous earthquake-induced pipe breaks, several are expected on transmission pipelines, which will remove essen tial water supplies. Transmission pipelines are also highly exposed to individual landslide events, even without an earthquake or an extreme monsoon event.	a) Check the pipeline's structural capacity to resist forces resulting from permanent ground movement. There are methods for addressing needed structural capacity for anticipated permanent ground movements; b) Identify how to increase pipeline capacity to withstand ground movement based on results of the above action by either increasing strength and abi lity for joints to not separate, and/or adding flexibility into the pipeline; c) Identify areas prone to land sliding and engineer solutions for crossing these areas (i.e. , avoidance or bridging); d) Utilize points c and g in the above row.

S. No	Description	Challenges	Solutions/Resilient Actions
3	Pumping stations, tanks, reservoirs, and other structures vulnerable to earthquake shaking	Pumping station, tank, and reservoir structures are vulnerable to damage from earthquake shaking. The damages commonly occur in roof connections, floor anchorage, undersized structural components, and buildings lacking an adequate lateral force resisting system. Load-bearing (unreinforced) masonry and non-ductile concrete frame structures commonly have poor seismic performance. Certain features, such as very tall walls and gables in masonry buildings, and soft storeys in concrete buildings, make these structures more vulnerable to damage.	a) Add flexible connections for pipelines at interfaces. Rigid connections can fail during earthquake shaking; b) Analyse structures to determine if strong earthquake shaking will result in collapse or damage such that they cannot be entered or used (design of the building code is inadequate to ensure structures are usable following a design-level event). Use a prioritization scheme as outlined in Item 8a below; c) Anchor equipment, cabinets, and material storage units so that they do not injure workers, result in damage, damage any stored contents, or release any dangerous materials.
4	Treatment systems and equipment vulnerable to earthquake shaking, landslides and sloshing	Damages can occur from shaking, permanent ground movements and water sloshing.	a) Add flexible connections for pipelines at interfaces. Rigid connections can fail during earthquake shaking; b) Analyse structures to determine if strong earthquake shaking will result in collapse or damage such that they cannot be entered or used (design of the building code is inadequate to ensure structures are usable following a design-level event). Use a prioritization scheme as outlined in Item 8a below; c) Anchor equipment, cabinets, and material storage units so that they do not injure workers, result in damage, damage any stored contents, or release any dangerous materials; d) Evaluate if specialized equipment is vulnerable to sloshing damage; e) prepare repair plans and include them in an emergency response plan; f) Identify methods for bypassing treatment plants to provide some water supply, even if the quality is poor.
5	Limited gravity water supply; High resilience on energy for pumping	The strong dependency on energy for pumping requires resilience in other systems for water system resiliency.	a) Add a fuel-based (e.g., diesel) pumping system as emergency backup if it does not already exist, and maintain fuel supplies; b) Maintain emergency fuel contracts so that emergency supplies can be guaranteed; c) Strengthen electric power substations (anchor transformers and other equipment, design bushings for flexibility, etc.); d) Work with the electric power company to ensure a seismically reliable system.

Source: Information sourced from GeoHazards, 2020

3.4.3 Making Water Supply Systems Cyclone-Resilient

The volume of scientific evidence that shows the effect of climate change on the frequency of tropical cyclones is inconclusive. Projections of changes in cyclone frequency are highly uncertain. Some experimental modelling of tropical cyclones in the western Pacific projected decreases of 20%-28%. However, increases in the number of tropical cyclones tracking close to the coast of the PRC (People's Republic of China) have been observed, reportedly due to a northward shift in the dominant region for the formation of cyclones in the West Pacific (ADB, 2015). Nevertheless, from the point of view of water supply, what is relevant is that cyclones are followed by very heavy rains and often floods and landslides. Following are some of the strategic and practical measures for building resilience:

3.4.3.1 Strategic Measures

Promoting Risk Reduction: The promotion of risk reduction measures, both structural and non-structural, requires the following: (i) Development of an appropriate system of incentives and disincentives; (ii) Increased awareness regarding risks; (iii) Accurate cost-benefit information of potential risk-reducing actions; and (iv) Political and public support.

Political will is essential to provide the leadership required, create the policies and legislative framework, implement regulations (pertaining to laying power lines, water supply systems and construction of over-head water storage tanks), identify and prioritize risk reduction measures, and allocate a sufficient budget. Opportunities for public inputs into the process are usually provided- either through public discussions or by posting draft documents for public review. Public participation is considered essential to ensure buy-in and support for risk reduction measures.

Providing Incentives (Payment for Environmental Services or Eco-Compensation Mechanisms)

Payment for environmental services (PES) has been promoted as an incentive for resource conservation since the 1980s. PES is most commonly used for water quality protection and watershed conservation. Costa Rica's adoption of PES as a national strategy for forest conservation has been regarded as highly successful. Viet Nam recently began pilot implementation of PES to sequester carbon and protect forest resources.

Establishing Links with Climate Change Adaptation: Linkages between water related disasters (WRD) and adaptation strategies are being made by international organizations, NGOs, and multiple governments. Despite recognition of the uncertainty about the degree and scale of the impact of climate change on water resources, there is recognition of the need to incorporate available information from climate modelling and to follow adaptive management strategies. For instance, the high intensity runoff caused by intensive rains occurring in the aftermath of a cyclone landfall can be modelled to understand the magnitude of floods caused by cyclones.

Strengthening Linkages Between Water-Related Disaster Management and Integrated Water Resources Management: WRD planning using IWRM principles adopts the river basin as the planning unit for land, water and other natural resources. Consideration of water availability includes groundwater as well as surface water, particularly given the importance of groundwater systems during drought periods. Plans have a clear definition of the outcomes that are desirable (i.e., they do not start from a proposed solution), apply rigorous, scientific analysis, provide a comprehensive assessment of planning options, incorporate appraisals based on the triple bottom line of sustainable development (incorporating economic viability, social equity, and maintaining environmental quality), perform cost-benefit analysis, and are prepared with stakeholder involvement that extends outside the government sector. Flood management plans should follow the concepts of integrated flood management.

Increasing Participatory Management: The roots of inadequacy in natural resources management, including water, lie not only in poor financing or technology or natural scarcity of water but also in "poverty, inequality, and unequal power relationships, as well as flawed water management policies that exacerbate the impact of water-related disasters. Providing opportunities for water user associations, NGOs, and community-based associations to become involved in strategic planning and implementation of disaster reduction is a commonly accepted approach to identifying vulnerabilities, reducing risks, improving monitoring, and coordinating a quicker response during a WRD.

Loss Estimation: Loss estimation is an important factor in risk assessment and in making decisions about managing risk. The accuracy of loss estimates varies greatly both within and between countries, being subject to local capacity and knowledge of underlying processes. Loss estimates are reported to be better and more accurate for larger events, such as disasters, because of greater interest, a larger number of estimates, and the aggregation of estimates.

To estimate the losses, a globally accepted tool named PDNA (Post Disaster Needs Assessment) is used for assessing damage and loss following a disaster. Through this tool, governments can assess the impact of disasters, identify recovery needs, estimate recovery costs, and define a strategy for recovery. This tool looks at 'recovery from a development perspective'. PDNA is initiated by the State Disaster Management Authority (SDMA). Depending on the nature and scale of the disaster, PDNA's scope is decided. After following all the key steps such as drafting a TOR, finalising a timeframe, involving the participation of various government sectors, collecting data, interviewing local communities and report writing. Results are presented to the SDMA and the state government. Based on the extent of the disaster, the government can allocate the resources sector-wise. The time and resources required will be determined by the implementing agency concerned with the sector (NDMA, nd).

A critical aspect of recovery and reconstruction is the implementation of key recovery interventions. These recovery interventions are critical to household and community recovery. Based on the loss assessment, these interventions can be classified into the following thematic areas: 1) physical recovery: housing, physical and community infrastructure; 2) economic recovery: agriculture, livelihoods, businesses and enterprises, and markets; 3) social recovery: health, education, gender and social inclusion; and 4) cross-cutting issues: disaster risk reduction, environment, social protection, and governance (NDM, nd).

3.4.3.2 Practical Measures

1. **Backup Diesel Generators:** At the time of cyclones, when the main power supply is damaged, a backup diesel generator will be helpful to supply water to the households through the scheme/source.

2. **Wells Covered with Reinforcement:** The open wells may be provided with enough reinforcement to withstand the cyclone impacts such as heavy winds, intensive showers and uprooting of trees. They must also be provided with protective mesh so as to prevent falling tree leaves and plastic objects. This way, the water source becomes cyclone-resilient.

3. **Underground Pipelines for Water Supply:** It is also recommended to have underground pipelines (manufactured with resilient material such as rubber pipes, wherever technically feasible) to withstand the cyclone impacts and also act as a reliable medium to supply/distribute water safely to the target areas. In cases where this is not possible, the pipelines should be kept above the highest flood level, especially when they have to cross rivers that carry flood waters from cyclones.

4. **Underground Electric Lines:** During cyclones, over ground power lines are generally damaged, causing a power outage. It is recommended that underground pipelines be installed for power supply and to safely overcome the cyclone impacts.

5. **Creating Small Water Storage Structures at the Household Level:** it is recommended that the individual households in the cyclone-prone areas have independent water storage structures that are capable of storing water for domestic uses, sufficient for 2-3 days. This will give enough time for the formal water supply systems to be restored in case of power failures or the water supply operators not being able to attend work.

6. **Designing Reservoirs for Floods Caused by Cyclones:** The water supply reservoirs planned in cyclone-prone areas should be designed for evacuating the peak flood discharges that occur as a result of the intense rains that occur as the effect of severe cyclones to ensure their safety.

However, all the above-mentioned measures will work only for areas that are not directly hit by the cyclones and where evacuation of people and livestock is not required.

3.5 Funding Envelope and Proposed Institutional Arrangements

There are several central schemes on rural employment, groundwater management, water use efficiency in agriculture, rural drinking water security, and water quality management whose funds can be tapped for undertaking a number of activities that would help improve water resources management, ground water quality management, and the resilience of water supply schemes against natural hazards such as floods and landslides by supporting activities and interventions that improve the conditions that contribute towards these objectives.

However, in this section, we will discuss the schemes that contribute to the larger objective of climate resilience in rural water supply schemes, the activities under those schemes that actually contribute to achieving the objectives, the components of the schemes that are relevant, and the funds available under them in the state.

MGNREGS

The first and foremost scheme available to every state, and therefore Maharashtra, is the National Rural Employment Guarantee Scheme. There has been an annual budgetary allocation from the Central Government for this scheme since 2006 for all the states. There are many activities related to water conservation, flood control, drinking water provisioning, the renovation of traditional water harvesting structures, and water harvesting available under MGNREGA for which funds are allocated.

Out of these, the funds for flood control, protection and renovation of traditional water bodies can be used in the flood- and cyclone-hit areas of Maharashtra to make the rural water supply schemes more hazard-resilient. This will be mainly for increasing the storage capacity of the local water bodies that are silted up through desilting, construction/renovation of the waste weir, and desilting of the natural drains that are clogged up for draining out the flood waters.

The total amount of funds available under MGNREGA in the state of Maharashtra for the financial year 2021-22 was around INR 2116.21 crore under the four heads mentioned above (i.e., flood prevention and control, renovation of traditional water bodies, water conservation and water harvesting, and drinking water supply). However, only INR 377.577 crore was spent for these activities put together. Activities for another INR 460 crore were either pending or suspended. The activities against the funds to the tune of INR 1317.39 crore were not taken up, though approved. While the district Panchayats and the GPs remain the implementing agencies for this scheme, they need to be supported technically for designing interventions by the agencies concerned with rural water supply such as GSDA and Maharashtra Jeevan Pradhikaran (MJP).

Atal Bhujal Yojna

The Atal Bhujal Yojana (ABHY) is another central-sector scheme for facilitating sustainable groundwater management with an outlay of INR 6,000 crore. Out of this, INR 3,000 crore comes as a loan from the World Bank and INR 3,000 crore as a matching contribution from the Government of India. The scheme has two components: a) an institutional strengthening and capacity-building component; and b) an incentive component. The State of Maharashtra is one of the states selected for implementing the scheme based on a number of criteria, including degree of groundwater exploitation and degradation, established legal and regulatory instruments, institutional readiness, and experience in implementing initiatives related to groundwater management.

The total allocation for Maharashtra under this scheme is INR 925.71 crore, of which INR 737.5 crore is available for incentivizing various interventions, such as public disclosure of ground water data/information and reports; preparation of community-led water security plans; public financing of approved water security plans through convergence of ongoing/new schemes; adoption of efficient water use practices; and checking the rate of decline of groundwater levels.

The funds under the two heads, viz., preparation of community-led water security plans and public financing of approved water security plans through convergence of ongoing/new schemes, can be used to support projects to strengthen existing bore well-based schemes in areas where they are performing poorly during peak summer months, which can include artificial recharge schemes wherever they are feasible with favourable geohydrology and availability of surplus runoff. A good part of the funds should be used for carrying out hydrological and geohydrological investigations, scientific planning and the technical (hydraulic) design of the schemes so that the schemes perform efficaciously.

To complement this, the funds available under water use efficiency improvements can be channelized to support farmers in adopting efficient water use technologies such as drip irrigation and mulching for crops in areas where the intensity of groundwater use for irrigated agriculture is very high. The basic aim should be to reduce the pressure on the local aquifers for irrigation so as to improve the sustainability of the drinking water sources that tap water from the same aquifer.

The precondition for supporting such interventions should be that the farmers would not expand the area under irrigation after adopting these technologies. However, this would require behaviour change with regard to the use of groundwater, and such behavioural change can only be affected through the use of institutional mechanisms such as the enforcement of water entitlements or water use rights among the well owning farmers. The official rights to groundwater are still not well defined in India. De facto, the rights to use groundwater currently lie with the individuals or groups that own the overlying land. Though the use of such mechanisms was envisioned in the Maharashtra Water Resources Regulatory Authority Act (2005), they have not been implemented.

The agencies that implement these schemes in Maharashtra are the GSDA in the case of village water security plans and groundwater recharge schemes, and the State Agriculture Department in the case of the promotion of efficient irrigation technologies.

Jal Jeevan Mission

The Jal Jeevan Mission, whose goal is to provide piped water supply for every household in the rural areas of the country, has the following components:

- Development of in-village piped water supply infrastructure to provide tap water connections to every rural household
- Development of reliable drinking water sources and/or augmentation of existing sources to provide long-term sustainability of the water supply system
- Wherever necessary, bulk water transfer, treatment plants and a distribution network to cater to every rural household
- Technological interventions for the removal of contaminants where water quality is an issue
- Retrofitting of completed and ongoing schemes to provide FHTCs at a minimum service level of 55 lpcd

- Greywater management
- Support activities, i.e., IEC, HRD, training, development of utilities, water quality laboratories, water quality testing & surveillance, R&D, knowledge centres, capacity building of communities, etc.
- Any other unforeseen challenges emerging due to natural disasters/calamities, which affect the goal of providing FHTC to every household by 2024, as per the guidelines of the Ministry of Finance on Flexi Funds

It is quite clear from the list of specific components that funds from the Mission can be used for a wide range of activities related to rural water supply, from augmentation of existing water sources to providing new sources of water supply, including those that involve bulk water transfers, installing technologies for removal of contaminants from the source water, retrofitting of existing schemes to provide FHTCs to achieve minimum service levels, the development of reliable water sources, and capacity building of institutions for Water Quality Management. More importantly, it provides scope for sourcing funds to achieve these objectives from different schemes and programmes.

However, the components that are relevant here for improving the climate resilience of water supply schemes are the last component, which is kept for dealing with unforeseen challenges arising out of natural disasters. These funds should be handled by the MJP.

Out of the total outlay of INR 3258 crore from the centre and INR 2899 crore from the state (i.e., 6157 crore) since the inception of JJM, the total expenditure so far is only INR 1071 crore from central funds and INR 1194.98 crore from state funds. One major issue is the shortfall in the allocation, which is due from the state and is estimated to be INR 1237.8 crore as of April 1, 2022. Further, under the national water quality sub-mission, Maharashtra has received a fund allocation of INR 12 crore, which remains unspent.

4 Synthesis and Findings

The extent of area affected by floods, cyclones and landslides in Maharashtra is much less in comparison to the area affected by droughts. A few districts in the coastal areas are affected by cyclones and landslides. Landslides also affect a few districts in the Western Ghats. The experts who were at the helm of affairs with regard to rural water supply in Maharashtra were also of the opinion that the areas affected by natural hazards such as floods, landslides and cyclones are much smaller, limited to a few coastal villages.

The survey of eight villages that were affected by floods, landslides and cyclones in Ratnagiri district of Maharashtra showed that the impacts of the hazards were different in different situations, even though the source was of the same type. In the cases of floods, the contamination of the source with mud along with damage to water distribution pipelines occurred. In many cases, the structure was also damaged. In the case of landslides, the source became inaccessible or got filled with mud. In one or two cases, the damage extended to the pump house and the pump. In the event of a cyclone, a power outage affected water supply for a few days.

The retrofitting of the water supply infrastructure after the occurrence of the hazard included repair of the damaged Steining wall, construction of a new well away from the river bank that was flooded, removal of the debris from inside and surrounding the well, raising the height of the protection well, replacement of the damaged pipelines, rebuilding of the pump house, installation of a new pump, and installing the main pipeline below the river bed or above the high flood level. In the case of a power supply interruption that lasted for a few days, tanker water supply was arranged.

The survey of eight villages affected by floods in Kolhapur district showed that the river was the main source of water supply in all the villages. In all cases, the effects of flood hazards were felt on both the source water and the water supply system. The source was contaminated. The supply system, including the pumping machinery, the switch room and the panel boards, were damaged in most cases. The impact on the communities includes their relocation to temporary relief camps. During this time, drinking water was supplied to the relief camps through tankers by the Zilla Panchayat, and in some cases, water bottles were also supplied. The systems were repaired wherever the damage was severe, like in the case of Chikali, where the silt from the jack well had to be removed and the equipment had to be reinstalled at a higher level than the maximum observed floods.

A review of international experiences dealing with climate hazards such as floods, cyclones and landslides showed some specific design features of water supply schemes to make them resilient against these hazards. They include raising the level of the pumping installations and the hand pump installations above the high flood levels of the rivers in the flood-prone areas and constructing protection walls around wells in the areas prone to landslides.

As per our review, the measures that can be adopted for flood resilience are:

Water Storage Tanks: improper construction may also lead to damage to storage tanks during floods. Good concreting techniques will surely increase the resilience of the storage tanks during the floods. Before constructing the storage tanks, natural drainages and flood detention areas must be avoided.

Hand pumps: By constructing a raised slab above floodwater level, flooding can be avoided. Where flooding is inevitable, the risk may be reduced by sealing the manhole, fixing the hand pump securely to a slab that has been properly cured, choosing a hand pump with a spout above the maximum water level, and using a closed rather than an open system.

Boreholes: The site for boreholes should be correctly selected. By having a deeper foundation, erosion of aprons may be avoided. The construction of raised slabs and a mound above floodwater level will also lead to better resilience in the system during floods. Watertight casing should also be constructed above the water table.

For cyclone resilience, the practical measures include provision of backup diesel generators; wells covered with reinforcement; underground pipelines for water supply; underground electric lines; and creation of small water storage structures at the household level.

For securing resilience against landslides, including those due to earthquakes, the measures suggested to reduce the risks from the specific hazards are:

Numerous pipe breaks all at once in distribution pipelines: stockpiling of pipes, clamps, etc., which can be used for rapid repairs.

Transmission pipelines exposed to landslides: a) Checking the structural capacity of the pipelines to resist forces resulting from permanent ground movement; b) Identifying the ways to increase pipeline capacity to withstand ground movement based on results of the above action by either increasing strength and ability for joints not to separate, and/or adding flexibility into the pipeline; and c) Identifying areas prone to land sliding and engineering solutions for crossing these areas

Pumping stations, tanks and reservoirs vulnerable to earthquake: a) Adding flexible connections for pipelines at interfaces; b) Analysing structures to determine if strong earthquake shaking will result in collapse or damage such that they cannot be entered or used; c) Anchoring equipment, cabinets, and material storage units so that they do not injure workers, result in damage, damage any stored contents, or release any dangerous materials

Treatment systems and equipment vulnerable to earthquake shaking, landslides and Sloshing: a) Adding flexible connections for pipelines at interfaces; b) Analysing structures to determine if strong earthquake shaking will result in collapse or damage such that they cannot be entered or used; c) Anchoring equipment, cabinets, and material storage units so that they do not injure workers, result in damage, damage any stored contents, or release any dangerous materials; d) Evaluating if specialized equipment is vulnerable to sloshing damage; e) Preparing repair plans and including them in the emergency response plan; f) Identifying methods for bypassing treatment plants to provide some water supply, even if the quality is poor

Limited gravity water supply; High resilience on energy for pumping: a) Adding a diesel-based pumping system as emergency backup and maintaining fuel supplies; b) Maintaining emergency fuel contracts so that emergency supplies can be guaranteed; c) Strengthening electric power substations; d) Working with the electric power company to ensure a seismically reliable system

5 Conclusions and Policy Direction

Knowledge and Information

The climate risk mapping undertaken for this study showed that there are many districts in the state of Maharashtra where rural water supply schemes are prone to climate-induced risks. To be precise, a total of 10 districts had risk values equal to or above 0.27-Amravati, Ahmednagar, Bid, Buldana, Gondiya, Mumbai, Nanded, Palghar, Parbhani, Pune and Thane, which indicates moderately high risk. The hazards that cause these risks are droughts, riverine floods, cyclones and landslides. Among all these, the most widespread impacts were from droughts given the unique geohydrological environment (hard rock geology), the socioeconomic conditions (limited gravity irrigation from canals and very high dependence on groundwater for irrigation), and the heavy dependence on wells for rural water supply. Though the effects of cyclones and riverine floods are restricted to a few coastal villages, they often damage the water supply infrastructure.

The field survey conducted in select villages affected by cyclones, landslides and riverine floods has shown that the local Gram Panchayat has undertaken retrofitting work subsequent to the damages caused to the infrastructure, wherever possible. In cases where the schemes were damaged beyond repair, new water supply schemes were built.

Planning

In order to ensure the drought resilience of the rural water supply schemes, it is important that care be taken when selecting the sources at the time of planning itself. In areas where climate-induced risks in water supply are high due to low rainfall, high aridity and a high magnitude of occurrence of droughts in the form of rainfall departure from normal values. Such areas are also characterised by intensive groundwater irrigation, and therefore the drinking water bore wells face competition from irrigation. The droughts only add to the problems.

Policy

As regards policy change, such high-risk areas need to gradually shift to reservoir-based water supply schemes wherein the official agency can exercise control over water allocation. The new JJM (Jal Jeevan Mission) guidelines provide for funding for multi-village water supply schemes in such areas to find a permanent solution to drinking water shortages.

Resource Mobilization

Resource mobilization is an important task. In the case of areas that are affected by other natural hazards such as cyclones, floods and landslides, funds need to be tapped from the State Disaster Management Authority from SDRF to retrofitting (PNDA: Damage and loss assessment and planning for recovery and reconstruction). However, future building of rural water supply schemes in such areas should consider special features in the system design to protect the infrastructure against the damages caused by the hazards and additional materials and equipment to deal with emergency situations (prepositioning of materials such as pipes and clamps, diesel generators, storage tanks, batteries, etc.). It is important that the design of water supply infrastructure in such areas follow the guidelines framed by the National Disaster Management Authority.

Section III:
LCC Analysis of Water Supply Schemes and Interventions for Building Climate-Resilient, Multiple Use Rural Water Systems

Summary

In India, the planning of water supply normally does not consider the multiple water needs of rural households, especially water for productive needs such as animal watering, animal washing, watering of the kitchen garden, and water for small household industries. The selection of technology for rural water supply is generally driven by investment cost considerations. Little attention is paid to source sustainability concerns. As a result, the tendency of the water supply agencies is to go for local groundwater-based bore well schemes that have low investment costs, are easy to drill, and are easy to operate and maintain. Such schemes fail during the summer months, especially during drought years.

The permanent failure of such schemes is also widespread in hard rock areas. Poorly yielding wells and the reduced life of the scheme increase the cost of supplying a unit volume of water. Further, due to the failure of the schemes during the peak summer season, water has to be supplied through unconventional sources such as tankers, which further adds to the cost of water supply for the basic minimum services. The life cycle cost analysis of water supply schemes helps us evaluate the actual cost of supplying water through such sources by capturing the actual life of the scheme and the costs that are incurred annually. Such an analysis would force us to look beyond the commonly preferred water supply systems and also consider additional investments to improve their climate resilience.

The first part of this section analyses the life cycle cost of water supply schemes in an area that is subject to high variability in annual rainfall and that also does not have any groundwater stock that can provide drought resilience. The second part deals with the causes of failure of drinking water wells in rural areas, the determinants of performance of rural water supply schemes, and the measures that are to be adopted for making the water supply scheme in different typologies of Maharashtra climate resilient and sustainable. The third part deals with models of rural water supply for different agro-ecologies in Maharashtra that are capable of providing water to meet domestic and productive needs throughout the year.

In terms of findings, the comparative analysis of groundwater levels during monsoon for dry and wet years for five districts in Nashik division and six districts in Kongan division of Maharashtra clearly shows that the sustainability of water supply schemes is threatened by droughts, with reduced recharge during monsoon in the dry years. In the case of Ratnagiri district, where the groundwater condition was better, the incidence of the occurrence of droughts was almost nil, and the incidence of well failure was not reported. This was also reflected in the negligible difference in monsoon water level fluctuation between a wet year and a dry year. The LCC analysis carried out for Latur district shows that the real cost of groundwater-based drinking water schemes in such areas will be high. While the life of the schemes varied from four to 35 years, the life cycle cost ranged from Rs. 2.7 per m3 to Rs. 15.7 per m3. This reinforces the argument for either entirely shifting to reservoir-based schemes or going for conjunctive use of groundwater and water from surface reservoirs, depending on the gravity of the problems vis-à-vis groundwater scarcity.

Among the four typologies of areas identified in Maharashtra vis-à-vis the probability of success of rural water supply schemes, there are only a few districts belonging to one typology where the drinking water wells perform well. The strategies for improving the sustainability of the rural water supply schemes in the remaining three typologies are: 1) groundwater-based schemes that require augmentation by surface water during the lean season for the districts falling in typology 1; 2) surface water schemes based on nearby sources for districts falling in Typology 2; and 3) bulk water transfer for the Regional Water Supply Scheme from the WFRs to the Marathwada region for districts falling in Typology 3.

The high life cycle cost of rural water supply schemes justifies the investment to build surface water schemes that involve bulk transfer of water from water-rich areas, despite the high capital cost of building such schemes. But the amount of money spent on supplying water through tankers during the lean season alone can justify the investments required for water transfer when building multi-village drinking water schemes based on surface water. With a conservative estimate of 20 per cent of the rural households in the districts where drinking water wells do not perform well, depending on tanker water for three months in an average year, the additional water to be supplied through tankers comes to 77.75 MCM per annum. At an average price of INR 250/m3 for tanker water, the annual expenditure would be INR 1,943 crore per annum for tanker water supply alone.

Building on an earlier work in Maharashtra that analyzed multiple use water needs of the rural areas and also explored viable techno-institutional model of rural water system that can provide water for multiple uses in each situation, we have also proposed techno-institutional

models for multiple use water systems in rural areas of the state, for different typologies that are capable of providing water for productive as well as domestic uses. Keeping in view the need for multiple use water services, the approach and methodologies for planning, technology selection and design of water supply schemes for rural areas were also discussed.

The high life cycle cost of drinking water wells in hard rock areas with poor resource potential supports the argument that it is not advisable to invest in bore well-based schemes in such areas, as the cost of supplying water through tankers during the peak summer months increases the real cost of water supply from groundwater in such regions. The analysis makes the case for investing in reservoir-based water supply schemes in such regions, catering to multiple villages. Because reservoir-based multi-village schemes are highly capital intensive, the life cycle cost approach should be used in planning rural water supply schemes if they are to become a government priority. Such a strategic shift will allow the water supply agency to change the norms pertaining to per capita supply levels so as to accommodate water for productive as well as domestic needs.

However, for this to happen, the thinking within the water supply agencies needs to be reoriented through training. The concept of life cycle cost needs to be understood by the senior policy makers of these agencies. Earlier analysis had shown that source strengthening of bore well-based schemes in districts where they do not perform well by augmenting them with surface water supplies during the lean season (for three months) and complete replacement of poorly-performing bore well-based schemes with multi-village schemes based on surface water would require an investment to the tune of INR 9,550 crore for securing additional water supplies to meet a total annual demand of 1,361 MCM of water. However, such investments appear to be cost-effective when we consider the fact that the annual expenditure on tanker water supply in the state to tide over the crisis during the summer months would be to the tune of INR 1943 crore.

1 Introduction

In India, rural water supply systems are planned and designed for a bare minimum water supply of around 55 litres per day. The planning of water supply does not consider the multiple water needs of rural households, especially water for productive needs such as animal watering, animal washing, watering of the kitchen garden, and water for small household industries. Secondly, the selection of technology for rural water supply is generally driven by the consideration of investment cost rather than considerations of source sustainability and its implications for the overall performance of the water supply scheme and the life of the scheme. As a result, the tendency of the water supply agencies is to go for local groundwater-based bore well schemes that are easy to drill, have low investment costs, and are easy to operate and maintain. But such schemes fail during the summer months, especially during drought years.

Permanent failure of such schemes is also widespread in hard-rock areas such as the Marathwada region, owing to extremely limited recharge and excessive withdrawal of water for irrigation. Poorly yielding wells and a reduced scheme life mean a high cost of supplying a unit volume of water from such schemes. Furthermore, failure of the schemes during the peak summer season, which is common in many poorly endowed areas, means water has to be supplied through unconventional sources such as tankers, which raises the cost of water supply even further. The additional cost of supplying water through tankers during periods of stress (when the conventional schemes fail) adds to the actual cost of maintaining the basic minimum water supply in rural areas. The life cycle cost analysis of water supply schemes helps us evaluate the actual cost of supplying water through such sources that capture the actual life of the scheme as well as the costs incurred annually to keep the schemes running. Such an analysis would force us to look beyond the commonly preferred water supply systems and make additional investments to improve the climate resilience of water supply schemes.

The first part of this section analyses the life cycle cost of water supply schemes in an area that is subject to high variability in climate, particularly annual rainfall, which also does not have any groundwater stock that can provide resilience against drought conditions. The selection of such an area was made in order to get the actual impact of climatic variability on the sustainability of the source.

The second part deals with the causes of the failure of drinking water wells in rural areas and the determinants of the performance of rural water supply schemes. Based on these, the measures that are to be adopted for making the water supply scheme climate-resilient and sustainable are identified for different typologies that exist in Maharashtra that are defined by the extent to which groundwater-based water supply schemes sustain in terms of their ability to meet the water needs of the rural areas throughout the year.

That said, if water has to be supplied for productive as well as domestic uses, the current criteria for selecting water supply technologies do not work. The level of performance has to become an important consideration for the selection of water source and water supply technologies. In the third part of this section, we suggest models for rural water supply for different agro-ecologies of Maharashtra that are capable of providing water to meet domestic and productive needs throughout the year. The work builds on the earlier work done on multiple use water services in Maharashtra that covered three districts, each one from a unique agro-ecological and socio-economic setting. The regions covered were western Maharashtra, Marathwada and Vidarbha.

2 Assessment of Life Cycle Cost Analysis (LCCA)

2.1 Theoretical Perspectives on Life Cycle Cost Analysis in WASH and a Review of Studies

Life Cycle Cost Analysis (LCCA) is an approach used to assess the total cost of owning a facility or running a project (CFI Team, 2022), the present context being the Bore Well Based Rural Water Supply Scheme. LCCA considers all the costs associated with obtaining, owning, and disposing of an investment (CFI Team, 2022). Life-Cycle Costing is a common approach in developed countries to calculate and monitor the renewal of assets as well as optimise spending on operations and maintenance of water systems. Life-cycle costs (LCC) "represent the aggregate cost of ensuring delivery of adequate, equitable and sustainable water, sanitation and hygiene (WASH) services to a population in a specified area" (Fonseca et al., 2010).

The cost categories include Capital Expenditure (CapEx), Operations Expenditure (OpEx), Capital Maintenance Expenditure (CapManEx), Expenditure on Direct Support (ExpDS), Expenditure on Indirect support (ExpIS), Cost of Capital (CoC) (Triple-S Uganda, 2013). The Life Cycle Costs Approach (LCCA) is a flexible approach to show what is needed to sustain, repair and replace a water or sanitation system through the whole of its cycle of wear, repair and renewal and what is needed to support the various institutions engaged in organizing and providing water services at local (direct support) and national levels (indirect support) (Triple-S Uganda, 2013).
Source sustainability, and poor operation, maintenance and water quality are the main reasons for slippage in India (Reddy et al., 2012). The allocations to the rural drinking water sector are low at the design stage but end up costing more due to ad hoc interventions (Reddy et al., 2012). It is argued that the adoption of LCCA would enhance the efficiency and effectiveness of the budget allocations to the drinking water sector. There is a need for Life Cycle Cost Analysis (LCCA) in choosing the best alternatives in water supply systems (UNICEF & IRAP, 2013).

The large investments made to construct utilities intended to provide facilities for water supply are generally becoming unproductive, mainly on account of poor maintenance, wherein after a few years, these schemes become defunct (GOI, 2013). This is because the departments and water supply boards are not able to ensure that the maintenance staff follows valid practices of O&M. Hence, proper training is needed for this staff (GOI, 2013).

Historically, drinking water supply in the rural areas of India has been outside the Government's sphere of influence (GOI, 2013). When the life cycle cost of the system is considered, the cost of production and supply of water from a bore well drilled in a hard rock area is likely to be much higher than that of a tube well drilled in an alluvial area (even with the same initial water table conditions), as the former can become dysfunctional due to drawdowns in water levels and yield reductions much faster than the latter (UMA, 2018).

Assuming that a community has a full suite for a water system, a life cycle approach shows that a groundwater system with community standpipes is the most environmentally sustainable and improved option, as well as one of the most financially sustainable options (Jones et al., 2012). Studies show LCCA to be useful to identify financial gaps and economic sustainability, which if unaddressed can lead to non-functional or underperforming water schemes (Milne et al., 2020).

In the Democratic Republic of the Congo (DRC), the national rural WASH programme is called "Healthy Villages and Schools" (Village et École Assaini, VEA) (Jones, 2019). In this context, the DRC WASH Consortium was established in 2013 as a complementary initiative to the national programme (Jones Stephen, 2019). The first objective of the WASH Consortium in adopting the life-cycle costs approach was to enable local actors (communities and local health services) to make informed decisions about whether the possible installation of an improved water point was likely to lead to sustainable services in the long term (given local capacities) (Jones, 2019; Stephen, 2019). The secondary objective was to also permit an informed decision between different feasible technical options in terms of estimated costs vs level of service (Jones, 2019; Stephen, 2019).

In Ethiopia, the life-cycle costing assessment (LCCA) aims to raise the government's and other service providers' awareness and understanding of the full costs involved in providing sustained water supply services and to ensure these are included in yearly budgets. The LCCA process has been useful for the Gololcha government to get accurate estimates of all the different cost components required to reach and sustain universal basic water supply access (Water Aid Ethiopia, 2018).

2.2 Impact of Climate Variability on Life Cycle Cost of Water Supply Schemes: Evidence from the Field

The sustainability of drinking water supply schemes based on bore wells and open wells that tap shallow hard rock aquifers is highly sensitive to the recharge of the aquifer during monsoon, for which water level fluctuations during monsoon serve as a robust indicator. In Maharashtra, nearly 90% of the geographical area is underlain by hard rock aquifers of basalt and crystalline origin. Nearly 90% of the rural water supply is from single village or single hamlet schemes based on groundwater, with bore wells, open wells and handpumps.

Analysis carried out in different parts of Maharashtra shows how climate variability affects the quantum of recharge. During excessively wet years, the water level fluctuation is generally very high, indicating a large amount of recharge, whereas in the dry years, the water level fluctuation is quite low, resulting from very poor recharge. Sometimes, the water level, instead of rising, drops further during the monsoon season due to pumping for agriculture in the absence of rains. Such sharp drops in groundwater levels can dry up the drinking water wells. The analysis of data on (spatial) average groundwater level from the districts of Nashik and Konkan divisions illustrates this point. It can be seen that the difference in water level fluctuations (WLFs) between a dry year and a wet year is very high in both cases.

For the analysis of Nashik data, the year 2012 was taken as the dry year, and 2006 was the wet year. The first round of analysis considered data from different districts. The results are presented in Figure 3.1 and Figure 3.2, for a wet year and a dry year, respectively. It shows that in all five districts, viz., Ahmednagar, Dhule, Jalgaon, Nashik and Nandurbar, the water level fluctuation during the monsoon was much higher during the wet year when compared to the dry year. The water level fluctuation was to the tune of 3.87m, 4.79m, 7.24m, 4.61m and 4.67m for Ahmednagar, Dhule, Jalgaon, Nashik and Nandurbar, respectively, during the wet year. Against this, during the dry year, the corresponding fluctuation was to the tune of 0.39m, 0.40m, 1.42m, 2.30m and 1.51m, respectively. As a result, the water level rise during the dry year is very low. In addition to poor recharge, one reason for the big difference in WLF values could be that during the drought year, farmers might pump water to irrigate their crops due to water stress, bringing down the water table further. For the division as a whole, the water level fluctuation during the wet year was estimated to be 4.60 m, while that during the drought year was 1.21m.

Figure 3.1: Water level fluctuation in districts of Nashik division during wet year (2006)

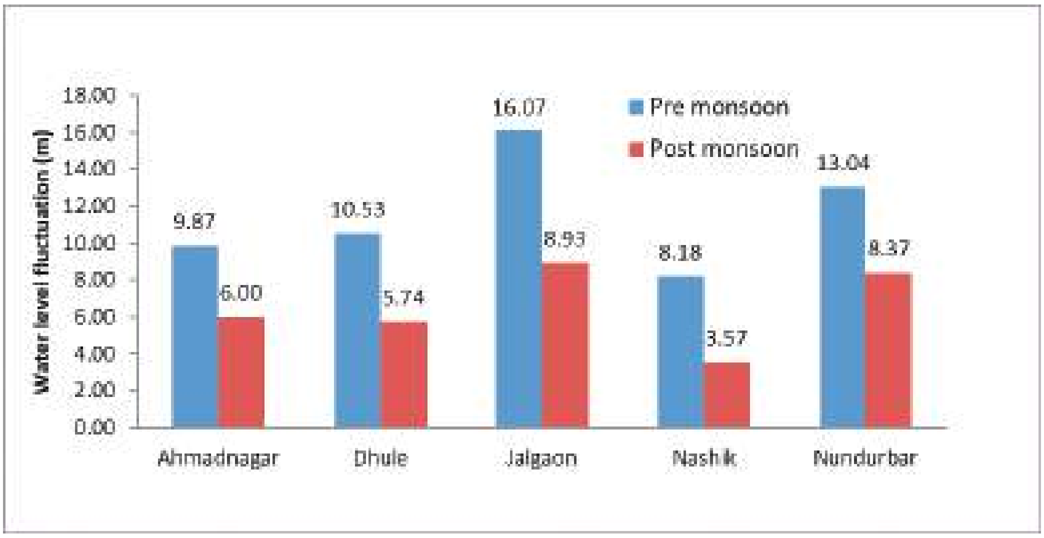
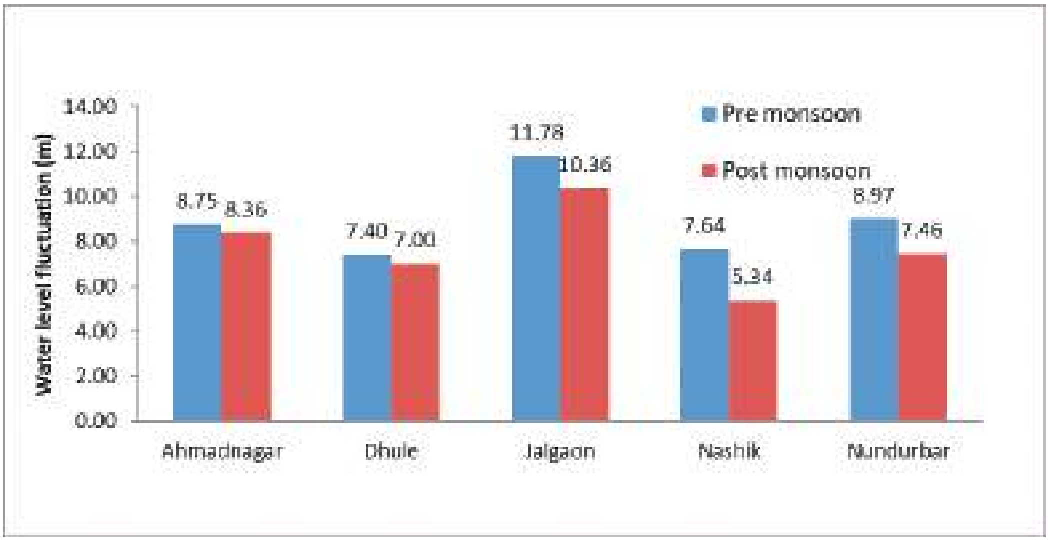


Figure 3.2: Water level fluctuation in districts of Nashik division during dry year (2012)



A similar analysis was repeated for the districts in the Konkan division, viz., Mumbai, Mumbai suburb, Raigarh, Ratnagiri, Sindhudurg and Thane. The results are presented in graphical form in Figures 3.3 and 3.4, for a wet year and a dry year, respectively. The comparison showed more or less the same pattern. The water level fluctuation during the wet year was 2.8m, 2.6m, 2.8m, 2.3m, 3.7m, and 4.7m, respectively for Mumbai, Mumbai suburb, Raigarh, Ratnagiri, Sindhudurg and Thane. The corresponding values for the drought year were 1.6m, 4.0m, 2.0m, 2.2m, 2.7m and 2.2m, respectively. Therefore, with the exception of one district (i.e., Mumbai suburb), the pre-post monsoon water level fluctuation during the wet year was greater than that of drought year. Overall, for the whole of the division, the average water level fluctuation was 3.1m during the wet year, compared to 2.6m during the dry year.

One important finding that emerged from the foregoing analysis is that rainfall is a very important factor explaining the water level fluctuation and post monsoon depth to water level. However, it is also clear that rainfall is not the only factor. Had it been so, the relationship should have been much stronger. Given the fact that around 90% of the geographical area of Maharashtra is underlain by shallow, hard rock formations, with very limited storage potential, it is quite unlikely that the recharge would increase linearly with rainfall. Storage space in the aquifer could be an important determinant. The storage space in the aquifer for receiving the infiltrating water during the monsoon is heavily influenced by the pre monsoon depth to water table. Hence, to examine the influence of the storage space on water level fluctuations during the monsoon, an indicator of recharge, regression analysis was carried out with spatial average rainfall and pre-monsoon depth to water level as independent variables and average water level fluctuation (during the monsoon) as the dependent variable for two districts, viz., Ahmednagar and Aurangabad.

Figure 3.3: Water level fluctuation in different districts of Konkan division during wet year (2019)

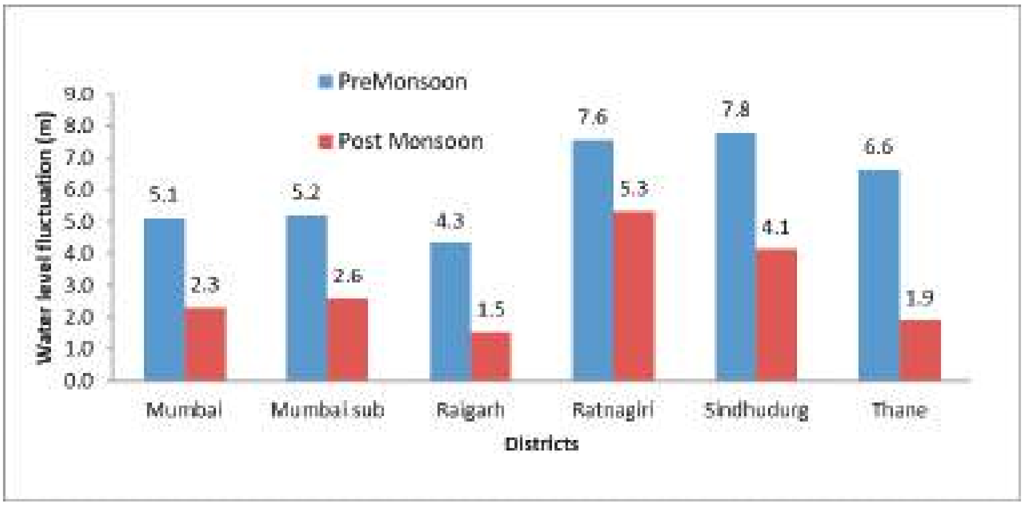
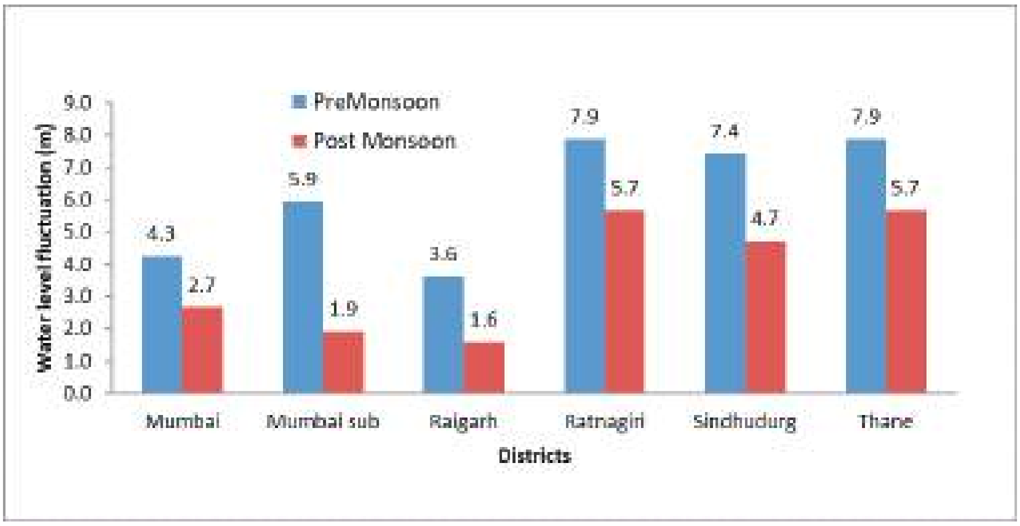


Figure 3.4: Water level fluctuation in different districts of Konkan division during dry year (2015)



It is also important to remember that high water level fluctuation is not always a good indicator of high recharge if the aquifer has a very low specific yield. In other words, even a large amount of recharge during the monsoon will not result in high water level fluctuation in an area with a very good aquifer (with a high effective porosity).

However, good recharge during the monsoon may not always guarantee the sustainability of drinking water wells. A good monsoon recharge is just one of the factors influencing the performance of drinking water wells. The success of the wells also depends on the degree of pressure on the groundwater from competitive use, the most important of which is irrigation. The higher the pressure on groundwater for irrigation, the lower will be the chances of drinking water wells surviving during the lean season. Further, the presence of gravity irrigation systems in an area will also affect the performance of the drinking water wells positively by improving recharge to groundwater on the one hand and reducing pressure on the other by providing an alternative source of water for irrigation. Another important factor is surface morphology. In hilly and undulating areas, the natural recharge from rainfall doesn't remain in the aquifer throughout the year as there will be a natural discharge (outflow) of groundwater into the streams owing to the steep groundwater gradient. Such phenomena can also adversely affect the sustainability of drinking water wells. Such failures increase the life cycle cost of the scheme.

As a part of Life Cycle Cost Analysis for bore well based rural water supply schemes, a field study was conducted in six villages from three blocks of the Latur district of Maharashtra. The district is underlain by hard rock formations of basalt origin. Nearly 82 per cent of the rural population of the district is covered by water supply schemes based on groundwater. Failure of drinking water bore wells is rampant in the district, as evident from the heavy dependence of rural areas on tanker water supply for domestic uses. The dependence was an average of 3.9 tankers per 1,000 people during 2016 (Kabir et al., 2022).

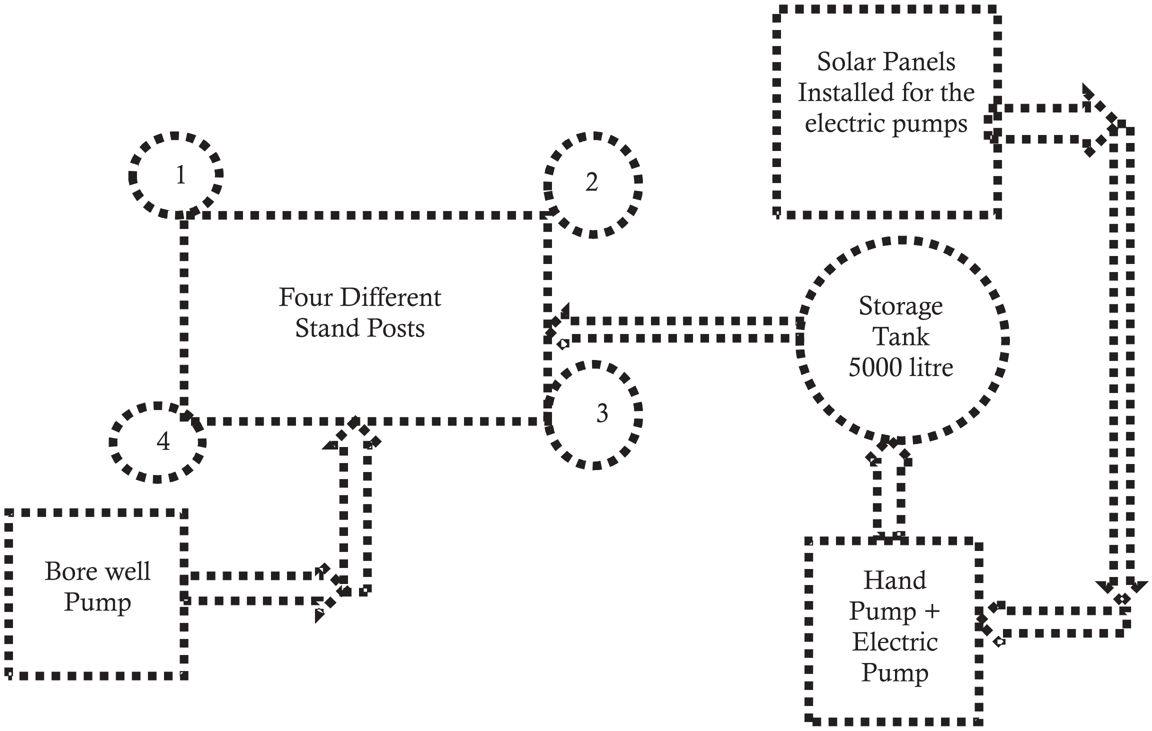
Jewali Village is located at about 16 km from the Latur district Head Quarters. As per the discussions had with Sarpanch (Shri. Vaidya Dhananjay Dandiram), the total number of households is 100, with a population of nearly 400.

The bore well based Rural Water Supply Scheme was originally inaugurated under the guidance of GSDA Maharashtra during the year 1998. The original cost of the scheme was about Rs. 1 lakh. The pipeline installed in this bore well was at a depth of 450 feet, and an electrically powered pump was installed at a depth of 420 feet below ground level. About 4 stand posts were located in the Village premises as supply points to the villagers. Subsequently, this bore well scheme had many technical flaws (pump failure, erratic power supply, motor winding problem, etc.), which brought in the new intervention of a solar power based bore well scheme in the year 2007, with a storage tank of about 5,000 L capacity and onward supply to the stand posts. Approximately INR 5 lakhs were spent during the installation of the solar power based scheme.

A hand pump, which also had a solar powered pump, was used for drawing out the water as a part of this rural water supply scheme. Depth of solar powered hand pump was installed at a depth of 160 feet below ground level. All the households were mainly dependent on this scheme until 2019, when the entire process came to a standstill and the system became defunct. On average, people were spending about 15 to 30 minutes per trip to collect about 20 litres of water. This varied from household to household as the total water requirement is dependent on the number of family members in each household.

None of the household members used to pay any charges for utilizing the water through this scheme. Only on a yearly basis, the villagers were paying about Rs. 75 per year per household as GP tax, which included water tax, and this was mandatory. Regarding the water quality tests, chemical tests were conducted twice a year. However, on the other hand, the biological tests were conducted 4 times in a year. Interestingly, no issues related to biological tests were reported. On the other hand, intermittently high nitrate concentrations were found in the water due to the usage of fertilisers in the nearby agricultural fields. Villagers are dependent on the GP for the treatment of water on a personal level. A very few of them use microbial drop and RO filtration machines, depending on their socio-economic conditions. The GP used to bear all the expenses with respect to maintenance and electricity consumption. Figure 3.5 below depicts the schematic diagram for the Jewali Scheme.

Figure 3.5: Schematic Diagram - Jewali Scheme



Kanadi Boregaon Village is located at about 45 km by road from Latur Head Quarters. The village has three habitations: Kanadi Borgaon, Bhasinwadi and Sevadasnagar. In Bhasinwadi, as per the discussions had with the GP worker, about 65 households were dependent on this bore well-based scheme, which is defunct now.

The bore well-based Rural Water Supply Scheme was funded by the District Planning and Development Council (DPDC) in the year 1985. For about 2 years there was no issue in the scheme. However, in the year 2019, there were many technical issues with the bore well, as the frequency of pump breakdown increased due to erratic power supply and frequent repair of the pump/motor. The entire cost of maintenance was covered by the GP. Subsequently, the pump stopped working in the year 2020. As per the locals and the GP officials, the roots of the surrounding trees reached the pump in the bore well and clogged the entire system. Till now, two pumps have been clogged and remain inside the bore well despite the GP's having tried to remove them with local technicians.

When the scheme was in operation, water was supplied twice daily. An underground pipeline was laid, through which the water was supplied to individual household taps. During the monsoon and winter, on average, the household members collected water twice daily, each time spending about 2 hours. However, in summer, it took around 3 hours each time to collect water through the individual taps.

This water was mainly used for drinking, bathing, and cooking. The submersible pump in the bore well was at a depth of 250 feet below ground level. As part of this scheme, nearly INR 1000 per month was spent on electricity by the GP. For checking the water quality, chemical tests were conducted twice a year. Also, biological testing for the water from this scheme was done four times a year. The cost of chlorination was approximately INR 7,000 per year. It is noted that due to the failure of this scheme, about 12 private bore wells were installed at the household level to meet the water requirements.

Haregaon Village in Ausa block is located at about 42 km from Latur district headquarters. A per the discussions had with the Sarpanch, about 50 households were directly dependent on this bore well-based rural water supply scheme when the scheme was operational.

This bore well-based rural water supply scheme was started under the MLA scheme (spending approximately INR 1.5 lakh) in the year 2008 and was in operation until 2018. Frequent pump repair works and an erratic power supply are the main reasons for the failure of this scheme. Nearly 150 people from 50 households in this village were depending on this water scheme. A pipeline from the bore well was there, leading to a common storage tank (a concrete tank) in the village. Site photographs for Haregaon Village at the time of the survey are presented in Annexure-1.

This water was mainly used for drinking, cleaning, washing of clothes and utensils, bathing and cooking at the household level. However, people were also dependent on other sources for drinking water.

An electric pump with a capacity of 7.5 HP was installed in the bore well for pumping out the water. The submersible pump was at a depth of almost 600 feet below ground level. About INR 10000 was spent on maintenance of the same on a yearly basis, which was incurred by the GP. As per the information shared by the Sarpanch, it is also noted that individual household members also contributed for the repairs/maintenance of the electric motor. The expenses for electric power consumption were nearly INR 17000 per year with a unit rate of INR 3 to INR 4 per unit. Testing of water samples was carried out three times a year for chemical contaminants and four times for biological contamination. Chlorination was also done frequently, for which INR 2000 was spent by the GP in one year.

Matola Village in Ausa block is located about 55 km from Latur district headquarters. The bore well-based rural water supply scheme was started in the year 2008 and stopped functioning in the year 2019. Nearly 150 households were dependent on this scheme.

The water was collected in a 4000-litre storage tank. The total cost incurred for this scheme was INR 1.5 lakh, which also included a 5 HP pump. The electric pump was at a depth of 290 feet below ground level. Apart from this, the yearly maintenance cost was INR 10,000. However, the power charges were about INR 10,000 per year for running this 5 HP motor. As per the information shared by the villagers, about 100 KWH units of electricity were consumed in a month.

As a part of maintenance, in the year 2017, about INR 50,000 was spent on replacing some of the pipes. Chemical and biological tests were carried out on this water twice a year, respectively. Chlorination was also done once every two months. Each year, about 300 grams of chlorine/TCL were used, at a cost of nearly INR 1000 (annually). One dedicated person was hired for the overall operation of this scheme, and he was paid INR 5000 per month. Matola Scheme site pictures are shown in Annexure-1.

Nandurga village in Ausa block is located at about 60 km from the Latur district headquarters. Under the rural water supply scheme, a bore well was started in the year 2012, and nearly 50 households were dependent on this scheme for water. However, this scheme stopped working in the year 2016.

The pumped-out water was stored in a 2500 litre storage tank. About Rs. 2 lakh was spent on this scheme initially. The scheme is defunct now due to erratic power supply. On maintenance of the pump, etc., about INR 10,000 was spent annually. The annual power charges were INR 15,000. Chemical and biological tests were carried out on this source twice a year. Chlorination was also done twice annually, and about INR 5,000 was spent on the same. Nandurga site pictures are presented in Annexure-1.

Pangaon village is located about 38 km from Latur headquarters. In the entire village, about 34 bore wells were installed, of which 6 are not working. One bore well near Duddegalli is completely defunct.

This scheme was commissioned in the year 2008 by the ZP, and it cost around INR 1.5 lakh, including the pump. This scheme became defunct in the year 2013. Apart from this, the Gram Panchayat funds of INR 60,000 were also spent on the maintenance of this pump. The depth of the bore well was 540 feet below ground. The 5 HP electric submersible pump was installed at a depth of 530 feet below ground level. The pumped-out water was stored in a 3000-liter storage tank, from which the villagers used to take water for their daily needs. From each household, INR 100/month was collected by the GP towards water supply under this scheme. Annual power consumption charges were about INR 10,000. The unit rate of power was about INR 10 to 12.

Quarterly water testing was done from this source, which included both chemical and biological tests. According to interactions with the local people, the water from this source had a slightly high salt content. Most of the villagers who sourced water from this scheme used it mainly for bathing, cleaning and washing purposes only. As a part of chlorination, Medichlore liquid was used once on a monthly basis. One person at the GP level was responsible for this scheme. He was paid INR 10,000 per month for taking care of the bore well operation. During the survey, the following pictures were captured at Pangaon Village.

The summary of the field survey findings (Latur District) is presented village-wise in Table 3.1.

Table 3.1: Summary of the Field Survey results on Life Cycle Cost Analysis of bore well-based schemes in Latur District of Maharashtra

S. No	Name of the Village	Type of Scheme	Year of Installation and Defunct	Present Condition of the Source	Pop. Covered	Reason for getting the scheme defunct	Quality of Water received from bore well	Effect on villagers	Cost of Maintenance and Repair	Contribution from the villagers to fix the system
1	Jewali, Latur	Gram Panchayat-funded with the assistance from GSDA	*Installation:* 1998 *Defunct:* 2019	Source unaffected	400	Electric pump has been non-operational since 2007, when it became stuck inside due to lateral collapse of the soil stratum. So, another bore well is installed within a 5m radius of the existing with a solar operated pump at a depth of 425 feet below GL. This also went defunct due to several pump failures and higher maintenance costs.	Water is safe for drinking. No quality issue has been observed to date.	The villagers were dependent on the water source. It was used for drinking, cooking, and other uses.	At the GP level, a total of INR 25,000 per year was spent for the maintenance of the scheme. Electricity bill was around INR 12,000 per year. Cost of chlorination was around INR 1200 per year.	Villagers used to pay INR 75 per year as tax, which included a water cess.
2	Kanedi Borgaon (Bhasinwa di Tanda), Latur	Zilla Parishad (DPDC funded bore well)	*Installation:* 1985 *Defunct:* 2020	Source unaffected	550	The pump got dysfunctional, and it was stuck inside due to the roots of a nearby banyan tree.	Water is tested every 4 months. Water is safe for drinking. No quality issue has been observed to date.	The villagers were dependent on the water source. It was used for drinking, cooking, and other uses.	At the GP level, a total of INR 20,000 per year was spent for the maintenance of the scheme. Electricity bill was around INR 12,000 per year. Cost of chlorination was around INR 1000 per year.	Villagers used to pay INR 360-400 per year as tax, which included a water cess.
3	Haregaon, Ausa, Latur	MLA-LAD AMDARPAN	*Installation:* 2008 *Defunct:* 2018	Source unaffected	200	Due to erratic power supply, the pump was frequently non-operational. But the ZP recovered it several times. Since the O & M costs were increasing, the scheme became defunct.	Water is tested in every 6 months. Water is safe for drinking. No quality issue has been observed to date.	The villagers were dependent on the water source for drinking, cooking, and other uses.	From GP level, a total of 10000 per year was spent for the maintenance of the scheme. Electricity bill was around INR> 17,000 per year. Cost of chlorination was about INR 2000 per year.	Villagers used to pay INR 350-500 per year as water cess

S. No	Name of the Village	Type of Scheme	Year of Installation and Defunct	Present Condition of the Source	Pop. Covered	Reason for getting the scheme defunct	Quality of Water received from bore well	Effect on villagers	Cost of Maintenance and Repair	Contribution from the villagers to fix the system
4	Matola, Ausa, Latur	Zilla Parishad scheme	*Installation:* 2007 *Defunct:* 2018	Source unaffected	750	Due to erratic power supply, the scheme became defunct.	Water is tested every 6 months. Water is safe for drinking. No quality issue has been observed to date.	The villagers were dependent on the water source for drinking, cooking, and other uses.	At the GP level, a total of INR 10,000 per year was spent for the maintenance of the scheme. Electricity bill was around INR 10,000 per year. The cost of chlorination was around INR 1000 per year.	Villagers used to pay a yearly water cess of INR 100.
5	Nandurga , Ausa, Latur	Gram Panchayat-funded scheme	*Installation:* 2012 *Defunct:* 2016	Source unaffected	250	Due to erratic power supply, the scheme became defunct.	Water is tested annually. Water is safe for drinking. No quality issues have been observed to date, except for some smell issues.	The villagers were dependent on the water source for drinking, cooking, and other uses.	At the GP level, a total of INR 10,000 per year was spent for the maintenance of the scheme. Electricity bill was around INR 15,000 per year. Cost of chlorination was around INR 800 per year.	Villagers used to pay a monthly water cess of INR 100.
6	Paangaon (Duddegal i), Renapur, Latur	Zilla Parishad funded scheme	*Installation:* 2007 *Defunct:* 2013	Source remains unaffected throughout the year except for two months in the summer (April and May). In these two months, the water table goes deeper and a lesser amount of water is pumped from the source.	200	Because of the low voltage, the pump became dysfunctional, and it was stuck inside due to lateral collapse of the soil stratum.	Water is safe for drinking. Salinity in the water was observed. Later, a RO Plant was installed by the GP.	The villagers were dependent on the water source for drinking, cooking, and other uses.	At the GP level, a total of INR 36,000-40,000 per year is spent for the maintenance of the scheme. Electricity bill was around 10,000-12,000 INR per year.	Villagers once spent a total of INR 2000 to fix the dysfunctional pump despite paying the water cess of INR. 100/month. In general, the GP took the responsibility for all expenses in maintaining the scheme.
7	Posare	Zilla Parishad	*Installed:2018* *Defunt:2021*	The source became inaccessible due to damage to the infrastructure.	240	Due to landslide	Water was safe for drinking.	The villagers shifted to an alternate community well for 6 months.	An amount of INR 10,000/- was estimated by the Zilla Parishad.	None
8	Dhangew adi	Zilla Parishad	*Installed:2015* *Defunct:2019*	Source dried up	97	This scheme became defunct because the source dried up.	Water was safe for drinking, and the villagers used it for domestic and drinking purposes.	The villagers collect water from an alternate source: hand pump	An amount of INR 10,000/- was estimated by the Zilla Parishad.	None

2.3 Impact of Climate Variability on Life Cycle Cost

As discussed in the conceptual framework, the way to analyze the impact of climate variability on the life cycle cost of water supply schemes based on groundwater is to analyze two distinct situations, one in which the impact of climate variability (particularly drought) will be visible on groundwater and the other in which the impact will not be visible. Therefore, a survey was carried out in Latur district, which witnesses extreme variability in annual rains, and Ratnagiri district, which does not witness much variability in rainfall and if at all ever witnessed, the sustainability of its groundwater resource will not be threatened. The analysis for Latur district shows that the life of the scheme ranges from a minimum of four years to a maximum of 35 years. The range was quite wide. The level of water supply from each scheme was estimated through a sample household survey that studied the daily water consumption by the households against the daily requirements. From this, the annual water supply from the scheme was estimated by considering the total number of households served by the scheme and the average daily water consumption (Table 3.2).

The annualized capital and O & M costs of water supply were estimated for each scheme based on the data obtained from the concerned Gram Panchayats. From these data, the cost per m3 of water supplied was calculated. The results are presented in Table 3.3. As one would expect, in the case of schemes with a long life, the cost per m3 of water supplied was quite low, and in the case of schemes with a short life, the cost per unit volume of water was high. The highest cost was INR 15.7/m3 for a scheme that lasted only four years.

Table 3.2: Water Consumption Per Year from each scheme

S. No	Village	Average Daily per HH in litres	Average HH Size	No. of HHs dependent on the scheme	Total daily HH Consumption in litres	Annual Water Consumption (m3)	m^3 per year
1	Jewali	278	6.7	100	27,800	10,147.0	10147
2	Kanadi Boregaon	412	7.2	65	26,780	9,774.70	9775
3	Haregaon	299	7.8	50	14,950	5,456.75	5457
4	Matola	312	5.9	150	46,800	17,082.0	17082
5	Nandurga	291	4.9	50	14,550	5,310.75	5311
6	Pangaon	333	7.9	200	66,600	24,309.0	24309

Source: Estimated from the primary survey data collected.

Table 3.3: LCCA for the six defunct bore well-based schemes in Latur District

S. No	Village	Life of the scheme (n, years)	Capital Cost in INR	k=Discount Rate	$(1+k)^n$	$[(1+K)^n]-1$	$[(1+k)^n] / [(1+K)^n]-1$	K * {[(1+k)n] / [(1+K)n]-1}	Annualized Capital Cost in INR	O & M Cost in INR	Cost including O&M in INR	Annual Water in m^3	Cost of water in INR/m^3
1	Jewali	12	500,000	0.06	2.01	1.01	1.99	0.12	59639	38200	97839	10147	9.6
2	Kanadi Boregaon	35	150,000	0.06	7.69	6.69	1.15	0.07	10346	33000	43346	9775	4.4
3	Haregaon	10	150,000	0.06	1.79	0.79	2.26	0.14	20380	29000	49380	5457	9.0
4	Matola	11	200,000	0.06	1.90	0.90	2.11	0.13	25359	21000	46359	17082	2.7
5	Nandurga	4	200,000	0.06	1.26	0.26	4.81	0.29	57718	25800	83518	5311	15.7
6	Pangaon	6	150,000	0.06	1.42	0.42	3.39	0.20	30504	52000	82504	24309	3.4

Source: Estimated from the Primary Survey Data

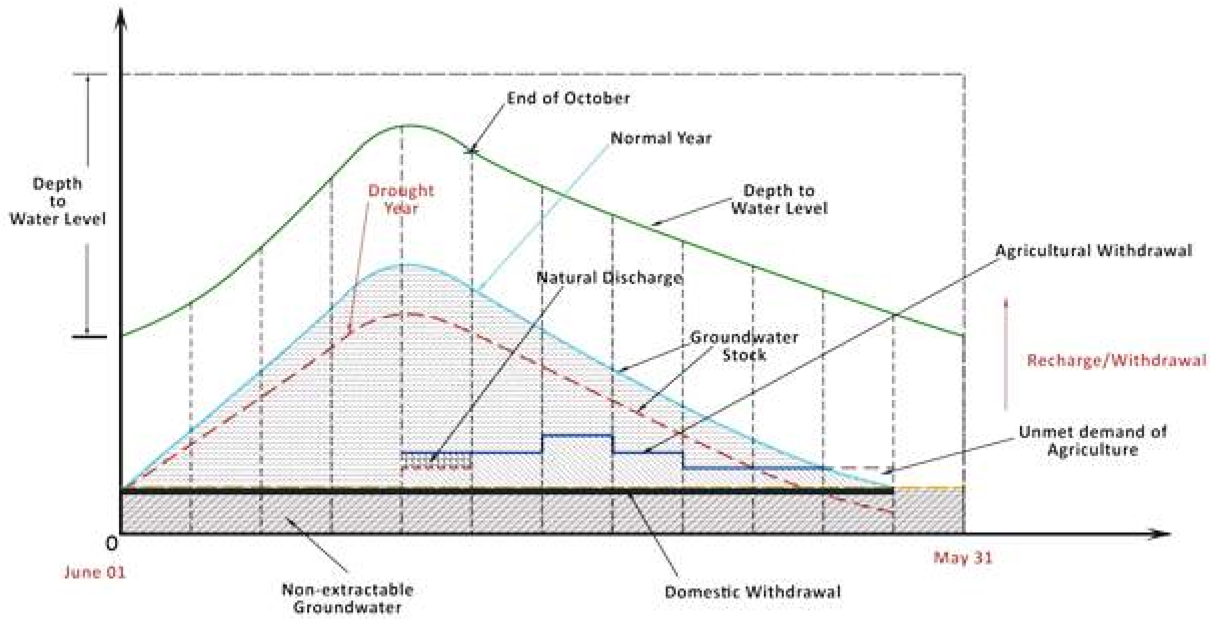
3 Interventions for Making Groundwater Based RWS Schemes Climate-Resilient in Areas Where the Resource Faces Sustainability Threats

3.1 What Explains the Failure of Drinking Water Wells?

Groundwater behaviour in hard rock (consolidated) formations is complex due to a number of factors influencing the water balance. They include natural discharge into streams, rejected recharge due to limited storage space, etc. Hence, it is difficult to derive any meaningful inference purely based on analyses of the groundwater level trends at the aggregate level. Thus, a more nuanced understanding of the aquifer characteristics and their response to rainfall and pumping is required, as illustrated in Figure 3.6. During the monsoon months, the water level rises continuously in such aquifers due to very low specific yield. However, the extent of recharge and therefore water level fluctuation is also controlled by the depth to water level before the monsoon. For the same amount of rainfall, a higher depth to water level can guarantee a higher recharge and, therefore, higher WLF during the monsoon at high magnitudes of rainfall. The small quantity of water pumped for domestic uses does not cause any decline in the water table during the season, as it is insignificant in comparison to the recharge effect of rainfall.

It is also common to find overflowing dug wells in the hilly and undulating regions during the monsoon, as the cumulative infiltration from rainfall exceeds the storage potential of the aquifer (space in the weathered formation and the fissures). However, once the monsoon ends, there is a sudden fall in groundwater level, usually starting in November, as pumping for irrigation of winter crops starts, and there is a very limited amount of recharge during non-monsoon months. The water abstraction for irrigation peaks in December and January when the soil moisture gets exhausted. Though the irrigation demand comes down during the summer months, the aquifer no longer has any water left, thus leading to seasonal water scarcity. In addition to the abstraction, there is also a natural discharge of water from the formations, mainly influenced by the geomorphology. While there would be hardly any water to meet the irrigation demand of summer crops grown in tiny plots in normal rainfall years, there is a shortage of water to meet the domestic needs during the season during dry years. Thus, in such formations, groundwater is not a reliable source for domestic water supply.

Figure 3.6: Groundwater behaviour in hard rock formations (Source: Kabir et al., 2022)



3.2 Determinants of Performance of Groundwater-Based Schemes

It is well understood that groundwater-based schemes, which are the major source of water for rural water supply in Maharashtra (around 90% in terms of habitations covered), face sustainability threats due to excessive dependence on groundwater by the farmers for meeting their agricultural water needs. It is important to understand the conditions under which such schemes are likely to fail (determinants of failure) or succeed (determinants of success) when evolving strategies for making them sustainable.

A recent study carried out in Maharashtra on the factors influencing the performance of drinking water supply schemes shows the following: the chances of failure of schemes are high if they are groundwater-based; the chances of failure of groundwater-based schemes are high in areas where the underlying formations are of hard rocks (basalt or crystalline formations), and there is low aquifer storage space; the groundwater-based schemes are also likely to fail in areas with poor effective recharge rate; the groundwater-based schemes are likely to fail in areas where the demand for irrigation water is high due to the presence of a large area under cultivation and aridity; and the groundwater-based schemes are likely to fail in areas where the extent of coverage of surface irrigation is quite low. Conversely, when the aquifer has good storage space (due to a high specific yield), if the effective recharge in the district is good, if the extent of surface irrigation in the district is high, or if the demand for irrigation water is quite low, then the groundwater-based schemes perform well, manifested by the least dependence on tanker water supply during summer months.

These above-mentioned results provide the basis for identifying districts where groundwater-based schemes need source strengthening to improve their sustainability, as well as the interventions that are required for the same once the conditions of those districts are known. The conditions are with regard to the total annual effective recharge rate (which is determined by the rainfall, recharge coefficient and surface morphology), storage space in the aquifer (determined by the depth to water table prior to monsoon and the specific yield), the demand for irrigation water (which is determined by the climate and area under cultivation as a proportion of the total cultivable area), and the extent of gravity irrigation. It will also provide clues as to where groundwater-based schemes will not be sustainable due to inherent problems (of the physical and socioeconomic environment) and where a shift to new sources is required.

The districts that score lowest on all four key attributes-sufficient recharge rate per unit area; adequate aquifer storage space, limited irrigation demand; and a large extent of surface irrigation-are given in Box 1. The information provided in the box needs to be read carefully. It shows that for limited irrigation water demand, Gadchiroli gets the lowest score. This basically means that Gadchiroli had the highest irrigation water demand. Similarly, on recharge per unit area, Sangli gets the lowest score. This means that recharge per unit area is lowest in Sangli among all the districts.

Box 1: The bottom 10 districts (in each category)

Recharge per unit area	Aquifer storage space	Limited irrigation water demand (mm/year)	Proportion of area under surface water irrigation
Sangli	Chandrapur	Jalgaon	Garhchiroli
Solapur	Garhchiroli	Parbhani	Gondiya
Satara	Kolhapur	Jalna	Pune
Ahmednagar	Gondiya	Latur	Chandrapur
Kolhapur	Nagpur	Buldhana	Nandurbar
Nagpur	Bhandara	Beed	Satara
Aurangabad	Pune	Aurangabad	Kolhapur
Bhandara	Aurangabad	Akola	Bhandara
Beed	Satara	Washim	Nashik
Pune	Yavatmal	Hingoli	Wardha

Source: authors' own analysis based on data presented in Kabir et al. (2022)

3.3 Measures for Improving the Sustainability of Groundwater-Based Schemes

Based on the analysis of the situation in each district vis-à-vis the five attributes explained above (as the determinants of performance of groundwater-based schemes), the districts of the state were divided into four typologies: 1) districts where groundwater-based schemes would perform well; 2) districts where groundwater-based schemes would require strengthening through the provision of surface water by way of reallocating water from the existing reservoirs or building new surface reservoirs within or outside the districts; 3) districts where groundwater-based schemes are unsustainable, but new surface storages can be created using the local runoff for water supply; and 4) districts where groundwater-based schemes are highly unsustainable and surface water is also not available but will have to be obtained through water import. The typology development is also in line with the current strategy of the state and central governments of adopting the conjunctive use of surface water and groundwater. The overall approach and strategy are shown in the diagram (Figure 3.7).

Figure 3.7: Overall approach and methodology

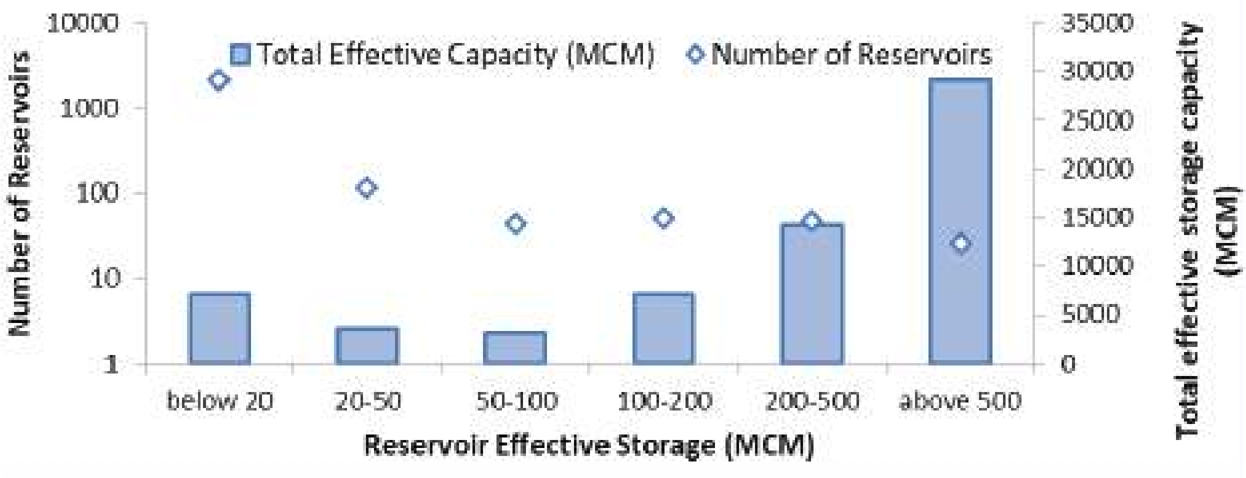
Group 1: Groundwater-based schemes that can sustain for 12 months	• **Konkan Divsion:** Palghar, Ratnagiri, Raigad, Sindhudurg, & Thane districts • **Amravati Division:** Akola, Amravati, Buldhana, Dhule, Jalgaon, Nandurbar, & Washim districts
Group 2: Groundwater-based schemes that need to be supported by surface water during lean (summer) season	• **Nagpur Division:** Bhandara, Chandrapur, Gadchiroli, Gondia, Nagpur, & Wardha districts
Group 3: Surface water schemes based on nearby sources (small dams in the hills or river lifting schemes serving individual villages and groups of villages)	• **Western Maharashtra:** Kolhapur, Pune, Sangli, Satara, Solapur, & Ahmednagar districts
Group 4: Bulk water transfer for Regional Water Supply Scheme (From WFRs to Marathwada region)	• **Aurangabad Division:** Aurangabad, Beed, Jalna, Osmanabad, Nanded, Latur, Parbhani, & Hingoli districts

The viability of this strategy depends on the following: i) the geographical location of large surface reservoirs and the engineering feasibility of transferring water from these reservoirs to areas where groundwater-based schemes are either not feasible or need to be augmented in certain parts of the year; and ii) the amount of un-utilized surface water resources in different river basins and the engineering feasibility of transferring water in bulk from these basins to areas inside the basin or outside the basin to either strengthen groundwater-based schemes or to build new surface water based schemes. It is quite obvious that the viability depends on the topography, the location of the reservoirs having surplus water, their FRLs and distance from places of demand, and how far the basins, where un-utilized surface water is available, are away from the locations of water demand. The topography, location and the reservoir elevation will determine the need for tunnelling, the distance of water transfer and the amount of lifting required, all of which have cost implications. In the subsequent section, we will illustrate how this strategy can be implemented.

Further analysis revealed that there are plenty of un-utilized water resources available in the east-flowing rivers of Maharashtra and in some sub-basins of the Godavari basin, which can be transferred to regions (such as Marathwada) where surface water resources are scanty. For instance, our estimates showed that the water resource availability in the east-flowing rivers is 62,600 MCM per annum. In the Godavari, it was 18,430 MCM per annum and in Tapi, it was 3,140 MCM per annum. Such transfers would require tunnelling, especially for water to be brought in from the east-flowing rivers as it has to cross the Western Ghats. The feasibility of such a water transfer would depend on the ability to create storage for the imported water. However, this also will not be a problem for the state owing to the presence of a large number of large and medium reservoirs spread across the basin.

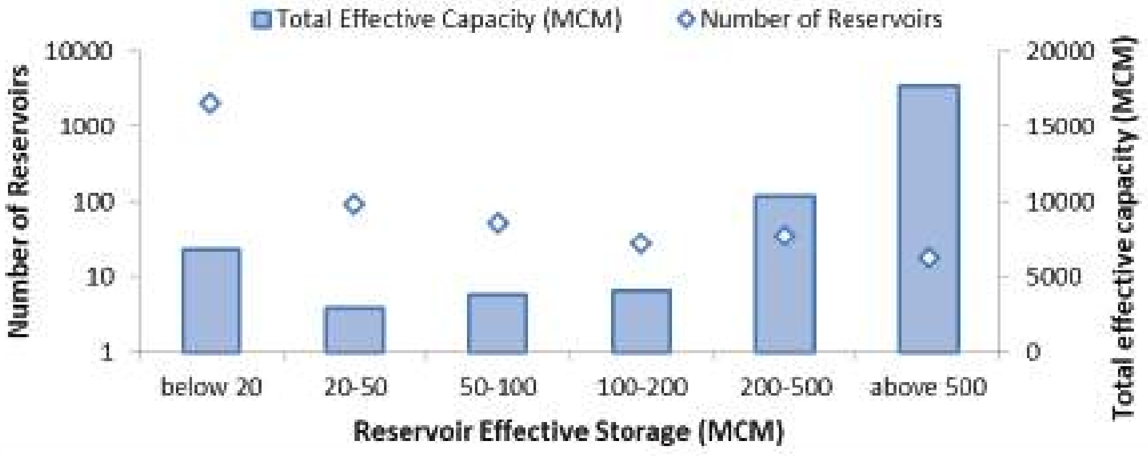
Our analysis showed that in Maharashtra, the overall gross storage capacity of around 2638 reservoirs for which data on storage is available is 64,130 MCM. Almost 88 per cent of the reservoirs have a gross storage capacity of less than 20 MCM each. Only three per cent of the total reservoirs (having storage capacities above 200 MCM) account for 68 per cent of the gross water storage capacity. Figure 3.8 shows the distribution of surface reservoirs in different storage categories and the total gross storage available under each category.

Figure 3.8: Distribution of reservoirs as per storage capacity and total gross storage

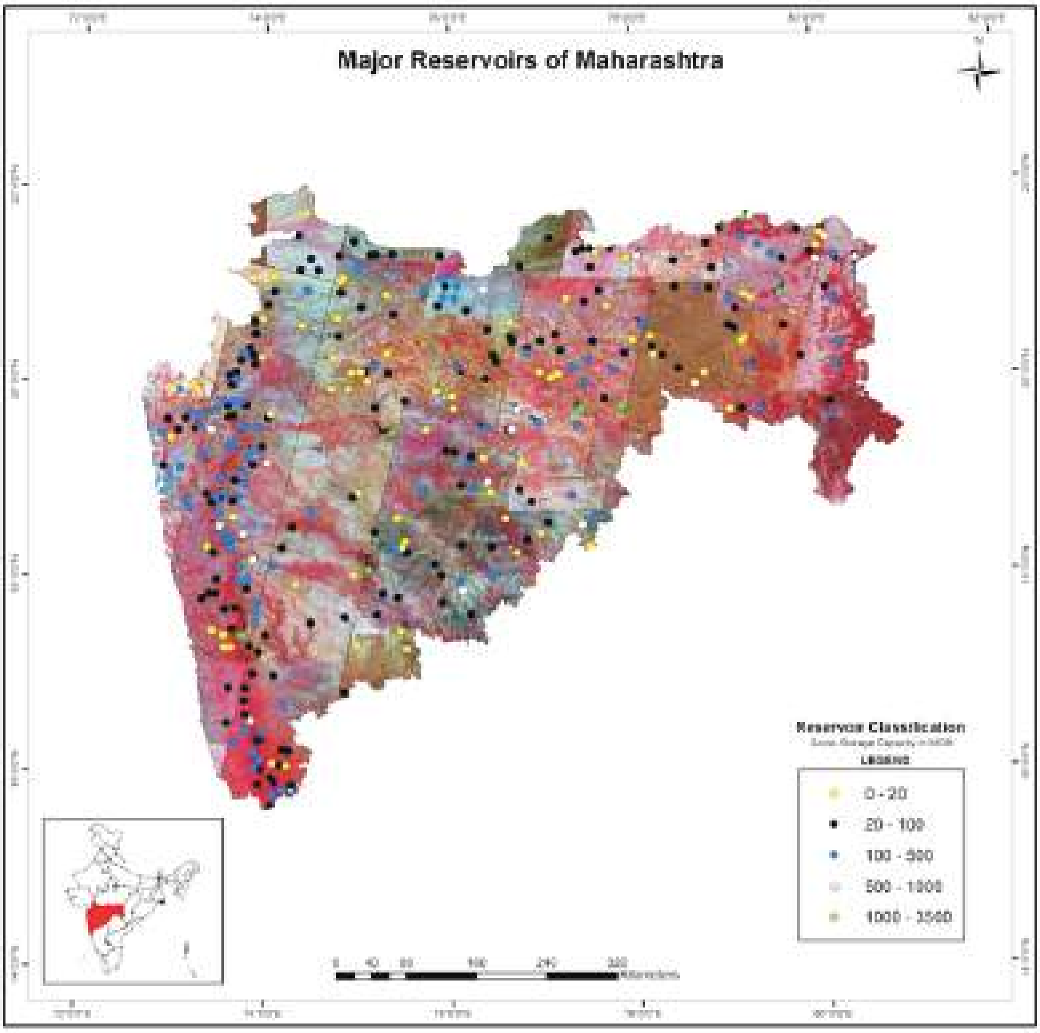


In terms of effective storage capacity, data for 2340 reservoirs are available. While 90% of the reservoirs have effective storage availability of less than 20 MCM each, only 3 per cent have above 200 MCM capacity. The latter accounts for 62 per cent of the effective water storage capacity, and the bulk water transfer for regional water supply schemes can be based on it. The smaller capacity reservoirs can be explored for strengthening the existing groundwater-based schemes. The distribution of the number of reservoirs and the effective storage capacity is presented in Figure 3.9.

Figure 3.9: Distribution of reservoirs as per the effective storage



Map 3.1 Shows the spatial distribution of the 240 reservoirs in the state of Maharashtra.



Large reservoirs are spread all over the state. The good geographic distribution of reservoirs in the state makes it easy for the transfer of water from one region to another and the subsequent storage of water in the region that receives the imported water.

This will take care of the requirements of the Group 4 districts. Multi-village schemes need to be designed around such water transfer projects, which are likely to be prohibitively expensive. For the Group 3 districts, either the building of small reservoirs in the hills (such as in the hilly areas of Pune, Sangli, Satara, Kolhapur and Ahmednagar) or river lifting can be adopted. Water from these reservoirs can be earmarked for drinking water supply alone. Water from such reservoirs can be supplied to a group of villages by gravity to make them cost-effective. In the hilly and undulating areas of Group 2 districts, there are already several reservoirs. Some of the water from these reservoirs can be reallocated for drinking water supply. Water can be directly lifted from these reservoirs for transfer to villages that face drinking water shortages during the summer, and water distribution pipelines to individual villages could be built. In situations where reservoirs are not available, new reservoirs can be built either within the district or in the neighbouring districts, depending on where within the region extra runoff is available and from where water can be transported.

4. Techno-institutional Models for Building Climate -Resilient and Multiple Use Rural Water Systems

4.1 Multiple Use Water Services: Conceptual Aspects

In India, rural water supply schemes are generally planned to meet the domestic water supply needs of the population. The per capita water supply levels considered for the design of the rural water supply schemes are generally 55 litres per day, which is a minor improvement from the earlier norm of 40 litres per day. However, rural populations also have many productive water needs (van Koppen et al., 2006; Kabir et al., 2016). For instance, households require water to meet livestock's watering needs. No separate provision is normally made for livestock watering in rural water supply plans, in spite of the fact that the rural areas of the country have a large livestock population, with cows, buffaloes, goats and sheep. Likewise, rural households, which do not have their own farmland and irrigation sources, prefer water for growing vegetables for the nutritional security of their families. Further, households that are not dependent on agriculture and allied activities for their livelihoods may need water to meet one or more of the productive water needs, such as pottery, fishery, pickle-making, and duck-keeping (Kabir et al., 2016). This is important for households that are economically poor (van Koppen et al., 2009; Kabir et al., 2016). The type of productive water need of a household will depend on the cultural background, agro-climatic setting, and occupational profile of the household (Kabir et al., 2016).

As regards culture, there are several examples from different parts of India that demonstrate the influence of culture on the types of water needs at the household level. The tribal communities in India generally keep small ruminants such as goats; they also raise chickens and undertake backyard cultivation of vegetables. The tribal communities in the north eastern region rear pigs in their homesteads. The influence of the agro-climate in high rainfall, sub-humid regions of India, especially in the western Ghat region, prompts farmers to raise fruit trees, especially mangoes and guavas, as these trees can grow without irrigation (Kabir et al., 2016).

Livestock keeping is emerging as a major source of livelihood, even in many low- and medium-rainfall, arid and semi-arid regions of India, especially in areas where cereal crops are intensively cultivated, which increases the availability of dry and green fodder (Kumar, 2007; Singh et al., 2004). The households, which own land with irrigation sources, generally grow vegetables in their fields and therefore would not need water for productive needs in their dwelling premises. Cattle rearers need water for livestock drinking unless they have irrigation sources. Families that have regular sources of income from employment are able to manage without water for productive needs as their economic conditions allow them to buy vegetables and milk from the market (Kabir et al., 2016).

In rural areas, conflicts occur between using water for economic good and social good. When water becomes scarce, poor communities often compromise on their personal hygiene requirements in an effort to meet the water requirements for productive needs. Failure on the part of the water supply agencies to maintain supply levels that can take care of productive as well as domestic needs can result in households not being able to realize the full potential of water as a social good. This can happen for two reasons: (1) available water is reallocated (van Koppen et al., 2009); and (2) they end up spending a substantial amount of time and energy finding water to meet their productive needs, which reduces their ability to fetch water from public systems and use it for personal hygiene. This generally impacts their productivity in the long run as the communities become susceptible to water-related diseases (Kabir et al., 2016).

Another possible outcome is that the systems by default become multiple-use systems though they are not designed to be one. While some of the unplanned uses may be absorbed by the system, other uses can damage it (van Koppen et al., 2009). This is compounded by the often intermittent and unreliable nature of water supplies. Water supply systems that do not consider the livelihood needs of rural communities fail to play an important role in their day-to-day lives. As the communities are not able to perform economic activities with the water supplied through public systems, they show a low level of willingness to pay for the services. This affects the sustainability of the system as official agencies are not able to recover the costs of their operation and maintenance (Kabir et al., 2016).

However, there is a growing appreciation of the fact that whenever such unplanned uses occur from "single-use systems" without causing significant damage to the physical infrastructure, it brings about improvements in all four dimensions of livelihood related to water. These dimensions are: freedom from drudgery; health; food production; and income (van Koppen et al., 2009). This leads us to the point that a marginal improvement in drinking water supply infrastructure and a marginal increase in the volume of water supplied could remarkably enhance the value of the water supplied in social as well as economic terms.

In most situations, ensuring sustainable allocation of water for household needs from available resources, rather than overall availability of water in a locality, is a real issue. As a matter of fact, even in the most water-scarce regions, the water requirement for household needs would be a small fraction of the total water required, as irrigated agriculture is practised in such regions as well. Nevertheless, it is important to recognize the fact that the common pool (or open access) nature of the groundwater, which is the major source of water available almost everywhere in the water-scarce regions to be tapped for household uses, makes it almost impossible to physically allocate water for household needs when there are competing water demands from the agriculture sector.

The competition for water from the agriculture sector becomes fierce during droughts when the water availability in the natural system dwindles. In many situations, surface water will have to be brought in from outside (from reservoirs located within the region or from water-abundant river basins outside the region) to supplement the available local groundwater sources. Our analysis has shown that the extent of dependence on exogenous water will depend on a wide range of factors, including the characteristics of the aquifers (effective recharge rate); the pressure induced on the aquifer by irrigation water demand); the extent of surface water irrigation in the locality; and the amount of storage space in the aquifer. The greater the values of these variables, the higher the chances are for the local drinking water wells to perform well and the lesser the need to depend on exogenous water (Kabir et al., 2022).

The other option is to tap alternate sources of water within the locality, including those that are unconventional (such as water from local catchments, water from roof tops, water from ponds, etc.). Water of inferior quality can be tapped for animal watering, flushing of toilets, etc. The Jal Jeevan Mission encourages tapping exogenous water to augment the local drinking water sources and also tapping unconventional water sources wherever possible.

Hence, the conventional techno-institutional models of rural water supply will not work in those areas where agricultural water requirements exceed total water resources in the utilizable form. In the next section, we will present some of the options. In the next section, we will discuss the techno-institutional models for provisioning water for domestic and productive needs in different regions of Maharashtra.

4.2 Techno-Institutional Models for MUWS for Different Typologies of Maharashtra

An earlier work in Maharashtra had developed, techno-institutional models for building rural water systems for multiple uses. The study covered three different regions of Maharashtra and one district from each region. The districts and the regions that they fall in are as follows: Satara in Western Maharashtra; Latur in Marathwada; and Chandrapur district of Vidarbha region. The study locations and the districts were selected in such a way that each one represented a unique physical, and socioeconomic setting. Satara is from the hilly region, receiving excessively high rainfall (around 2,500mm) and experiencing sub-humid climatic conditions. It is socioeconomically more developed than the Marathwada and Vidarbha regions.

Vidarbha region has hilly and undulating terrain, receives moderate to high rainfall (approximately 1,000mm) and is socioeconomically very backward with a population dominated by tribes. The region experiences frequent droughts, which have impacts on agricultural production. Groundwater potential in most parts of this region is quite poor with crystalline formations. The overall utilization of surface water resources in this region, most of which is part of the Godavari river basin, is quite low.

Latur is part of the Marathwada region, which is very water-scarce because of the excessive demand for water for agriculture combined with low rainfall and high aridity. Sugarcane, which is a highly water-intensive crop, is grown extensively in this region along with many other cash crops. The region is underlain by hard rock formations of basalt origin. Dependence on groundwater for irrigation is very high in the region. When the region witnesses droughts, the severity is very high. The droughts have had a widespread impact on drinking water availability. The technological models for multiple use water services (MUWS) identified for these regions are presented in Table 3.4.

Table 3.4: Technical Models for MUWS

Region	District Name	Technology	Remarks
Western Maharashtra (Pune division)	Satara	Underground reservoir for tapping spring water during monsoon season, when the discharge is high.	Rainfall dependability in the region is quite high. The water stored in the underground reservoirs can be used during the last months of summer when the wells dry up.
Vidarbha (Nagpur division)	Chandrapur	Small dam tapping water from the hilly catchments	Rainfall dependability in this region is comparatively higher than in the Marathwada region.
Marathwada (Nashik and Aurangabad divisions)	Latur	Lifting water from the shallow aquifer during the monsoon and storing it in surface reservoirs for use during the lean season	Rainfall dependability is low in the region. However, only a small fraction of the recharge is required for domestic water supply during the lean season. Water can be stored in underground or surface reservoirs.
		In areas that receive water for irrigation and drinking water supply through water transfer, regional water supply schemes catering to several villages can be planned as a long-term measure.	There is plenty of water in the east-flowing rivers of Maharashtra. A small fraction of this water can be transferred to the Marathwada region for water supply and irrigation. Irrigation through gravity will also help improve the sustainability of drinking water wells in the region.

The types of technologies that are possible for the other two divisions of Maharashtra are discussed in Table 3.5

Table 3.5: Types of technologies possible for the other two divisions of Maharashtra

Region	District Name	Technology	Remarks
Konkan	Raigadh, Ratnagiri, Sindhudurg, Thane, Palghar and Mumbai City	In the alluvial and laterite areas, open wells can be used for supplying water for domestic and productive uses.	The rainfall is very high in the region, and the year-to-year variability in rainfall is also low. More importantly, the agricultural water demands are quite low. However, homesteads are common, and backyard cultivation is a common practice in the area. The domestic water supply systems in such areas need to take care of such needs of poor households that do not have private water supply sources.
Amravati	Akola, Amravati, Buldhana, Washim and Yavatmal	In the deep alluvial areas, single village schemes based on tube wells can be constructed. They can provide round-the-year water supply for domestic and productive uses. In areas underlain by basalt, the strategy proposed for the Marathwada region shall be followed.	Groundwater in this alluvial belt is depleting due to over-draft for irrigation. The region receives medium rainfall. There is a proposal to undertake large-scale recharging of aquifers in the region.

4.3 Funding Envelope and Proposed Institutional Arrangements to Operationalize

There are several central schemes on rural employment, groundwater management, water use efficiency in agriculture, rural drinking water security, and water quality management whose funds can be tapped for undertaking a number of activities that would help improve water resources management and the sustainability of existing rural water supply schemes by supporting activities and interventions that improve the conditions that contribute towards these objectives.

However, we will discuss the schemes that contribute to the larger objective of improving the sustainability of rural water supply schemes and enhancing their service levels (to meet productive as well as domestic water needs), the activities under those schemes that actually contribute to achieving the objectives, the components of the schemes that are relevant, and the funds available under them in the state.

MGNREGS

There are many activities related to water conservation, drinking water provisioning, the renovation of traditional water harvesting structures, and water harvesting & water conservation available under MGNREGA for which funds are allocated.

Out of these, the funds under the heads, 'water harvesting and water conservation', and 'renovation of traditional water harvesting systems' can be used for improving the sustainability of the rural water supply schemes in hard rock areas and raising their service levels. The funds available for water conservation and water harvesting, and drinking water supply can be used in areas such as western Maharashtra for building small dams for drinking water supply in the villages. These are areas where a lot of surplus runoff is available locally for harnessing. The details of the financial outlay are provided in 3.5 of Section II of this report.

The schemes for water harvesting and water conservation can be implemented by the district Panchayat and the GPs with technical guidance from GSDA. The schemes for building small dams can be implemented by MJP with technical guidance from the Water Resources Department of the state. The budget under renovation of traditional water harvesting can be used in areas where minor irrigation tanks are available locally for jungle clearance, cleaning, desilting and enhancing the storage capacity (wherever catchment hydrology is favourable). Water from such reservoirs can be used for augmenting domestic water supplies for low-value uses such as watering of animals and bathing.

Atal Bhujal Yojna

The funds under the two heads, viz., preparation of community-led water security plans and public financing of approved water security plans through convergence of ongoing/new schemes, can be used to support projects to strengthen existing bore well-based schemes in areas where they are performing poorly during peak summer months, which can include artificial recharge schemes wherever they are feasible with favourable geohydrology and availability of surplus runoff. To complement this, the funds available under water use efficiency improvements can be channelized to support farmers in adopting efficient water use technologies such as drip irrigation and mulching for crops in areas where the intensity of groundwater use for irrigated agriculture is very high. Marathwada is one such region where groundwater use is intensive and where farmers grow high-value horticultural crops that are also amenable to drip irrigation. Efficient irrigation technologies should be aggressively promoted in that region. However, the precondition for supporting such interventions should be that the farmers do not expand the area under irrigation post adoption of these technologies.

The agencies that implement these schemes in Maharashtra shall be the GSDA (in the case of village water security plans and groundwater recharge schemes) and the state agriculture department (in the case of the promotion of efficient irrigation technologies).

Jal Jeevan Mission

The funds from Jal Jeevan Mission can be used for a wide range of activities related to rural water supply, from augmentation of existing water sources to providing new sources of water supply, including those that involve bulk water transfers, retrofitting of existing schemes to provide FHTCs to achieve minimum service levels, and the development of reliable water sources. These funds should be handled by the MJP. The plan for augmentation of the existing schemes should consider the water requirements for productive as well as domestic water needs of rural households, the chances of drying up of the existing sources during the lean season, and the number of months for which water from exogenous sources would be required. The plans for the creation of new sources should also consider the productive as well as domestic water needs of the rural households while assuming that the entire water demand is met from the new source. Accordingly, fund allocation will have to be decided. For non-conventional sources such as RWHS, RO systems and small dams, the design will have to be tailor-made, and the costs will have to be worked out on the basis of the local conditions.

5. Synthesis

The impact of rainfall variability, an important dimension of climate hazard that causes droughts, on the life cycle cost of water supply schemes was analyzed. The life cycle cost is a clear indicator of the physical sustainability of the water supply scheme in the sense that a high LCC suggests poor sustainability of the scheme. This was done by analyzing the life cycle cost of water supply schemes in two distinct areas: one where the annual rainfall is low to medium with high year-to-year variation and groundwater is available in hard rock formations, and the other where the rainfall is high with lower year-to-year variation but better groundwater conditions with some stock in the alluvial and laterite formations. The analysis showed a very high cost of water supply with bore wells in Latur district, due to the very short life of the scheme owing to failure during droughts.

The comparative analysis of groundwater levels during the monsoon for dry and wet years for five districts from Nashik division and six districts from Kongan division of Maharashtra clearly illustrated how the sustainability of water supply schemes is threatened by droughts, with reduced recharge during the monsoon in the dry years. In the case of Ratnagiri district, where the groundwater condition was better, the incidence of the occurrence of droughts was almost nil, and the incidence of well failure was not reported.

The real cost of groundwater-based drinking water schemes in such areas will be high, as our analysis for Latur has shown. While the life of the schemes varied from four to 35 years, the life cycle cost ranged from INR 2.7 per m3 to INR 15.7 per m3. The analysis of LCC of the water supply schemes once again reinforces our argument for either entirely shifting to reservoir based schemes or going for conjunctive use of groundwater and water from surface reservoirs, depending on the gravity of the problems vis-à-vis groundwater scarcity. However, the life cycle cost approach is still not used by the government agencies that plan and invest in rural water supply schemes.

Among the four typologies of areas identified in Maharashtra vis-à-vis the probability of success of rural water supply schemes, the strategies for improving the sustainability of the rural water supply schemes in the last three typologies are: 1) augmentation of groundwater-based schemes from surface water during the lean (summer) season in districts falling in Typology 1; 2) surface water schemes based on nearby sources (small dams in the hills or river lifting schemes serving individual villages and groups of villages) for districts falling in Typology 2; and 3) bulk water transfer for the Regional Water Supply Scheme (from WFRs to Marathwada region) for districts falling in Typology 3. The experts who were interviewed by the researchers were of the opinion that in regions such as Marathwada (which falls under Typology 4), long-term measures such as bulk water supply would be required for ensuring the sustainability of the rural water supply schemes, unless we are able to control unbridled groundwater withdrawal for irrigation.

The high (life cycle) cost of rural water supply schemes based on wells in low- to medium-rainfall hard rock areas that witness high well failures (as mentioned previously) justifies the investment for building surface water supply schemes that involve bulk transfer of water from water-rich areas, though the capital cost of building such schemes is quite high. As our earlier analysis has shown, the amount of money spent on supplying water through tankers during the lean season alone can justify the investments required for water transfer schemes for building multi-village drinking water schemes based on surface water. The cost-effectiveness of such interventions can be judged by looking at the extent of dependence on tanker water supply, and the amount of money households spend procuring water. If we go by a conservative estimate of 20 per cent of the rural households in the districts where drinking water wells do not perform well, depending on tanker water for three months in an average year, the additional water to be supplied through tankers to overcome water scarcity comes to 77.75 MCM per annum. At an average price of INR. 250/m3 for tanker water (i.e., INR 0.25/litre), the expenditure would be INR 1,943 crore per annum for tanker water supply alone.

Building on an earlier work in Maharashtra (covering three districts, viz., Satara, Latur and Chandrapur) that analyzed the multiple use water needs of the rural areas and also explored viable techno-institutional models of rural water systems that can provide water for productive as well as domestic uses in each situation, we have also proposed techno-institutional models for multiple use water systems in rural areas of the state for different typologies that are capable of providing water for productive as well as domestic uses. The development of such models also considered the larger macro-level strategies for promoting the conjunctive use of surface water and groundwater in rural areas to improve the sustainability of rural water supply schemes. Keeping in view the need for multiple use water services, the approach and methodologies for planning, technology selection and design of water supply schemes for rural areas were also discussed.

6 Conclusions and Policy

The high life cycle cost of water supply schemes based on groundwater in hard rock areas with poor groundwater potential supports the argument that it is not advisable to invest in bore well-based schemes in such areas, and the cost of supplying water through tankers during periods of stress (peak summer months) that is required to maintain the minimum level of service increases the real cost of water supply from groundwater in such regions. The analysis makes the case for investing in reservoir based water supply schemes in such regions, catering to multiple villages. However, reservoir-based multi-village schemes are highly capital intensive, despite having a much longer life. Hence, in order for government priority to shift from bore well-based single village schemes to multi-village schemes based on groundwater, it is important that we follow the life cycle cost approach in planning rural water supply schemes. The adoption of multi-village schemes based on large reservoirs will allow the water supply agency to change the norms pertaining to per capita supply levels so as to accommodate water for productive as well as domestic needs, as the agency will be able to exercise control over water allocation and use from public reservoirs.

However, this calls for a paradigm shift in the planning of rural water supply schemes. The thinking within water supply agencies should be reoriented to consider the life cycle cost of the infrastructure while looking at investments for rural water supply schemes rather than just the initial capital cost. This necessitates training of officials at the higher level in departments concerned with rural water supply on the concept of LCCA and ways to employ this concept for analysing the comparative costs of different types of water supply schemes. Fund mobilization is also equally important. Earlier analysis showed that source strengthening of bore well-based schemes in districts where they do not perform well by augmenting them with surface water supplies during the lean season (for three months) and complete replacement of poorly-performing bore well-based schemes with multi-village schemes based on surface water (from within the region and outside) would require an investment to the tune of INR 9,550 crore for securing additional water supplies to meet a total annual demand of 1,361 MCM of water. However, such investments appear to be cost-effective when we consider that the annual expenditure on tanker water supply in the state required to tide over the crisis during the summer months would be to the tune of INR 1943 crore.

Section IV:
Technical Feasibility and Cost Effectiveness of Solar-Powered Drinking Water Supply Schemes

Summary

In recent years, there has been an increasing tendency among the government agencies working in the water and energy sectors to go for cleaner technologies as a strategy for reducing carbon emissions to mitigate climate change and for increasing the ability to secure electricity for running the pumps in the remote areas that are not connected to the electricity grid. Since there are many remote villages in every state that are not connected to the electricity grid, solar power has received great attention in the recent year for drinking water supply. The technology is largely viewed as a reliable source of power with an average life of 25 years, against the erratic power supply provided by the state power utilities in many rural areas.

The government of Maharashtra has also launched a scheme to introduce solar-powered drinking water supply systems, especially in the remote areas of the tribal dominated districts of the state. A total of 1830 schemes are already installed in the Gadchhiroli district alone. Solar PV systems are highly capital intensive. However, there is hardly any scientific assessment of the workings of these schemes to see their technical feasibility, emission reduction benefits and overall cost-effectiveness.

Given this background, a study was undertaken to examine the efficacy and cost-effectiveness of the solar-powered schemes. The study involved a case study of six villages from Gadchiroli district. The analysis showed that the solar powered schemes are working well and are able to provide reliable water supply for drinking and domestic uses in the hamlets in which they were installed. However, they are found to be more expensive than water supply wells powered by electric motors in terms of the cost of water supply per unit volume of water supplied, even after considering the clean energy benefits of such schemes. However, they were found to be a little less expensive than diesel engines. The cost of running the solar PV system was INR 125,408, compared with INR 29,770 for an electric pump and INR. 168,929 for a diesel engine.

The analysis considered the cost of a solar PV system to generate the amount of solar energy required to pump a total of 30.332 m3 of water (capable of meeting the water requirement of a hamlet with a population of 214 persons) and compared it with the cost of running an electric motor and a diesel engine, which can generate the electrical energy that is required to lift the same volume of water. The combined life of the solar PV system, the electric motor and the diesel engine considered for the analysis was 12 years. The discount rate considered was 6 per cent. The benefits from the reduction in carbon emissions through the use of solar power were estimated to be a mere INR 4650 when compared with electric pumps and INR 3881 when compared with diesel pumps.

Hence, such schemes will be desirable in very remote villages that do not have reliable power supply and where obtaining diesel for running diesel engines is difficult. They can also be considered for some of the economically most backward tribal areas of the state, where the communities do not have the wherewithal to pay for the cost of operation and maintenance of the conventional schemes run by electricity.

1. Introduction

In recent years, there has been an increasing tendency shown by the government agencies working in the water and energy sectors to go for cleaner technologies as a strategy for reducing carbon emissions aimed at the mitigation of climate change impacts. This tendency is seen in the drinking water sector as well, with the state water supply agencies going for solar-powered drinking water supply schemes. In addition to reducing carbon emissions, one major reason for the increasing preference for this technology for drinking water supply schemes is the ability to secure electricity for running the pumps in remote areas that are not connected to the electricity grid. Since there are many remote villages in every state that are not connected to the electricity grid, solar power has received great attention in the recent year. The technology is largely viewed as a reliable source of power, against the erratic power supply provided by the state power utilities in many rural areas. It is also assumed that the system will last for as many as 25 years in good working condition, producing clean energy. The state of Maharashtra has also launched a scheme to introduce solar-powered drinking water supply schemes, especially in the remote areas of the tribal dominated districts of the state.

A total of 1830 schemes are already installed in Gadchhiroli district alone, which has seen the highest adoption of solar PV systems for powering drinking water wells. Solar PV systems are highly capital intensive. Maharashtra already has more than 5,000 such schemes. However, there is hardly any scientific assessment of the workings of these schemes, to see their technical feasibility, emission reduction benefits and overall cost-effectiveness. Given this background, a study was undertaken to examine the efficacy and cost-effectiveness of the solar-powered schemes.

2 Theoretical Aspects of the Working of Solar-Powered Drinking Water Supply Schemes

There are two major issues that concern the operation of solar-powered drinking water supply schemes. The first is the ability to generate reliable power, which in turn is to be used for running the water pump. The second issue is the cost per unit volume of water pumped through a solar-powered system. The first issue concerns technical feasibility, and the second concerns cost-effectiveness. The ability to generate power on a daily basis depends on the solar irradiance in a day, which depends on the number of hours of sunshine per day and the intensity of the solar radiation. In situations where the available sunshine is of short duration (due to cloud cover during the monsoon or during winter) or of low intensity (during winter), the amount of power generated by a unit area of the solar PV system will be severely affected. In such cases, this can be compensated for by increasing the size of the panel. However, this would increase the cost of the system. In such cases, the energy production potential will vary with the season. The most ideal situation is when the power generation potential of the system coincides with the demand for power, i.e., when the power generation potential is high, the demand for water is also high, and the source (for example, an aquifer, lake, a pond, or a river) has an adequate quantum of water to supply. The cost-effectiveness of the system will also depend on how optimum the design of the panel is, i.e., how well factors such as the peak demand for electricity during any part of the year and the lowest power generation potential of the panel during any part of the year have been taken into account while fixing the size of the panel. It is also important to reckon with the fact that the availability of water at the source would limit the peak power demand.

3 Working of Solar-Powered Drinking Water Supply Schemes in the Tribal Areas of Maharashtra: Field Evidence

3.1 Socioeconomic Features of the District of Gadchiroli

Gadchiroli District is situated in the south-eastern corner of Maharashtra and is bound by Chandrapur district in the west, Gondia district in the north, Chhattisgarh state in the east, and Andhra Pradesh state in the south and southwest. Gadchiroli district stretches over an area of 14,412 sq. km. In terms of geographical extent, the district constitutes 4.68% of the total area of the state (see Table 4.1).

The total district population, according to the 2011 census, was 1,071,795. The district is highly rural. Of the total population, 93% live in the rural area. About one-third (38.3%) of the population is tribal (13). Around 75% of the total land area of the district is covered by forests. The literacy rate of the district is 66%. Subsistence farming and farm labour are the main occupations in the district, and in 2011, the per capita annual income was Rs 33,504 (see Table 4.1).

Out of the total geographical area of the district, 1133 thousand hectares are under forest. The district is largely known for its tribes. Most of the geographical area (85.76%) of the district is occupied by forest, and therefore, cultivable land is very limited. The primary profession of individuals is cultivation or farming. There is no large Industries in the whole district.

Table 4.1: General profile of the Gadchiroli District

District Headquarter	Gadchiroli
Geographical Area of the district	14412 sq.km.
Average Rainfall (2022)	885 mm
No. of Tehsils	12
Total Population	1071795
Male	542813
Female	528982
Population Density	67 per sq. km
Literacy total rate	66.03%
Male	72.98%
Female	58.92%

Of the total area of 14,412 sq. km, only around 13 per cent of the land is cultivable. Paddy is the major crop. However, forest-based resources contribute significantly to the primary sector and the economy of the sector. Gadchiroli is an industrially backward district. There is only one large sized industry unit in the district, viz., Ballarpur Industries (paper industry). The district has 733 Micro, Small and Medium Enterprises (MSME), employing 4,843 persons. As of September 2012, the prominent MSME industries in the district were 'wood, products of wood', 'food products and beverages', and 'furniture'.

As of 2010-11, Gadchiroli district had the lowest Gross Domestic Product (GDP) in Maharashtra at Rs 4,851 crore (0.45 per cent of the Gross State Domestic Product). Even in terms of per capita, it ranked the lowest amongst all the districts at Rs. 43,058 per annum. This was almost half of the state average of Rs. 87,686. The district's economy is predominantly service-based, with the service sector's share of the GDP at 61 per cent in 2009-10. This is followed by the primary sector at 22 per cent and the secondary sector at 17 per cent.

3.2 Working of the Solar-Powered DW Supply Schemes

A total of 13 schemes were covered by the survey on solar-powered drinking water supply schemes in the tribal hamlets of Gadchiroli district. The implementing agencies are: Zilla Parishad in eight cases; Gam Panchayats in two cases; an NGO (BAIF, Pune) in two cases; and Groundwater Survey and Development Agency (GSDA) in one case. The schemes were implemented under programmes such as the National Rural Drinking Water Programme (NRDWP), Jal Jeevan Mission, the Special Central Assistance Scheme, and in a couple of cases, the projects run by NGOs. The total investment ranged from Rs. 4.1 to a maximum of Rs. 7.41. In five out of the 13 cases, the investment was INR 7 lac and above. The number of HHs covered by the scheme ranges from a low of 20 (in one case) to a high of 45 (in two cases). The average capital investment per HH ranged from a low of INR 16,000 to a high of approximately INR 30,000. In most cases, the source of water was a bore well; in some cases, it was an open well. Sensor-based automation was used to run the water pump in six out of the 13 cases. As regards the functionality, in three cases, leakages in the distribution system were found to be an issue. One of them has been found to have been defunct for the past three years. In one case, the pump broke down, and since then the scheme has been defunct. Only in one case was the village water supply committee found to be collecting the water charges from the households. In none of the cases were there issues with the functioning of the solar PV system.

The key observations made during the field visits regarding the salient features of the scheme are provided in Table 4.2 in a structured format.

Table 4.2: Salient features of the Solar-Powered Drinking Water Supply Scheme in Gadchiroli

Sr. No	Hamlet/ Village Name	Name of the Scheme	Implementing agency	Cost of the scheme (INR)	Sensor-based automation in operation of the scheme	Type of water source	Number of Households covered	Is water supplied through the distribution system (YES/NO)	Any functionality issue (explain)	O & M Costs (INR)	Water Charge (INR)
1	Patiltola, Kak Adyeli	Jal Jeevan Mission	Zilla Parishad	7,00,000	Yes	Bore well	30	Yes	None	None	None
2	Sadaktola, Kak Adyeli	Jal Jeevan Mission	Zilla Parishad	7,00,000	Yes	Dug well	30	Yes	Pump was stolen from the dug well	New pump was set up, with a cost of INR 90,000 (the pump replacement cost)	None
3	Mahajantola, Kak Adyeli	BAIF solar drinking scheme	NGO	7,41,000	No	Dug well	25	No, villagers collect water from stand post	None	INR 1,68,000 spent under PESA funds by the GP to provide the HH connection	INR 35 per month
4	Paraswadi	GSDA scheme	Groundwater Survey & Development Agency	5,43,000	No	Bore well	45	Yes	Pump failure from past six months	None	None
5	Kanatola, Lekha	Jal Jeevan Mission	Zilla Parishad	7,00,000	Yes	Bore well	34	Yes	None	None	None
6	Sawela	Rashtriya Grameen Payjal Yojana	Zilla Parishad	5,09,569	Yes	Bore well	25	No, villagers collect water from 5 stand post	None	None	None
7	Bhikar Maushi	Jal Jeevan Mission	Zilla Parishad	7,00,000	Yes	Bore well	45	Yes	Leakage issues in distribution pipelines	None	None

Sr. No	Hamlet/ Village Name	Name of the Scheme	Implementing agency	Cost of the scheme (INR)	Sensor-based automation in operation of the scheme	Type of water source	Number of Households covered	Is water supplied through the distribution system (YES/NO)	Any functionality issue (explain)	O & M Costs (INR)	Water Charge (INR)
8	Ambetola, Bhikar Maushi	Rashtriya Grameen Payjal Yojana	Zilla Parishad	5,09,569	No	Bore well	20	Yes	None	None	None
9	Murumbodi, Bhikar Maushi	Special Central Assistance Scheme	Zilla Parishad	5,33,547	No	Bore well	30	Yes	None	None	None
10	Pandharasar	BAIF solar drinking scheme	NGO	7,41,000	NO	Bore well	25	No, Villagers collect water from stand post	None	None	None
11	Katezari	Gram Panchayat solar based drinking scheme	Gram Panchayat	4,10,000	NA	Bore well	25	Yes	Pipeline leakages were caused due to the bullock cart hitting the pipeline. Scheme has been inactive for 3 years.	None	INR 75 per month
12	Girola	Jal Jeevan Mission	Zilla Parishad	7,00,000	Yes	Bore well	40	Yes	Leakages at 5 places in the distribution line	None	None
13	Salebhatti	Gram Panchayat solar-based drinking scheme	Gram Panchayat	4,10,000	No	Bore well	40	Yes	Breakdown of the pump	None	None

Source: authors' own analysis based on the data collected during field visits

3.3 Analyzing the Technical Feasibility, Cost Effectiveness and Carbon Benefits of Solar-Powered Drinking Water Schemes

The technical feasibility of solar-powered drinking water schemes depends on the efficacy of the working of the solar photovoltaic system. At least during the first few years of the installation of the solar PV system, the technical feasibility of solar-powered pumps does not appear to be a concern, as demonstrated by the experience of the 13 villages of Gadchiroli that were surveyed. The potential constraints for smooth working of the solar PV systems are: i) insufficient solar radiation (due to cloud cover, especially during the monsoon season); ii) dusting and degradation of the panels; and iii) reduced voltage generation due to over-heating of the panels during peak summer months when the temperature rises to 42 to 45 degrees centigrade. In the case of cloud cover, the problem can be overcome if extra water is pumped and stored in buffer storage space on days when good sunshine is available. Or else a storage battery can be provided.

As regards dusting and panel degradation, such problems can affect the performance of the solar PV system in terms of the voltage generation. Now the problems due to dusting can be overcome if proper cleaning of the panels is done regularly. Such problems were not reported during the field work. As regards the problems of panel degradation, they generally occur in the long run, and the schemes in Gadchhiroli are too recent to witness such problems. As regards overheating of the panels, such problems were not reported to be affecting the scheme's performance. Even if such problems occur, they can be overcome by spraying water on the panels to cool them. Our analysis shows that in 46 per cent of the cases (i.e., 6 out of the 13 cases), no technical or other problems were reported (i.e., no issue of functionality). In the remaining cases (54 per cent), problems such as pipeline failure (7%), leakage in the pipeline (15.4%), pump failure (15.4%) and pump theft (15.4%) were reported (see Figure 4.1).

The results of the survey done in the 13 villages of Gadchhiroli are presented in Table 4.3. It can be seen that the average size of the population covered by the schemes is quite low, equal to that of a hamlet. It can also be seen that the average volume of water supplied by the scheme is nearly half the amount required by the households to meet all the human and animal uses. While it is more than the amount of water required to meet human needs, it is much less than what is required to meet the entire household's needs, which include livestock watering. Because most households would use the water from public schemes for high-priority needs like drinking and cooking, bathing, cleaning and washing, only a fraction of the total water required for animal uses may be met by the schemes. It is quite likely that the rest of the water needs of the animals are met from informal sources, including the old open wells, ponds and farm wells.

Table 4.3: Technical performance of the solar-powered drinking water schemes (N=13)

S. No	Parameters	Mean Value	Minimum/ Maximum
1	Average number of HH connections	29	20/45
2	Average length of the rising main (meters)	65	19.5/80
3	Average Total Head (meters)	15	4.93/70.75
4	Average Dynamic Head (meters)	42	10.5/72.5
5	Average Size of the Population (of the 13 villages) dependent on the scheme	216	100/725
6	Average Livestock Population of 13 villages	282	170/670
7	Average total daily water requirement of the village for human uses (lit/day)	11,880	5500/39875
8	Average total daily water requirement for livestock (lit/day)	18,442	9000/37500
9	Average total daily water requirement of the village (lit/day) (including human and livestock populations)	30,322	18090/77375
10	Average daily per capita water requirement of the households (lpcd)	156	97/210
11	Average depth of the pump (meters bgl)	38	6/68
12	Average depth of water table (meters bgl)	7	2/9.1
13	Average depth of the bore well/open well (meters)	47	10/73
14	Average hours of pumping in a day (hours)	5.7	
15	Pump Discharge (m^3/hour)	2.706	
16	Average volume of water pumped in a day (litre)	15,420	

Source: authors' own analysis based on primary data

As regards cost-effectiveness, unlike conventional energizing devices (such as diesel engines and electric motors) used for pumping water from underground, the cost effectiveness of the solar PV system is a direct function of the capacity utilization, as it is only the installation cost and the life of the panel that mainly determine the cost-effectiveness, since the operation and maintenance costs are, by and large, very minor.

That said, several of the above-mentioned factors can affect the cost effectiveness of the system. An increase in the number of days of cloud cover means a greater requirement for a storage battery or storage reservoir. Both increase the cost of the system. Faster degradation of the solar panels means a shorter life of the system, which again increases the cost of pumping a unit volume of water. Increased heating of the panel can drastically reduce the outputs due to a sharp reduction in voltage. Reduced hours of sunshine, especially during the winter and rainy seasons, would demand a larger-sized panel, raising the cost yet again.

Hence, the solar PV system will have to be designed to provide a sufficient quantum of water to cater to a day's total water requirement for drinking water supply under the most adverse conditions (limited hours of sunshine and low intensity of solar radiation). Needless to say, the most favourable condition is one in which the sunshine is uniform throughout the year.

To work out the cost of the solar PV system, the main cost variable is the size of the panel.

The main design consideration for working out the size of the PV panel is the total amount of solar energy available per sq. m of the panel under standard conditions , the energy conversion ratio of the panel (15%), the total water to be lifted from the source per day, and the amount of energy required to pump a unit volume of water. The design variable is the area of the panel required.

The solar panel area can be worked out as: Total energy required per day to pump the water from a depth / the energy produced by the panel with an area of 1 sq. m

$= ((V \times 9800 \times H)/ (3600 \times \mu))/ (1000 \times n)))$; where n is the energy conversion ratio, which can be considered as 0.15

$= 0.018 \times V \times H/\mu$ (where V is in m3; H is in metres; and μ is the efficiency of the pumping device).

The volume of water to be lifted using the pump 'V' is determined by the domestic water requirement of the village or hamlet that is to be catered to per day. The estimation of V (m3) should consider the water for livestock as well as human uses.

The cost of the solar PV system can be compared against the cost of running a standard electric engine or diesel pump for drinking water supply, based on the premise that it will pump out the same volume of water (V') in a few hours every day. Since in the case of a solar PV system, the capital cost includes the cost of the solar pump, in the case of electric and diesel engines, both the capital cost of the engine and the operation and maintenance cost had to be considered.

A few assumptions were made for evaluating the cost of various options. First, the life of the solar panel is assumed as 12 years. The life of the electric pump is also taken to be 12 years. The discount rate considered is 6 per cent. Since all other appurtenances are the same between a solar-powered drinking water scheme and an electric motor driven well, they are not considered in the cost comparison. The cost of connection to the grid is not considered as it is assumed that the village is electrified. The energy conversion ratio for diesel engine is considered to be 1 KWhr of energy = 0.315 litres of diesel, and therefore the amount of diesel required for running the pump to generate 1,041 watts, which is the energy required to pump the water required for water supply, is 0.32 litres per day.

The results are presented in Table 4.4. It can be seen that the direct cost of supplying water using a solar PV system is far greater than that of an electric pump but lower than that of diesel engines. Now, if we consider the benefit of reducing our carbon footprint through solar power, which is considered clean energy, then the cost of running an electric pump using the power from the grid (which is based on fossil fuel) should include the cost of carbon emissions.

The carbon footprint from the generation of every kilowatt hour of electricity produced from thermal power is 0.96 kg of CO_2 or 0.26 kg of carbon . In order to estimate the monetary value of this cost, we follow the following methodology: David and Herzog from MIT had estimated the mitigation cost of carbon emissions from various thermal power plants. They estimate that for a Pulverized Coal power plant, it costs US $ 49 to reduce carbon dioxide emissions by one ton. Here, preventing 0.96 kg of CO_2 emission from a thermal power plant would require USD

[3]To determine solar panel efficiency, panels are tested at Standard Test Conditions (STC). STC specifies a temperature of 25°C and an irradiance of 1,000 W/m^2. This is the equivalent of a sunny day with the incident light hitting a sun-facing 37°-tilted surface. Under these test conditions, a solar panel efficiency of 15% with a one sq. m surface area would produce 150 watts.

[4] These estimates are based on data available from the United States Department of Energy on the amount of electricity produced from various fossil fuel-based power plants.

0.047, or 1.02 Indian rupees (based on a purchasing power parity adjusted conversion rate of I USD = 21..69 INR). This can be considered the negative externality of running an electric pump that consumes 1 kilowatt hour of electricity. Hence, the total cost of carbon emissions for the entire life of 12 years comes to INR 4650 (1041 X 365 X 12 X 1.02/1000).

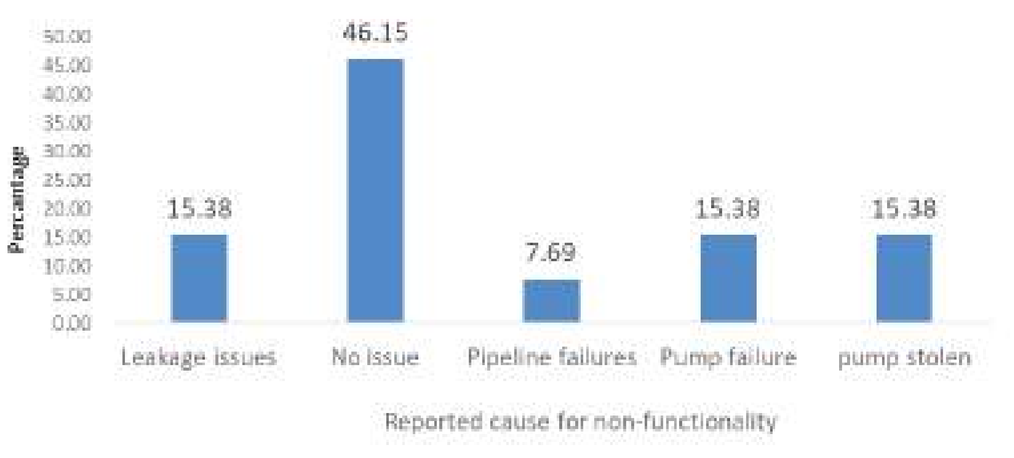
Similarly, using a diesel engine to pump the same amount of water that the solar PV system pumps out for drinking water supply would require 1436 litres of diesel in the entire life of the pump (12 years). The total CO2 emission from this will be 2.65 X 1436 = 3,805 kg of CO2. Hence, the carbon emission cost will be Rs.3881 (i.e., 3,805 X 1.02) during the entire life cycle of the engine. Even after considering the indirect cost of using the electricity generated from fossil fuels, solar-powered drinking water wells are not as cost-effective as those powered by electric pumps. However, they are more cost-effective than diesel engine-powered drinking water wells.

Table 4.4: Cost comparison for solar, electric motor and diesel engine-powered drinking water schemes

Particulars	Solar pumping system (INR)	Electrical pumping system (INR)	Diesel engine powered pumping system (INR)
Capital Cost of the System	1,23,731.00	4,500.00	13,000.00
Average Annual Maintenance Cost	200.00	500.00	1,000.00
Cost of supplying electricity through the grid (for the same number of years for which a solar PV system is functional)	N.A	16,428.00	
Cost of diesel for running diesel engine for supplying the same quantum of water (to produce 1041 watts of energy daily)			1,43,664
Total of annual maintenance cost, discounted to the zeroth year	1,677.00	4,192.00	8,384.00
Total Direct Cost of the system, including O & M	**1,25,408.00**	**25,120.00**	**1,65,048.00**
Cost of carbon emissions from using the electricity generated through fossil fuels		**4,650.00**	**3,881.00**
Total Cost including the Carbon Emission Cost	**1,25,408.00**	**29,770.00**	**1,68,929.00**

Source: authors' own analysis based on primary and secondary data

Figure 4.1: Percentage of solar systems that faced non-functionality due to various reasons



3.4 Funding Envelope and Proposed Institutional Arrangements to Scale Up

There is a centrally sponsored scheme of providing clean drinking water supply using solar power from the Ministry of Renewable Energy called the Special Assistance Central Scheme. In Maharashtra, the scheme is administered by the Maharashtra Energy Development Agency (MEDA). A subsidy of 30% is available under the central scheme for installed capacity up to 3 kWp. There are also schemes available under the Jal Jeevan Mission to provide reliable drinking water supplies to remote rural/tribal areas. The capital cost of the scheme can be covered by the funds available from the JJM for the state (please see section 3.5 of Section II for details of the financial outlay). Both can be tapped for building solar-based drinking water supply schemes in the remote tribal areas of Maharashtra that are not grid-connected and where obtaining diesel for running diesel-powered pumps is difficult. GSDA is the nodal technical agency for planning and designing solar-powered drinking water supply schemes in the state.

4 Conclusions and Policy Inferences

In this report, we have also analyzed the techno economic viability of solar-powered pumps in the tribal areas of Maharashtra, with a case study of six villages from Gadchiroli district. From the point of view of technical feasibility, the analysis showed that the solar powered schemes are working well and are able to provide reliable water supply for drinking and domestic uses in the hamlets in which they were installed. However, they are found to be more expensive than water supply wells powered by electric motors in terms of the cost of water supply per unit volume of water supplied, even after considering the clean energy benefits of such schemes, though more expensive than diesel engines. The benefits from the reduction in carbon emissions through the use of solar power were estimated to be a mere INR 4650 when compared with electric pumps. Our analysis also corroborates with the views of the government officials who are currently or were earlier at the helm of affairs in GSDA.

Hence, such schemes will be desirable in very remote villages that do not have reliable power supply and where obtaining diesel for running diesel engines is difficult. They can also be considered for some of the economically most backward tribal areas of the state, where the communities do not have the wherewithal to pay for the cost of operation and maintenance of the conventional schemes run by electricity. This was largely the opinion of one of the experts who was at the helm of affairs in GSDA.

Section V:
Approach & Methodologies for Conceptualization, Planning, Technology Selection and Design of Water Supply Schemes, and Water Quality Surveillance

Summary

Managing rural drinking water supply has two aspects: managing quantity and managing quality. As regards managing quantity, the water supply agencies in India are oriented to design drinking water supply schemes based on a single source, considering only those sources that have the supply potential to meet the entire requirements of the area that they have to serve. Often the sources fail due to a variety of problems, but mostly due to resource depletion, and the water supply agency and the communities have to seek alternative sources. Conversely, many times, the agencies ignore the fact that communities depend on multiple sources to meet their different water requirements. Therefore, they end up designing schemes to meet the entire requirement, resulting in increased dependence on exogenous water sources and involving large infrastructure and energy use.

As regards managing water quality, water supply surveillance generates data on the safety and adequacy of drinking water supply in order to contribute to the protection of human health. The data generated through well-designed and implemented surveillance programmes can be used to provide public health input into water supply improvements. The key to designing such a programme is using information about the adequacy of water supplies and the health risks faced by populations at national or sub-national levels to identify areas that are vulnerable. But this is scarce in many countries. Information about the status of environmental sanitation conditions is also scarce.

Most current models of water supply surveillance come from developed countries and have significant shortcomings if directly applied elsewhere. There are differences between developed countries and developing countries not only in socio-economic conditions but also in the nature of water supply services. For instance, in India, most rural households do not have access to tap connections at home, and there is widespread use of a wide variety of communal water sources. These include public taps, water sold by households with a connection and water purchased from vendors. They also include a variety of small point water supply sources such as bore wells with hand pumps, protected springs and dug wells.

This section deals with two critical aspects of the management of rural water supply. The first is the planning, technology selection and design of rural water supply systems, wherein we discuss an approach and methodology to be adopted that allows us to consider multiple sources of water in rural areas for water supply planning and then choose source waters and water supply technologies that ensure cost-effectiveness and physical and environmental sustainability.

In this part, we discuss the method to be used for realistically estimating the requirements for water in rural areas for domestic water supply that includes water for productive needs. We then discuss a framework for selecting water sources for developing rural water supply schemes with a view to achieving physically and environmentally sustainable water supply that uses certain specific indicators of source sustainability and thresholds for each type of source water. A method of tentatively estimating the unit cost of water supply from each source is proposed. Then a method of obtaining an optimal combination of sources from a list of all potential water sources available in a rural setting that meets the criterion of overall cost effectiveness is proposed. Analytical procedures for estimating design floods, high flood levels, and negative externalities associated with the use of fossil fuel for pumping water were also discussed. Finally, the procedure for designing non-conventional water supply sources is discussed.

The second part deals with an innovative water quality surveillance approach based on an assessment of the risk associated with water contamination and pollution. It discusses the development of a composite index for assessing the water quality surveillance needs of different geographical areas, presents the results of mapping the index for different blocks of Maharashtra, and identifies areas where water quality monitoring needs to be intense in terms of the number of parameters to be covered and the frequency of monitoring.

The water quality surveillance index is a tool for surveillance of drinking water sources aimed at source protection. The tool uses a wide range of natural, physical, socioeconomic and institutional parameters for assessing the pollution risk of an area. The tool assesses the water quality surveillance needs at the block level. The DWQSI values estimated at the block level help identify the blocks that pose the highest public health risks caused by exposure to contaminated or polluted water for drinking and where frequent and rigorous monitoring and surveillance of water resources and drinking water sources is required to prevent waterborne diseases.

As regards the computed values of the 'risk', Shegaon block in Buldhana district is at the highest risk (DWQSI of 0.090), and Panhala in Kolhapur district is at the lowest risk (DWQSI of 0.582). Overall, 77 blocks are in the high-risk category (DWQSI ranging from 0.064 to less than 0.216), accounting for 22% of all the blocks in the state; 273 blocks in the moderate-risk category (DWQSI values ranging from 0.216 to less than 0.512), and only 4 blocks are in the low-risk category (DWQSI value greater than 0.512). The low-risk blocks are Panhala, Radhanagari, Hatkanangle and Karveer, all in Kolhapur district of Pune division, which is better off in terms of rainfall and surface water availability.

1 Introduction

In this section, we deal with two critical aspects of the management of rural water supply. The first is about the planning, technology section and design of rural water supply systems, wherein we discuss an approach and methodology to be adopted that allows us to consider multiple sources of water in rural areas (such as natural catchment runoff, groundwater, roof runoff, wastewater, saline water and water from ponds, tanks, and lakes) for water supply planning and then choose source waters and water supply technologies that ensure cost-effectiveness and physical and environmental sustainability. This marks a major departure from past approaches in the planning and design of rural water supply schemes.

In the second part, we deal with an innovative water quality surveillance approach, which is suited to developing countries like India, and is based on an assessment of the risk associated with water contamination and pollution. This approach also marks a significant departure from the conventional approach of monitoring water quality for a few parameters everywhere with the same frequency. Without the knowledge of the pollution risk that individual areas are susceptible to. It discusses the development of a composite index for assessing the water quality surveillance needs of different geographical areas, presents the results of mapping the index for different blocks of Maharashtra, and identifies areas where water quality monitoring needs to be intense in terms of the number of parameters to be covered and the frequency of monitoring.

2 Approach and Methodologies for Planning, Technology Selection and Design of Water Supply Schemes, and Ways to Operationalize Them in Maharashtra

2.1 Approach and Methodologies for Planning, Technology Selection and Design of Water Supply Schemes

The water supply agencies are oriented to design drinking water supply schemes based on a single source, considering only those sources that have the supply potential to meet the entire requirements of the area that they have to serve. Often, sources fail due to a variety of problems, but mostly due to resource depletion, and the water supply agency and the communities have to seek alternative sources. Conversely, many times, the agencies ignore the fact that communities depend on multiple sources, including informal sources and old sources, to meet their different water requirements (due to a variety of reasons), and end up designing schemes to meet the entire requirement, resulting in schemes that must depend on exogenous water sources, involving large infrastructure and energy use for transporting water. Such an approach leads to an increase in the cost of the scheme per unit of water supplied. This results in sub-optimal solutions in terms of local water resource development for community water supply. The approach needs to change to consider the multiple sources of water in rural settings (ponds, streams, roof catchments, old open wells and bore wells) while planning water supply schemes, based on considerations of physical, financial and environmental sustainability. The approach and methodology consist of the following key steps:

1. **Realistically estimating the demand for water in the area,** based on future growth needs-considering the climatic conditions, seasonal variation in water demands, overall socioeconomic conditions, and the expected future changes in conditions that can drive change in demand (population, per capita income, urbanization, etc.)

   The various considerations for estimating domestic water demand are:

   i) Overall climatic conditions of the area (cold & humid; hot & humid; hot & arid/semi-arid)

   ii) Socioeconomic profile of the HHs (economic status, occupational profile)

   Household income impacts domestic water needs in rural areas. With a rise in income, rich households in rural areas tend to own more items of assets and gadgets, including improved toilets and household appliances such as washing machines, heating rods, and so on (IRAP, CTARA & UNICEF, 2018). Hence, their demand for water will be higher. In order to have a reliable water supply, they also tend to go for piped water supply within their premises or develop their own sources of water, such as a dug well, bore/tube well or hand pump. The proportion of households having access to a piped water connection (whether within the premises or inside the dwelling) is higher among rich households. Better physical access to water in terms of distance between the source and the dwelling can increase per capita domestic water consumption considerably (Howard & Bartram, 2003; WELL, 1998).

Poor and landless rural households in developing countries are mostly dependent on small homestead gardens and livestock raising as their major livelihood activity (GSDA, IRAP & UNICEF, 2013). Such households use water supplied for domestic uses to irrigate their homesteads. There can be strong positive economic benefits for poor rural households if water supply systems are planned considering the productive water demands of rural households. For instance, Fan et al. (2013) estimated that in the Wei River basin of China, vegetable gardening increased the annual income of the small farm families by approximately 30% through providing fresh vegetables and reducing the food budget. Also, vegetable gardening significantly affected water consumption, as watering gardens accounted for almost 50% of the total domestic water consumption.

iii) Livestock holdings of the families

The rural households that own livestock use the water supplied for domestic purposes to feed domestic animals. Greater the number of livestock holdings per household, higher the amount of water that will be required to meet the livestock water demand (IRAP, CTARA & UNICEF, 2018). Generally, there are three different types of water requirements in livestock keeping: (1) for preparing its feed mix; (2) for animal drinking; and (3) washing the animal.

The drinking water requirement of the livestock will depend on its breed, age and weight, the farming system and the climatic conditions of the region (Chapagain & Hoekstra, 2003).

Table 5.1 shows the voluntary water requirement of the animals under different climatic conditions.

Table 5.1: Voluntary water requirements of livestock under different climatic conditions

Animal Type	Average Live Weight (kg)	Total Livestock Units (TLU)	Average Daily Dry Matter Intake	Daily Voluntary Water Intake (litres)		
				Wet season; air temperature, 27°	Dry cold season; air temperature, 15° to 21°	Dry hot season; air temperature, 27°
Buffalo	400	1.60	7	22.8	43.0	62.0
Cattle	180	0.70	5	10	19.0	27.0
Sheep	25	0.10	1	2	4	5
Goat	25	0.10	1	2	4	5

Source: Palla, 1986, as cited in Bassi et al., 2021

iv) Presence of kitchen gardens

Direct health benefits are derived from improved nutrition and food security from irrigated kitchen gardens. Indirect health benefits arise from improvements in household wealth from productive activity. Therefore, it is essential that the productive water needs of households be identified before planning a domestic water supply system for any region. The water requirement for a kitchen garden depends on the climate, the area of the plot being considered, and the season. The water requirement will be generally lowest during the winter season, when reference evapotranspiration ET0 is lowest, and highest during the summer, when reference evapotranspiration is the highest. If reference evapotranspiration is nearly 3 mm per day during the winter season, a fully matured vegetable garden (say, tomatoes, brinjal, chilly, carrot or cauliflower) raised during that season for an area of 50 sq. m will require nearly 165 litres of water per day for a family if we consider a crop factor (K) of around 1.15.

For the same area of a plot, the water requirement can increase to 500 litres during summer months when the average daily ET0 touches 10 mm (IRAP, CTARA & UNICEF, 2018). In both hot and humid and cold and humid, high rainfall areas, vegetable gardens are generally raised by the communities throughout the year, whereas in the hot and arid regions, they are preferred by the communities only during the rainy season and winter season, due to the fear of damage to the plants due to heat stress and water shortage. Cultural factors also seem to influence the decision to go for kitchen gardens or backyard vegetable cultivation. In tribal villages (of Maharashtra, Kerala, Karnataka, Odisha, and the North East), kitchen gardens are a common feature (Bassi et al., 2021).

But in many situations, the grey water from kitchens and bathrooms is diverted to homesteads having vegetables and tree crops, and separate arrangements are not made for watering them.

Hence, a proper plan for the reuse of wastewater from kitchens can help effectively reduce the water demand for kitchen gardens (Bassi et al., 2021).

2 Identification of All Potential Sources of Water in the Area

The framework for identifying the water supply technologies is provided in Table 5.2. It considers the topography, altitude, hydrology, geology and geohydrology, and chemical quality of groundwater, the key factors that influence the overall viability of different water supply options.

Table 5.2: Framework for identification of appropriate water sources for different physical/environmental conditions

Sr. No	Characteristics of the area	Technical Option for water supply	Extent of water supply—in terms of no. of seasons that the source can cover	Supplementary Source
1	Hilly and undulating area with high and very high rainfall	Small & medium sized reservoirs for water supply + lifting and piping	Throughout the year	Generally not required, except when there is a mechanical breakdown
2	Deep alluvial areas, with medium to high and very high rainfall	Deep tube wells, tapping the confined freshwater aquifer, serving more than one village	Throughout the year	Water from protected ponds and lakes during the monsoon and winter seasons after treatment
3	Deep alluvial areas, with medium to high rainfall; groundwater has chemical contaminants (iron, nitrates, fluorides)	Deep tube wells, supplying water for all domestic uses except drinking & cooking	Throughout the year	Water from ponds & lakes, during the monsoon and winter season after filtration Desalination of water for supply for drinking and cooking
4	Hard rock areas with medium to high and very high rainfall (plateau), with good quality water	Bore wells	Only during the monsoon and winter seasons; will dry up during summer months	Rainwater harvesting on roof tops
5	Rocky and mountainous areas with very high rainfall	Cisterns to harness the mountain springs, and supply through gravity pipes	Only during the monsoon and winter seasons	Small dams and water lifting; RWHS to supply water during the lean season
6	Shallow alluvial areas with high and very high rainfall	Open wells with protective cover and filter or shallow tube wells	During the monsoon and winter months; likely to dry up during peak summer	Water from protected ponds and lakes during the summer months, after treatment
7	Hard rock areas with medium to high rainfall, having poor quality groundwater (fluoride)	Bore wells for domestic water supply, other than drinking and cooking	During the monsoon and winter months; likely to dry up during peak summer	Small dams for water supply during summer + RWHS for drinking water supply

Note: Medium rainfall: 600-800; High rainfall: 800-1000mm; Very high rainfall: 1000-1500mm.

3 Estimating the potential of these sources to contribute to the supplies needed to meet the requirements-quantification of water from the source (see Table 5.2)

The assessment of the potential of drinking water sources that tap groundwater in terms of their ability to meet the requirements in quantitative terms is too complex a task. This is because groundwater is also tapped for other uses (crop production, manufacturing, etc.). Irrigation water demand/use is several times larger than domestic water demand. It is well established knowledge that annual water availability in semi-arid and arid hard rock regions is far less than the aggregate demand for water from all sectors. A slight change in the pattern of use of water for agriculture can change the availability of water for domestic requirements that are perennial. So, the assessment of the extent of supply available for meeting the domestic requirements is based on experience in different typologies of areas (defined by the geology, geohydrology, rainfall, topography, climate, etc.).

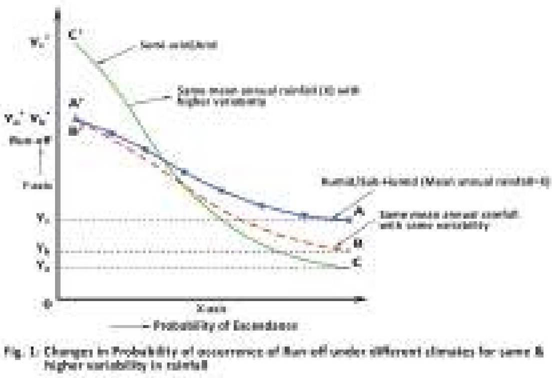
For surface water sources, quantification of supplies for domestic requirements is easier. It is because there is little uncertainty about competing water demands or the ability of the agency concerned to regulate the withdrawal of water to meet those demands. Basically, it is possible to earmark the water from surface systems for certain designated uses.

<u>Quantification of water from surface reservoirs (ponds, tanks and lakes):</u> The total amount of water that a surface reservoir that harnesses water from natural catchments can effectively supply is defined by the following: 1) the total inflows from the catchment; 2) the live storage capacity of the reservoir; and 3) the total amount of water that is released from the reservoir during times of inflow. The third parameter, however, becomes relevant only if the gross storage capacity is less than the inflows. In that case, the effective water supply will be the sum of live storage and the release during the times of inflow. In any case, such a 'release' that adds to the effective storage cannot be more than the inflow during that period. If the inflow is less than the gross storage capacity, the effective water supply potential will be equal to the inflow.

The inflow is the runoff from the catchment minus any upstream impoundments. Runoff is a function of the rainfall (quantum), the pattern, and the catchment characteristics (land cover, soil type). The runoff can change between years, depending on the total amount of rainfall received during the year. If the stream flow data for the catchment are available, for predicting the future inflow, a rainfall-runoff relationship can be developed based on time series data of annual rainfall and the observed annual stream flow . If the stream flows are not gauged, the runoff needs to be estimated using standard methods like the US Soil Conservation Service's curve number (CN) method. Such rainfall-runoff models can be used to predict the future runoff based on the measured values of annual rainfall.

It should be mentioned here that the storage capacity of the reservoirs is generally fixed on the basis of the dependable yield of the catchment, obtained from time series data of observed yield or estimated yield. Normally, a yield corresponding to a probability of exceedance of 90% is considered for designing municipal and domestic water supply schemes. If the 90% dependable yield is X, it means that in 90% of the years, the runoff or catchment yield will be more than X. Obviously, the runoff corresponding to 90% dependability will be much less than that of 75% dependability. The runoff dependability curve for typical hydro-climatic conditions is given in Figure 5.1.

Figure 5.1: Changes in Probability of Occurrence of Run-off in different climates for the same & higher variability in rainfall



[5]If there are upstream diversions, then the virgin flows need to be arrived at based on the observed flows and the effective upstream diversions.

In the case of artificial catchments (like roof water catchments), the runoff RO_{ROOF} can be estimated as:

$RO_{ROOF}=R \times A_{ROOF} \times C$ ………………. (1)

Where R is the rainfall; A_ROOF is the roof area; and C is the Runoff coefficient for the roof catchment. It is advisable to consider the rainfall corresponding to 75% dependability for estimating the runoff volume and decide on the storage volume required. The runoff coefficient depends on the type of roof. For RCC, a value of 0.70 can be considered, and for tiled roof, the value can be 0.60.

4 Analyze the Sustainability Aspects of Water Supply from Each Source

In this section, we will deal with physical sustainability, which is either on a long-term basis or on a seasonal basis, and water quality protection.

The physical sustainability of the water supply scheme is to be assessed in relation to the characteristics of the source. This is because, with changing characteristics of the source, the factors contributing to negative sustainability effects will change as well. For instance, for a reservoir-based scheme, the sustainability threat can come from permanent silting up of the reservoir and pollution of the water body from disposal of toxic effluents that are difficult to treat. At the same time, for a bore well based scheme that taps a hard rock formation, the sustainability threat can come from either depletion of the local aquifer or a prolonged drought, which can result in a lower quantity of water or the drying up of the well. This was found to be a common phenomenon in Chitrakoot, where many bore well-based schemes were reported to have failed due to the source drying up. The average depth of the bore wells has increased from 100 meters to 120-150 meters during the last 10-15 years in Chitrakoot district. In alluvial areas, however, the schemes fail due to entirely different reasons. For instance, tube wells can fail either due to a long-term decline in water levels or due to contamination of the aquifer as a result of mineralization of water (arsenic, fluoride, TDS or nitrates) or due to rusting of pipes (casing and suction) or due to collapse of the sand filter around the blind pipe. Rusting of pipes happen due to excessive levels of salts in the water. In districts like Gorakhpur, located in the alluvial belt, failure of tube wells (the common rural water supply scheme) occurs due to rusting of pipes (casing and suction pipes) or due to mineralization of water. In Gorakhpur district, the ground water table is high, and water could be extracted from 3 to 5 meters of depth. However, to avoid water contamination, bore wells for drinking water purposes are dug up to a depth of 120 meters. This is a good strategy and should be replicated where chances of contamination are high.

Hence, the criteria for evaluating the physical sustainability of the source will be decided by the source characteristics. Table 5.3 shows how the criteria and indicators for assessing the sustainability of the scheme change with changes in the characteristics of the source.

Table 5.3: Criteria for assessing sustainability threats of different types of rural water supply schemes

Characteristics of the Source	Criteria for Physical Sustainability	Indicators	Thresholds
Deep tube well in an alluvial area (tapping a deep aquifer)	1. Condition of the aquifer that is being tapped/	1.a. Annual water level drawdown	WL drawdown becomes excessive
		1.b. Contamination of water in the aquifer	The level of chemical contaminants like arsenic, fluoride, salt and nitrates exceeds permissible levels due to mineralization
	2. Condition of the well	2.a. Quality of water pumped by the well due to failure of filter	The system fails, with heavy 'sand-rush' or high salt concentrations
		2.b. Rusting of the casing pipe and the suction pipe	The casing pipes and suction pipes collapse

Characteristics of the Source	Criteria for Physical Sustainability	Indicators	Thresholds
Shallow tube well or open well in an alluvial area (tapping a shallow aquifer)	1. Condition of the aquifer that is being tapped	1. No. of hours a pump can be run in a day	1. Drying up of the well during summer
	2. Contamination of the water with fertilizer and pesticide residues	2. Presence of fertilizer and pesticide residues in the water	2. The level of pesticide and fertilizer residues exceeds permissible levels
Bore well /hand pump tapping weathered rocks	Condition of the aquifer	Bore well discharge/ no. of hours for which pump can be run in a day	Bore well dries up during summer or discharge reduces drastically
Small or medium reservoirs for water supply, with lifting and piping	Condition of the reservoir	Rate of silting up of the reservoir and loss of live storage	Reservoir siltation rate is far greater than 'design value'
	Condition of water lifting and distribution infrastructure	Leakage in the pipeline	Leakage in the pipe lines becomes excessive
Roof top water harvesting system	Condition of the roof catchment (cleanliness)	Runoff water from the roof catchment becomes polluted with organic matter and carbon	The filtration that removes the bacterial load device becomes dysfunctional The roof catchment becomes too dirty to be cleaned If filters are not available, then the water from the roof catchment becomes unusable
Desalination system	1. The condition of the membrane	1. The interval at which the membrane needs replacement	1.Membrane replacement becomes very frequent
	2. Disposal of the reject water	2. Proportion of the reject water	2.Proportion of the reject water grows over time
Ponds and lakes	The condition of the lake with respect to quantity and quality of the water	1.a. No. of months during which water remains in the lake/pond	1.a. The lake/pond dries up soon after monsoon or the inflow becomes highly variable (between years)
		1.b. Quality of water in the lake	1.b. The quality deteriorates to the extent that the treatment system fails to remove the harmful contaminants
Sources based on river lifting	Conditions of the river with respect to water levels, during high floods and the position of the infrastructure, such as pumping machinery, etc.	1a. No. of times in which the water level in the river exceeds the HFL (High Flood Level)	1a. Water level in the river exceeds the HFL
		1b. The level difference between the HFL and the position of the pumping machinery	1b. The pumping machinery gets submerged by the rising water level in the river

5 Estimating the design flood and high flood levels

For planning water supply schemes in flood-prone areas around rivers and lakes, maximum care needs to be exercised to make sure that the scheme does not get affected by floods that have damaging effects. For this, it is important to estimate the magnitude of floods that occur with a reasonably high return period. While the selection of the return period would depend on the design life of the scheme, a return period of 50 years would be appropriate for rural water supply schemes. The return period can be estimated by considering the time series data of historical stream-flows, and by taking the maximum hourly discharge that occurs in each year, and carrying out the probability distribution to arrive at the extreme values.

If streamflow data are not available, analysis shall be carried out using the maximum daily rainfall that occurred in each year based on time series data of daily rainfall. From the design rainfall for a given return period, the maximum hourly discharge can be estimated using a unit hydrograph for a one-hour rainfall event and then arriving at the cumulative streamflow hydrograph for a 24-hour storm. The water levels corresponding to the maximum (design) flood can be estimated using the data on channel hydraulic properties (slope, roughness coefficient and channel cross section). This parameter shall be a critical variable (consideration) for designing water supply schemes, whether it is a river lifting scheme or a hand pump or a bore well/open well.

In cyclone-prone areas, special care needs to be taken to include the years that witnessed cyclones, as cyclones also bring very high-intensity rains of high magnitude that cause floods.

6 Estimating the tentative unit cost of supplying water from each source

The cost should be worked out on the basis of the assumption that all sources provide the same service levels (for instance, taking water to the dwelling). For this, the standard norms prevailing in the region shall be used for conventional technologies. **For the un-conventional ones, the procedure for working out the cost is given in the subsequent section on 'design' of the water supply system using unconventional sources.**

However, such straightforward comparisons can happen only in ideal situations. In any situation or locality, the service levels of the water supply scheme will change with technology. In a high-rainfall, hilly region with consolidated formations, the performance of a bore well will not be the same as that of a small or medium reservoir. It will be much lower. There are high chances that the bore well will dry up with the onset of summer. Hence, the cost of supplying water through alternate sources during the lean period should be added to the cost of the bore-well for comparison with an alternative that can assure round-the-year water supply.

Another important concern is the life of the scheme. The unit cost, i.e., the cost per unit volume of water supplied, is a function of the annualized capital cost, the annual O & M cost, and the amount of water supplied (or its physical performance). For a fixed capital cost, the annualized cost depends heavily on the scheme life. The longer the life of the scheme, the lower the annualized capital cost will be. However, scheme life is not constant. For any scheme to function for its entire design life, regular maintenance & repair are crucial. This would involve costs. When very little is spent on repair and maintenance, the life of the scheme becomes short. Hence, the assumption made about the life of the system should be realistic, and it will have a bearing on the annual O & M cost.

The cost per unit volume of water from the system can be estimated using the formula below:

$$A_{COST}/V_{SUPPLY} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where A_{COST} is the annualized cost of the system, and V_{SUPPLY} is the average volume of water that the system can supply on an annual basis.

$$A_{COST}=NPV X R/(1-(1+R)^{-n}) \ldots\ldots\ldots\ldots (2)$$

Where NPV (net present value of an annuity, 'R') can be estimated as:

$$NPV = \sum_{i=1}^{n} \left(\frac{Ct}{(1+R)^{t}} \right) \ldots\ldots\ldots\ldots (3)$$

7 Consider the negative externalities associated with the use of fossil fuel if the pumping of water is included in the cost of water supply-to discourage sources that involve high energy use to pump and transport water

Most water supply systems, except those that are manually operated, involve the use of electrical energy. This will involve the use of fossil fuel as long as the energy is produced from fossil fuel (like in thermal power stations using coal, gas or diesel) or the energy production system (like diesel engines or diesel generators), involves the direct use of fossil fuel, or the manufacturing of the renewable energy production system (like the solar PV systems or wind turbines) involves the use of electricity generated from fossil fuel (though the carbon footprint in this case is low). The only exceptions are those where the electricity used for running the system comes from hydropower. However, hundred per cent clean energy is next to impossible in India under the current circumstances. Since electricity use would leave a carbon footprint, the effort should be to minimize the use of electricity for supplying a unit volume of water.

The negative externality can be estimated as: the amount of electricity used to pump a unit volume of water in Kilowatts (*P*) X Volume of water to be supplied annually (*V)* X the carbon emission from a kilowatt of electricity consumed in kg (E_C) X the cost of carbon capture in rupees/kilogram of carbon CC_{COST}

The negative externality, as the additional annual cost, is therefore:

$COST_{EXTERNALITY} = P \times V \times E_C \times CC_{COST}$.......... (1)

As we have discussed, with an increase in the height/depth of pumping water, the amount of electricity required to pump a unit volume of water would increase proportionately.

The emission from one kilowatt hour of electricity, produced from coal based thermal power, is 0.26 kg or 0.96 kg of CO2 (source: United States Department of Energy). The cost of capturing this carbon in Indian rupees was worked out to be INR 0.47, the rupee equivalent of 0.047 US dollars (based on David & Herzog, nd).

Hence $COST_{EXTERNALITY} = 0.47xPxV$ .... (2)

8 Work out combinations of supply sources, with the extent of supply provisioning from each, so that the overall unit cost is as low as possible, beginning with the source with the lowest unit cost.

Here, the objective function is to minimize the total cost.

Total cost of water supply (C) =

$$V_1 X \Phi_1 + V_2 X \Phi_2 ... + V_n X \Phi_n$$

Where, V_n is the extent of water supply possible from source n; Φ_n is the tentative unit cost of water supply from the source, n.

This basically means that the source that offers water at the lowest cost (per unit) should be considered first, and only when it is exhausted should the subsequent ones be considered in the increasing order of their cost.

9 Design the scheme based on 'multiple sources' with the demand to be met from each source decided on the basis of the 'extent of supply possible' (see point # 7), using the standard design procedure used for the conventional sources (as per CPHEED manual).

The design of each component of the water supply system (like a bore well, a RWH tank, a small reservoir, or the RO system) should be done keeping in view the extent of supply required and possible from that component. Here, bore wells are conventional sources that need to be designed using the standard design procedure. The design should cover the bore well size (depth and diameter); the capacity of the pump set (decided on the basis of the safe yield of the aquifer, the depth to water table, the number of hours for which the power supply is available in the day, and the total volume of water required per day); and the size of the overhead reservoir will have to be determined. The most important consideration for fixing the size of the OHT is the volume of buffer storage required.

10 Explore the scope for using a common water distribution infrastructure and the additional storage facilities required for storing water from different sources and feeding it into the distribution system

In many instances, the villages are found to have the infrastructure of an old, defunct scheme intact. It might be possible to use a large part of this infrastructure for the newly created source, thereby saving money and time. Such an approach is envisaged in JJM as well. Some of the common infrastructure includes the pump house, overhead storage tanks (reservoirs), and main water pipeline, which takes off from the OH reservoir.

11 Carry out the design of the un-conventional water supply schemes, using the design procedure worked out and presented in this document. The unconventional sources are: roof top rainwater harvesting systems; reverse osmosis-based system for demineralizing the water; and drinking water wells run on solar pumps in areas lacking reliable electricity supply. The technical design procedure for unconventional sources is provided in the next section (Section 2.2).

2.2 Design of Unconventional Water Supply Schemes

For the non-conventional schemes, the design procedure is discussed below.

A Roof-Top Rainwater Harvesting System:

The main design considerations are the total amount of water that will be available from the roof catchment and the household demand. The key design variable is the storage capacity of the tank to be built for storing the rainwater.

The storage capacity required for the tank = Total runoff available from the roof top - Amount of water that will be drawn from the tank during period of inflow

Total runoff (m3) = Annual precipitation (m) X Roof Area (sq. m) X RO Coefficient for the Roof

Because precipitation varies from year to year, with wet, dry and normal years, the storage tank shall be designed for the highest rainfall condition to maximize benefit. However, for estimating the extent of supply contribution from this source, the worst-case scenario (of drought) shall be considered.

The storage capacity of the RWHS = Total runoff from the roof catchment (m3) - Effective water withdrawal by the household during the times of inflow (m3)

The equation basically suggests that if there is no withdrawal during the period when the inflow occurs (as a result of precipitation), then the storage capacity of the tank has to be the same as the runoff or the total water demand of the HH, whichever is lower. But if there is withdrawal from the RWH tank during the period of inflow (which is the situation if the rains occur during winter and summer times when the demand for water from such systems increases), then the storage requirements would reduce.

The demand for the water collected in the roof water collection tank will be another important consideration. The demand (m^3 of water) can be estimated as:

Per capita water requirement per day in litres (Φ) X Family Size X Number of days per year (during which water from the tank is used)/1000.

The per capita water requirement shall be decided by the types of requirements that the stored roof water can meet.

The size of the tank will be decided by comparing the storage requirement and the household demand for that water, whichever is less. However, if the household wants to use the roof water collection tank for storing water obtained through tankers, additional storage space can be provided in situations where the inflow or storage requirement is less than the demand.

B Solar Power-Based Drinking Water Wells:

The main design considerations are the total amount of solar energy available per sq. m of the panel under standard conditions , the energy conversion ratio of the panel (15%), and the total water to be lifted from the source per day, and the amount of energy required to pump a unit volume of water. The design variable is the area of the panel required.

The solar panel area can be worked out as: Total energy required per day to pump the water from a depth/ Energy produced by the panel with an area of 1 sq. m

= ((V X 9800 X H)/ (3600X μ))/ (1000X n))); where n is the energy conversion ratio, which can be considered as 0.15

=0.018 X V X H/μ (where V is measured in m3 and H is measured in metres).

However, the cost of installing the solar PV system (which depends on the panel size) will have to be compared with the cost of supplying electricity from the grid to the location for pumping the same amount of water for the entire life of the solar PV system.

The energy required per day from the grid = V X 9800 X H/3600μ = 2.72 VH / μ Watts.

The cost of supplying the energy through the grid for the entire life of the solar PV system =

$2.72\, x\, N x\, 365\, \text{x}\, P x\, V x\, H/\mu$

Where N is the life of the solar PV system

C Reverse Osmosis (RO) Plants

To be proposed in areas where surface water resources are not easily available for harnessing and groundwater is chemically contaminated with excessive mineral concentration, either with TDS exceeding 2,000 ppm or the fluoride levels exceeding 2.0 ppm. Since RO plants can reduce the fluoride and salinity levels substantially (to nearly 10% of the concentration in the raw water), the possibility of blending the desalinated water (RO treated water) with the natural groundwater can be explored. One of the unique features of RO systems is the fact that it is possible to get economies of scale with this

[6] To determine solar panel efficiency, panels are tested at Standard Test Conditions (STC). STC specifies a temperature of 25°C and an irradiance of 1,000 W/m2. This is the equivalent of a sunny day with the incident light hitting a sun-facing 37°-tilted surface. Under these test conditions, a solar panel efficiency of 15% with a one sq. m surface area would produce 150 watts.

[7] In certain situations, water might be available during some seasons (during the monsoon and winter), but there could be severe constraints in storing the water for use during the lean season because of high evaporation.

system-larger the size of the plant, lower the cost per unit volume of water treated.

The most important consideration in the design of an RO plant is the salt concentration of the raw water and the maximum permissible levels of salts in the treated water. Depending on the salt concentration in the raw water and the degree of reduction in the concentrate, the membrane has to be chosen. The higher the salt concentration in the raw water and the greater the required reduction in salt concentration, greater will be the capacity of the membrane, which helps increase the membrane cost. It is to be kept in mind that if blending of treated water with natural ground water is to be done, then the permissible level of salts in the treated water (from the RO) will have to be very low so that the output water after blending has salt concentrations within permissible levels.

The second most important consideration is the demand for treated water. Since RO-treated water is the purest water (free from all the physical, chemical and biological contaminants), it is desirable for drinking and cooking purposes. However, other domestic water uses (bathing, washing clothes, toilet use and cleaning utensils) do not require water of such high quality, and therefore it will not make economic sense to use this treated RO water for such uses. The quantum of water required per capita per day will be around 5 litres. Since the demand per household will be quite low (say, around 20-25 litres per day), it is important that each RO plant be planned to serve several households in multiple villages so as to have a large-sized plant, which would help minimize the cost per unit volume of water.

If the permissible level of a certain contaminant (say, dissolved salts) in the final output water is ?, and the volume of treated water from RO is V_1, and the volume of untreated water used for blending is V_2 and the concentration of the pollutant in the untreated water is β_2, then the maximum permissible level of concentrate in the RO-treated water (β_1) will have to be:

$$\beta_1=[\{(V_1+V_1)\beta-V_2 X\beta_2\}/V_1]$$

The RO system also poses some environmental challenges. In many situations (especially in inland areas), the disposal of 'reject water', which has a much higher concentration of minerals than raw water, is an issue. The disposal of this reject water on land can cause problems of soil salinization. Therefore, options for extracting salts from the reject water should be explored wherever possible through the use of evaporation ponds. In coastal areas, the reject water can be disposed-off into the sea.

D Design of Small Dams

From the point of view of water supply and demand, the design of small dams involves three important considerations: 1) the annual inflows from the catchment; 2) the annual demand for water; and 3) the pattern of occurrence of the flows in relation to the demand. The design considerations are the same as those of roof top rainwater harvesting systems. The only difference is in the catchment area and the runoff coefficient. In the case of natural catchments, the catchment area can be adjusted to a great extent to manipulate the inflows. But then the decision on the location of the dam, which determines the catchment area, is also influenced by considerations such as the length of the dam (across the gorge) and the submergence area. The location of the dam should be such that it gives the maximum storage volume with the minimum length and water spread area. Generally, narrow gorges are chosen for the construction of the dam.

The supply should be greater than the demand. The supply is equal to the runoff from the catchment, minus the dead storage in the reservoir.

The runoff from a catchment = Area of the catchment X Rainfall in the catchment X Runoff coefficient

Runoff - dead storage should be more than the water supply requirement (i.e., demand for water + losses in the system during conveyance of water)

$$RFxAREA_{CATCHMENT}\ x\ C\text{-}R.STORAGE_{DEAD} \geq DEMAND_{WATER}+LOSS_{CONV\text{-}SYS}..........$$

$A_{CATCHMENT}$ is the area of the catchment in sq. m.; *RF* is the annual rainfall in m; *C* is the runoff coefficient

Where, RF x C is the total annual runoff (m^3). For a given rainfall, it depends on the characteristics of the catchment, defined by the land use/cover and the hydraulic properties of the soil in the catchment, and the pattern of occurrence of the rainfall. Since the quantum of rainfall and its pattern of occurrence can vary from year to year, the proportion of rainfall that gets converted into runoff also changes, as does the runoff coefficient. Generally, when the rainfall is high, the runoff coefficient will also be high, as a higher proportion of the rainfall gets converted into runoff after the initial absorption. Further, the same amount of rainfall occurring in fewer wet spells with a minimum gap between two rainy events will generate higher runoff than when it occurs in many short wet spells.

If stream flow data for the catchment (or a very similar catchment) are available, the rainfall-runoff model for the catchment can be generated. Or else, the stream flow can be computed for daily rainfall events using the US Soil Conservation Service's Curve Number method and summed up to obtain the annual rainfall, and this procedure shall be repeated for 25-30 years. From this, the runoff corresponding to 90% dependability should be estimated.

$$DEMAND_{WATER} = \phi \times 365 \times N / 1000 \text{ in } m^3$$

Where, ϕ is the per capita water demand per day in litres; and N is the size of the population to be served by the proposed water supply scheme.

From the foregoing discussion, it is clear that the process of planning the scheme is 'iterative'. However, if the supply requirement is less than the amount of inflow available from the catchment corresponding to the best location, then the live storage (gross storage - dead storage) can be kept as low as the annual demand + losses in the system.

2.3 Ways to Operationalize the Approaches in Maharashtra

In order to operationalize the concepts discussed in Section 2.1 for planning rural water supply schemes, it is important to have reliable data on several variables that have to be used for planning but are currently unknown. Some of them are: 1) rainfall-runoff relationships for catchments in different hydro-climatic regimes in Maharashtra; 2) the actual utilization of groundwater resources in different geohydrological settings in Maharashtra available from natural recharge; 3) the amount of recharge available from gravity irrigation systems in canal command areas, including recharge from canal seepage and recharge from irrigation return flows; 4) estimates of per capita domestic water demands in the rural areas that include productive water needs, in different climatic and socioeconomic conditions; 5) the size of solar panels required in different regions of Maharashtra to pump out a unit volume of water from underground, which takes into account the variation in incident solar radiation and the variation in water level depths; and 6) the unit cost of different types of water supply schemes in different typologies defined by the geology, geohydrology, topography, rainfall conditions and hydrological regimes.

3 Approach and Methodology for Water Quality Surveillance for Source Protection

3.1 Defining Water Quality Surveillance

Water supply surveillance is defined as: "the continuous and vigilant public health assessment and oversight of the safety and acceptability of water supplies" (WHO, 1976, 1993, 2004). Many millions of people, in particular throughout the developing world, use unreliable water supplies of poor quality that are costly and distant from their homes (WHO & UNICEF, 2000). Water supply surveillance generates data on the safety and adequacy of drinking water supply in order to contribute to the protection of human health. Most current models of water supply surveillance come from developed countries and have significant shortcomings if directly applied elsewhere. There are differences not only in socio-economic conditions but also in the nature of water supply services, which often comprise a complex mixture of formal and informal services for both the 'served' and 'un-served' (Howard, 2005).

Some sections of society in the developing world enjoy water supply and other services of a quality comparable to those in developed countries, frequently at a lower cost (HDR, 2006; Howard, 2005). However, many households do not have access to tap connections at home. As a result, there is widespread use of a wide variety of communal water sources. These include public taps, water sold by households with a connection and purchases from vendors (Cairncross & Kinnear, 1992; Howard, 2001; Tatietse & Rodriguez, 2001; Whittington et al., 1991). They also include a variety of small point water supplies such as bore wells with hand pumps, protected springs and dug wells (Gelinas et al., 1996; Howard et al., 1999; Rahman et al., 1997). In India, communities depend extensively on private bore wells, even when individual tap connections for treated water are provided by the utilities.

The data generated through well-designed and implemented surveillance programmes can be used to provide public health input into water supply improvements. The key to designing such a programme is using information about the adequacy of water supplies and the health risks faced by populations at national or sub-national levels to identify areas that are vulnerable. But this is scarce in many countries (Howard, 2005). Scarce is also information on the state of environmental sanitation conditions. This is despite significant advocacy of 'people centred' and 'demand responsive' approaches in recent years.

3.2 Past Approaches to Water Quality Surveillance and Their Inadequacies

Few published studies exist in developing countries that address the development of water supply surveillance programmes. According to a review, while most countries have some form of guidelines on water quality, these are not routinely enforced (Steynberg, 2002). It suggested that the health sector often performs more monitoring than the water supply sector, but provided no evidence that systematic monitoring of water supply extended beyond utility piped systems. A recent assessment of drinking water supply surveillance by the WHO in the South-East Asia Region noted that none of the countries had a comprehensive national programme of surveillance (Howard & Pond, 2002). Though surveillance of piped water supplies was carried out, alternative sources and household water in urban areas were not typically included.

There are very few reported examples of surveillance programmes that covered different source types and service levels, or targeted vulnerable populations. Some projects tried to focus on alternative sources and household water, but were typically focused on single communities or were time-limited assessments of water (Howard, 1997; Karte, 2001). Poverty or vulnerable populations had not been a significant factor in the surveillance programme design.

In India, certain uniform protocols are followed by the Ministry of Drinking Water and Sanitation for water quality monitoring, and the same is followed by the Water Supply and Sanitation Department of Maharashtra. These protocols concern the number of water quality testing laboratories in different administrative areas, the water quality testing facilities that should be available in these labs-the human resources, instruments, the number of water quality parameters that these labs should test periodically, and the sampling procedures. The water quality testing capabilities of the laboratory are not decided by the water quality challenges a region or area faces but are purely based on the administrative status of the area, i.e., whether it is a state-level lab, a district-level lab, or a sub-district-level lab. The WQM protocol prescribes that the state-level water quality testing laboratories of the government should have facilities to test a total of 78 water quality parameters, the district-level labs should have facilities to test 34 parameters and sub-district-level labs should have facilities to test 19 parameters.

The inbuilt assumption in the Ministry's approach seems to be that water quality management challenges are uniform. While it specifies the WQ parameters to be analysed by each type of laboratory, it does not make any distinction amongst the sources being monitored in terms of the likely water contamination and pollution challenges they pose and does not assign the types of water quality parameters to be analyzed. However, the reality is that there are certain regions/areas in every state that face inherent contamination problems, especially with respect to groundwater, and there are regions where both surface water and groundwater resources are vulnerable to pollution from a wide range of sources by virtue of their location vis-à-vis their proximity to polluting industries, open defecation and a lack of grey and black water management systems, urban centres, unique characteristics of geological formations that the schemes tap, geohydrology, proximity to the sea, rainfall and climate.

Field monitoring of source water quality using test kits, as proposed by the Ministry of Drinking Water and Sanitation, will not be adequate to capture complex pollutants. Instead, in such regions, DW source monitoring for contaminants and pollutants will have to be more stringent and more frequent than that of others. Accordingly, the lower grade (sub-district level) laboratories located in such regions should be equipped with better facilities for water quality surveillance. On the other hand, in regions where serious water contamination problems are very rare, it will not make economic sense from the point of view of public health to monitor a large number of water quality parameters, as every additional parameter considered for water quality analysis increases the human resource, chemicals and equipment requirements and therefore the cost of water quality monitoring (DWI, 2017; USEPA, 2016). However, the current protocol does not recognize the need for differential treatment of regions/areas and the water-testing laboratories located there on the basis of water quality management challenges.

3.3 A New Approach for Identifying Water Quality Surveillance Needs

A composite index called the Water Quality Surveillance Index (WQSI) was developed with the aim of identifying the areas within the state that pose the highest public health risks caused by exposure to contaminated or polluted water for drinking and where frequent and rigorous monitoring and surveillance of water resources and drinking water sources is required to prevent water borne diseases. The use of such an index will help economize the investment made for water quality monitoring and lead to more judicious use of the existing water testing laboratory infrastructure in the state.

The development of the present index considers the factors that determine:

1] The 'threat' to water sources, or the chances of deterioration (through contamination or pollution) of a water source (such as groundwater or surface water), which is captured by a water quality index for the source water

2] The degree of exposure of the drinking water sources to contamination or pollution, which is determined by four key factors viz., availability of water in terms of quantity & quality; conditions of water supply infrastructure; access to water & sanitation; and climate, flood proneness & population density, and

3] The vulnerability of the communities, which is influenced by two factors, viz., the overall public health status, and institutions and management.

The total risk is computed by multiplying Threat (T) X Exposure (E) X Vulnerability (V).

The variables considered for assessing the three sub-indices of the Water Quality Surveillance Index, which correspond to the three dimensions of the risk, the manner in which they influence each of these three and pollution and the quantitative criteria for assigning values for these variables are discussed in Annexure 1.

The maximum value of each sub-index would be 1.0. The value of each sub-index is computed by adding up the values of various factors that influence it and then normalizing to obtain a maximum value of 1.0. For computing the value of the sub-index for 'threat', the 'water quality index' (of the source water), which is the only parameter that influences it, is used. For computing the value of the sub-index for 'exposure', values of variables A, B, C and G are added up and normalized. For computing the value of the 'vulnerability' sub-index, values of variables D and F are added up. Lower values of the index mean higher vulnerability. The factors considered for computing the sub-indices will also have equal weightage (measured on a scale of 0 to 1.0), and the sum of their values will have to be normalized so as to obtain a maximum value of 1.0. Here, it is important to reckon with the fact that the values being assigned to the indices and sub-indices used for computing the water quality surveillance index, and many of the variables used for computing various indices (say, for instance, the climate sub-index) are 'discrete distributions' and are NOT "real value functions" of real variables. This is used because what we have developed is a statistical model for computing the surveillance."

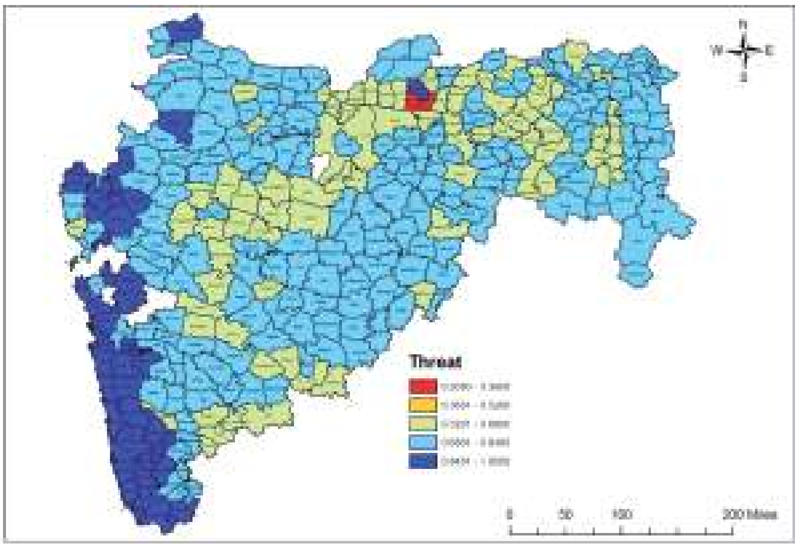
3.4 How Large Are the Water Quality Surveillance Requirements in Maharashtra?

The Drinking Water Quality Surveillance Index (DWQSI) was computed for the rural areas in all 36 districts and 354 blocks of Maharashtra. The maximum value of the WQSI is one indicating the absence of water quality-related public health risk for the population as the water resources in the area are of good quality. In other words, the area is unlikely to face public health risks posed by contaminated water. Conversely, lower the value of WQSI, higher will be likelihood of water related health risk of the area.

For analysing the threat to drinking water sources, the water quality index (WQI) was considered. In most of the rural areas of the state, drinking water sources are based on shallow groundwater. Since groundwater quantity and quality can be influenced by the anthropogenic pressure in the catchment (for instance, discharge of untreated effluent over land or into a reservoir or river can pollute the underlying aquifer as well), it is important to consider the quality of both surface water and groundwater resources. Water quality index values based on data from 251 surface water monitoring sites and 3694 groundwater monitoring locations were considered. It was found that the WQI is excellent for 50 of the blocks, i.e., a WQI value of 63-100 for surface water and less than 50 for ground resources. These blocks were distributed among Amravati and Nandurbar (one block each), Satara and Thane (two blocks each), Nasik and Pune (three blocks each), Kolhapur and Palghar (five blocks each), Sindhudurg (eight blocks), Ratnagiri (nine blocks), and Raigad (11 blocks) districts. Half of these blocks are in the Konkan division of Maharashtra, where the quality of surface water and ground water resources is much better (except for those in Mumbai City and Mumbai Sub-urban district) than the blocks in other divisions of the state. Further, out of the four blocks in the overall low risk category, two blocks (Panhala and Radhanagari) had excellent WQI.

A significantly large number of blocks (215) were in good WQI (a value of 50-63 for surface water and 50-100 for groundwater resources). Nevertheless, 89 blocks were found to have poor or very poor WQI (value in the range of 0-50 for surface water and 100-300 for groundwater), with the worst being Shegaon block in Buldhana district, Daryapur block in Amravati district and Jafrabad block in Jalna district. Shegaon block also has a high overall risk index score. Please refer to Figure 5.2 for an understanding of the variation in pollution/contamination threats to water sources.

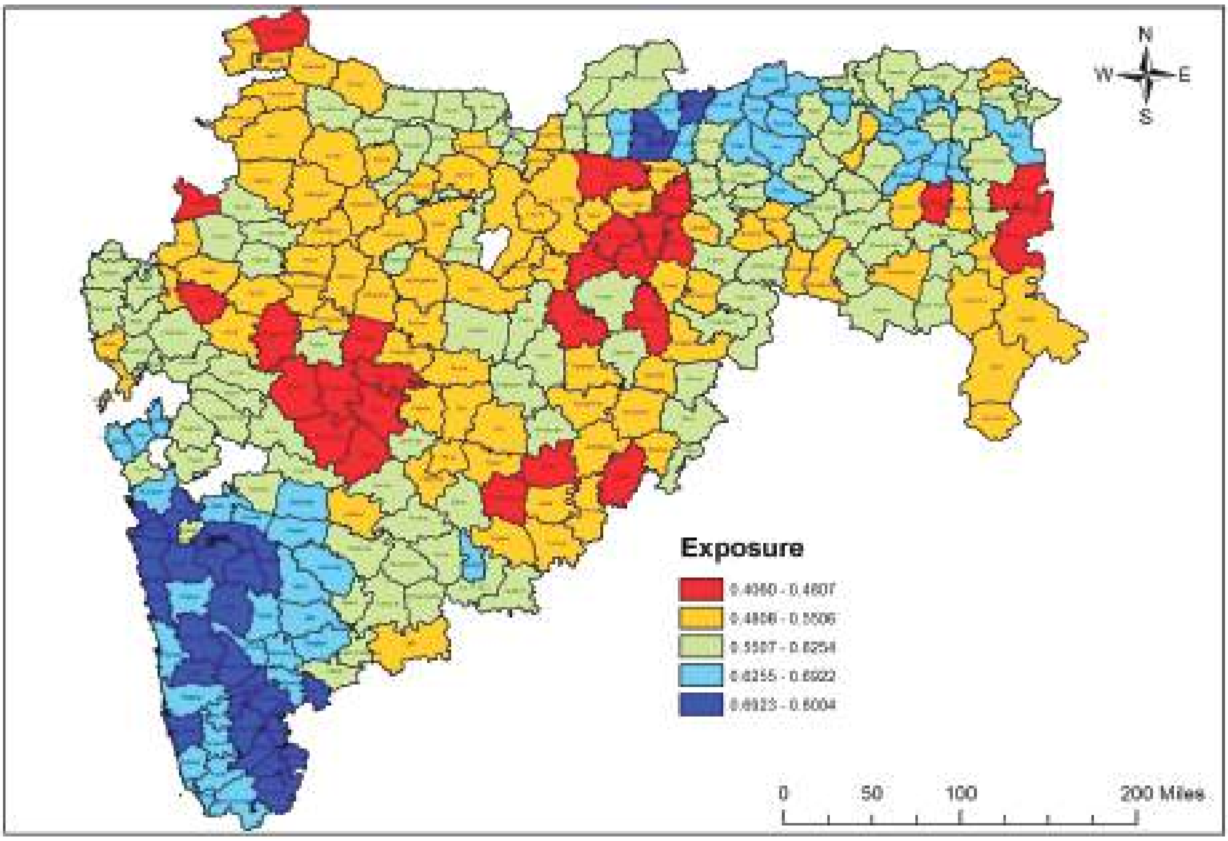
Figure 5.2: Threat to water sources in rural areas of Maharashtra



For analysing the degree of exposure of the drinking water sources to contamination or pollution, four factors were considered: availability of water resources in terms of quantity and quality; accessibility to water sources; infrastructure characteristics; and climate, flood proneness, and population density. Overall, exposure was low (sub-index value greater than 0.70) for 31 blocks spread across seven districts. These include Sindhudurg and Buldhana (one block each), Amravati (three blocks), Raigadh (four blocks), Satara (five blocks), Ratnagiri (six blocks), and Kolhapur (11 blocks). Out of these, 16 blocks are in the Pune division and 11 are in the Konkan division. Among them is also Shegaon (exposure sub-index value of 0.772), which faces a very high overall risk. The low exposure of the two divisions can be attributed mainly to: 1] the low vulnerability of water resources to pollution from industrial and domestic wastewater in the majority of the blocks in Konkan (except for those in Mumbai City and Mumbai Sub-urban district) and Pune division (except for Pune district); and 2] better household access to treated piped water supply (38% in Pune and 27.2% in Konkan division; the state average is only 25.5%) and sanitation facilities (70% in Pune and 60% in Konkan division; the state average is only 40%), reducing the chances of contamination of water during collection and storage and of vector borne diseases through food contamination, respectively.

Nevertheless, about 56 blocks have an exposure sub-index value below 0.5. They include blocks in Akola, Aurangabad, Nandurbar and Osmanabad (1 each); Beed, Chandrapur and Hingoli (2 each); Buldhana and Parbhani (4 each); Gadchiroli, Nasik and Washim (6 each); Latur (7); and Ahmednagar (12) districts. These blocks were mainly spread across Aurangabad, Amravati and Nagpur divisions. These are the divisions with poor household access to treated piped water supply (only 19.4% of the households) and sanitation facilities (only 27.3% of the households). Please refer to Figure 5.3 for an understanding of the spatial variation in the degree of exposure of the drinking water sources to contamination or pollution.

Figure 5.3: Degree of Exposure of the drinking water sources to contamination or pollution in rural areas of Maharashtra

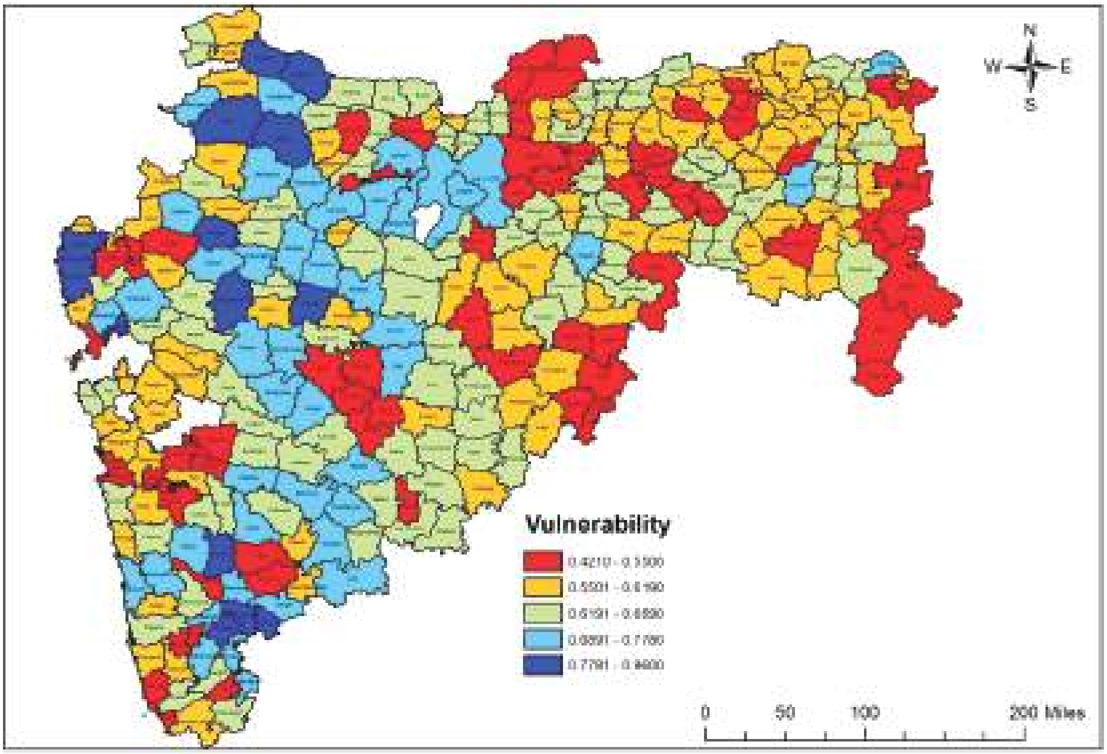


In order to determine the vulnerability of the communities to problems of exposure to contaminated water sources, two factors were considered: overall public health status, and institutions and management. In 56 blocks, vulnerability (value of the sub-index greater than 0.7) was found to be low, and in 99 blocks, it was found to be high (sub-index value between 0.4 and 0.55). Additionally, Pune City block was found to be highly vulnerable (sub-index score of 0.23). In 198 other blocks, vulnerability was moderate (sub-index values ranging from 0.56 to 0.70). Please refer to Figure 3 for an understanding of the spatial variation in the vulnerability of the communities to the public health risks associated with exposure to contaminated water sources.

Among the blocks with lower vulnerability, seven each were in Ahmednagar and Kolhapur districts, and four each in Aurangabad, Buldana, Dhule, Nashik, Satara, and Solapur districts. Most of these blocks are in Nashik and Pune divisions. Hatkanangle block of Kolhapur district has the lowest vulnerability (sub-index score of 0.960), mainly due to a low (13.5) under-five mortality rate (state average is 14.5) and a small proportion of the population (158 per block) affected by water-related diseases annually (state average is 352 per block). Even the Konkan division, which has low threat and exposure, has an under-five mortality rate of 14.2 and 355 people per block affected by water-related diseases.

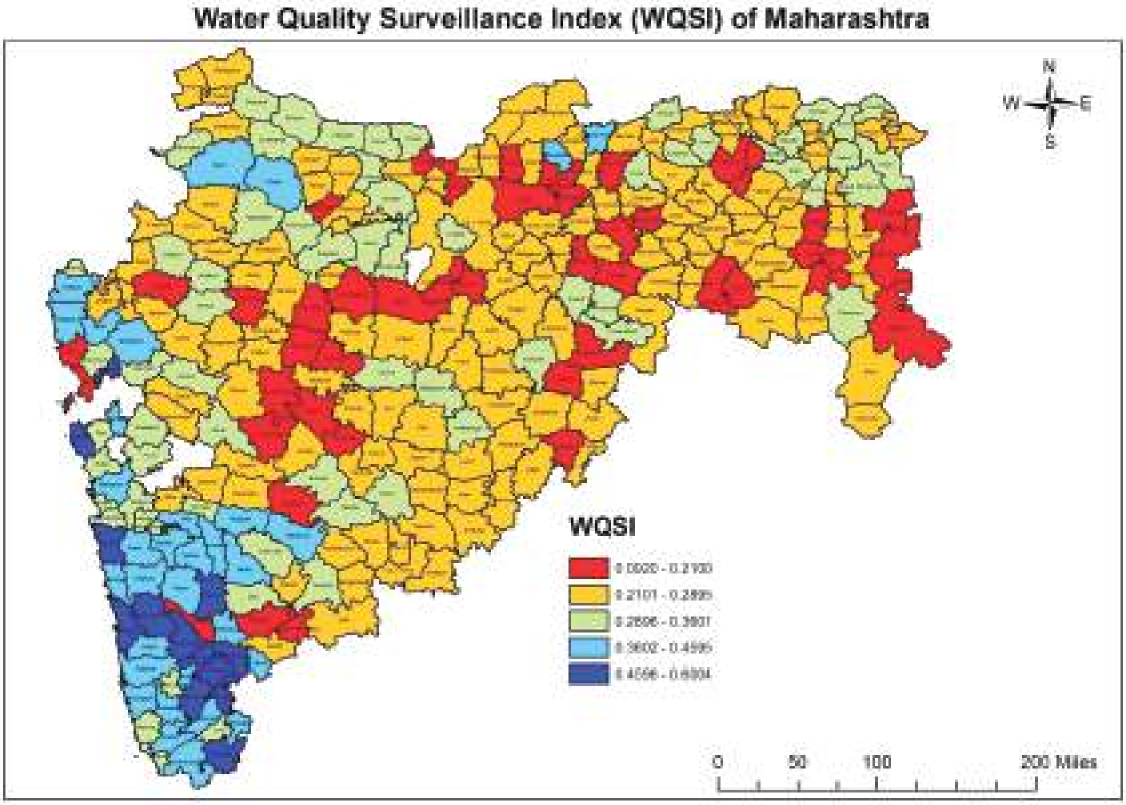
Most of the blocks with high vulnerability were spread across Aurangabad, Amravati and Nagpur divisions. Lonar block in Buldana district was found to have the lowest sub-index score (0.421), indicating high vulnerability mainly due to a high under-five mortality rate (90) and thus making the community (including children) highly vulnerable to problems associated with consuming water from contaminated sources.

Figure 5.4: Vulnerability of the communities to contaminated water sources



As regards the final risk assessment, Shegaon block in Buldhana district is at the highest risk (DWQSI of 0.090), and Panhala in Kolhapur district is at the lowest risk (DWQSI of 0.582). Overall, 77 blocks are in the high-risk category (DWQSI values ranging from 0.064 to less than 0.216), which constitutes 22% of all the blocks in the state; 273 blocks are in the moderate-risk category (DWQSI values ranging from 0.216 to less than 0.512), and only 4 blocks are in the low-risk category (DWQSI values greater than 0.512) (please refer to Figure 5.5). Sixty three out of the 73 high-risk category blocks are concentrated in Amravati, Aurangabad and Nagpur divisions, which receive less rainfall as compared to other divisions of the state and are underlain by hard rock aquifers with limited groundwater storage potential. The low-risk blocks are Panhala, Radhanagari, Hatkanangle and Karveer, all in Kolhapur district of Pune division, which is better off in terms of rainfall and surface water availability.

Figure 5.5: Water Quality Surveillance Index for the blocks in Maharashtra



3.5 How Do We Use This Index for Water Quality Surveillance?

The DWQSI values estimated and presented in this report help identify the blocks that pose the highest public health risks caused by exposure to contaminated or polluted water for drinking and where frequent and rigorous monitoring and surveillance of water resources and drinking water sources is required to prevent water borne diseases. This will result in economizing the investment made for water quality monitoring and lead to more judicious use of the existing water testing laboratory infrastructure in the state. The index can also be used for public health surveillance, i.e., to monitor the outbreak of diseases during weather-induced hazards that cause disruptions in water supply (both in terms of quantity and quality) and to take measures for preventing contamination of water supplied from public drinking water sources, such as the setting up of raw water treatment systems.

4 Synthesis

Management of rural water supply is about provisioning adequate quantities of water to meet all the domestic and productive water needs of the rural household with reliability, timeliness and good physical accessibility. In the first part of this section, we have discussed the method to be used for realistically estimating the requirements for water in rural areas for domestic water supply that includes water for productive needs. We then discussed a framework for selecting water sources for developing rural water supply schemes with a view to achieving physically and environmentally sustainable water supply that uses certain specific indicators of source sustainability and thresholds for each type of source water. A method of tentatively estimating the unit cost of water supply from each source is proposed. Then a method of obtaining an optimum combination of sources from a list of all potential water sources available in a rural setting that meets the criterion of overall cost effectiveness is proposed. Analytical procedures for estimating design floods, high flood levels, and negative externalities associated with the use of fossil fuel for pumping water were also discussed. Finally, the procedure for designing non-conventional water supply sources, such as roof top water harvesting systems, solar-powered drinking water schemes (particularly the design of the PV panel) and small dams for rural water supply, is discussed.

In the second part, a water quality surveillance index had been developed by the UNICEF-IRAP partnership as a tool for surveillance of drinking water sources aimed at source protection (from pollution). The tool uses a wide range of natural, physical, socioeconomic and institutional parameters for assessing the pollution risk of an area. The tool assesses the water quality surveillance needs at the block level. The DWQSI values estimated at the block level help identify the blocks that pose the highest public health risks caused by exposure to contaminated or polluted water for drinking and where frequent and rigorous monitoring and surveillance of water resources and drinking water sources is required to prevent waterborne diseases. This will result in economizing the investment made for water quality monitoring and lead to more judicious use of the existing water testing laboratory infrastructure in the state. The index can also be used for public health surveillance, i.e., to monitor the outbreak of diseases during weather-induced hazards that cause disruptions in water supply (both in terms of quantity and quality) and to take measures for preventing contamination of water supplied from public drinking water sources, such as the setting up of raw water treatment systems.

5 Conclusions and Policy Direction in Line With the Mandate of JJM

The past approach for the planning and technology sections of rural water supply schemes has been based on the consideration of decentralized management of the scheme by the local governments (GPs) along with minimizing the initial capital investments for the infrastructure. Such an approach has led to the selection of water sources and technologies, such as bore wells in hard rock areas that seriously compromise the concern of source sustainability. The Jal Jeevan Mission emphasises source sustainability and provides avenues for tapping new sources of water in situations where local sources are not able to provide dependable supplies throughout the year and also strengthening the existing sources through recharge measures for enhanced scheme performance. Such sources can include water from distant reservoirs, desalination, roof rainwater harvesting tanks, etc. However, such an approach poses new planning challenges. The planning objective should be optimal use of local and exogenous water resources while achieving cost effectiveness and a low carbon footprint. The cost-effectiveness should be assessed in relation to the actual cost of water supply per unit volume of water (considering the capital cost, operation and maintenance cost, realistic life and actual service levels possible), rather than the initial investment per capita.

Section VI:
Handbook on Water Resources Management and WQM For Sustainable Water Supply in Maharashtra in the Face of Increasing Climatic Variability

Summary

The problems of water resource depletion and water quality deterioration are increasingly posing major challenges for securing water supply for basic survival needs in rural areas. This is compounded by the increasing competition for the limited water from other competitive user sectors, especially agriculture. Unfortunately, the regions with limited water resources also witness high demands for water for irrigated crop production, which is constantly on the rise. Therefore, rural water systems should be designed with due consideration to the issues of sustainability of the source water and cost-effectiveness. The current resource scenario demands the use of best practices in planning, technology selection and design of rural water supply schemes that can overcome some of the challenges with regard to water availability and water quality.

Secondly, it is extremely important to protect the quality of the source water. The risk of pollution of drinking water sources from on-site sanitation is increasing in rural areas owing to the concentration of faecal sludge in a few places, while the capacity to do regular monitoring of water quality remains extremely limited. So it is important to know the best practices that the local institutions need to follow to ensure source protection.

The best practices for planning, technology selection and design of rural water supply systems for ensuring sustainability are: 1) realistic assessment of the actual domestic and productive water demands; 2) good mapping of all potential water sources that can be tapped from the locality and water that can be obtained from unconventional sources; 3) realistic assessment of the competing water demands from the potential sources mapped; 4) proper quantification of the amount of water that can be supplied by various sources and the amount of water that will have to be imported; 5) selection of water supply technologies based on a proper evaluation of the comparative cost of various combinations of water supply; 6) considering the life cycle cost (LCC) of the technologies; 7) design of systems for the extreme climatic conditions; 8) design of water supply systems for flood-prone areas; and 9) selection of sites for the schemes to prevent pollution of the source water.

In the second part of this section, we discuss the approach to be used for assessing the infrastructure, knowledge and staffing requirements of the laboratories in different areas based on the water quality surveillance needs of those areas. Now, for initiating actions for the protection of water sources, it is important to know the way in which poor sanitation influences public health. Hence we discussed the three types of factors that influence the public health impacts of poor sanitation, viz., physical, socio-economic; and cultural. That said, there is too little appreciation among the professionals working on sanitation issues of how these factors influence the way onsite sanitation impacts public health, how they increase the exposure of the communities to the hazards, and how they change the degree of vulnerability of the communities to the problem of exposure to contaminated water. In lieu of this, we have identified specific training needs for building capacities at the local level to analyze the impact of on-site sanitation.

To ensure cost-effective and efficient water quality surveillance, it has to be targeted at areas that pose the highest public health risk from water pollution. Hence, capacity building interventions are required for improving the analytical capabilities of the officials of the Water Supply and Sanitation Organization (WSSO) and the WQ testing laboratories for assessing the pollution risk posed to source water, and the strategies for improving the surveillance capabilities of the local communities and the role of the Jal Surakshaks. Specific interventions and strategies have been proposed.

Now, keeping in mind the kind of information that needs to be generated for water quality management and drinking water safety, we have discussed ways to improve the capabilities of GSDA for the processing and interpretation of water quality data. Finally, we also discussed the best practices in planning, technology selection and design of water supply schemes, as well as the best practices for protecting drinking water sources.

The best practices for source protection proposed for new schemes include: 1) reviewing the situation with respect to water safety; 2) employing a risk reduction strategy; 3) proper siting of the scheme, by locating it away from the high-risk areas; 4) capacity ascertainment with respect to WQM and surveillance for regular water sample collection and surveillance. In the case of existing schemes and new schemes, the measures suggested are: a) periodic monitoring of source water quality; b) increasing the frequency of monitoring source water through the

collection and testing of water samples during the months of monsoon; c) preventing animal waste disposal; and d) issuing proper warnings on the basis of the degree of risk involved in the event of contamination of the source.

1 Introduction

The twin problems of water resource depletion (groundwater depletion and over-appropriation of water from rivers and lakes) and water quality deterioration are increasingly posing major challenges for securing water supply for basic survival needs in rural areas. This is compounded by the increasing competition for the limited water from other competitive user sectors, especially agriculture. Unfortunately, the regions with limited water resources (naturally water-scarce regions) also witness high demands for water for irrigated crop production, which are constantly on the rise due to increasing demand for meeting rural economic needs. Therefore, it is extremely important that rural water systems are designed with due consideration to the issues of sustainability of the source water and cost-effectiveness of the system. Given the current resource scenario, depending on a single source of water to meet the entire demand will be extremely risky. It is important to know the best practices in planning, technology section and design of rural water supply schemes that can overcome some of the challenges with regard to water availability and water quality.

Secondly, once the scheme is built, it is extremely important that the quality of the source water is protected. The risk of pollution of drinking water sources from on-site sanitation is increasing in rural areas owing to concentration of faecal sludge in a few places, while the capacity to do regular monitoring of water quality remains extremely limited. So it is important to know the best practices that the local institutions need to follow to ensure source protection. This handbook deals with these two important aspects of rural water supply.

2 Best Practices in Planning and Design of Water Supply Schemes for Source Sustainability Using IWRM Principles and Ways to Operationalize Them in Maharashtra

1) A realistic assessment of the actual water demands and the likely future growth, including the demand for water for productive water needs such as livestock watering and kitchen gardening, is required. Often, livestock water needs are under-estimated. But dairy farming (with buffaloes and cows) has emerged as a major economic activity in the semi-arid and arid areas of India.

2) Good mapping of all potential water sources that can be tapped from the locality-water from roof catchment, water from lakes and ponds, water from natural surface catchments, water from underground sources (aquifers) and water that can be obtained through desalination of marginal quality groundwater

3) A realistic assessment of the competing water demands from the potential sources mapped, such as water for irrigation and water for industrial uses. It should be kept in mind that what matters is not the volume of water available at the source, but what will actually be accessible for domestic uses.

4) Proper quantification of the amount of water that can be supplied by various sources, and the amount of water that would be required through imports (in the case of water-scarce regions), including those in extreme climatic conditions (such as droughts and wet years). Proper quantification of the runoff that is generated from natural catchments under different rainfall conditions (from the driest year to the wettest year) is the key to assessing the runoff corresponding to different degrees of dependability.

5) Selection of water supply technologies based on proper evaluation of the comparative cost of various combinations of water supply, considering the indirect cost of the technologies that involve environmental effects and the indirect benefits of the technologies that involve clean energy benefits

   It is important to mention here that often cost of certain technologies such as Roof Top Rainwater Harvesting Systems is under-estimated.

6) Considering the life cycle cost (LCC) of the technologies for the region/area under consideration, taking into account the realistic life of the system and the operation & maintenance costs, in the evaluation of cost effectiveness

7) Design of systems for the extreme climatic conditions wherever it matters, such as surface reservoirs for the flow of highest dependability from the catchment, say, 98%, to ensure that they perform at the desired level even during the driest years. Similarly, in the case of groundwater-based schemes, the depth of the well (or bore well) shall be fixed by taking cognizance of the highest depth to water table possible with extreme events (droughts) and with future increases in the

exploitation of groundwater.

8) Design the water supply systems for flood-prone areas, considering the extreme floods with a high return period (T=50 years for large schemes) and their implications for river water levels and groundwater quality.

9) Sources such as open wells in low-lying areas shall be provided with a protection wall to prevent contamination of the source water during landslides, floods, etc. In the case of handpumps, the raising main should be on a raised platform above the ground with sufficient height so as to keep it above the water level during flood events.

10) Selection of sites for the schemes in such a way that they are least susceptible to pollution from onsite sanitation, industrial effluent disposal, etc.

In order to follow the best practices listed above, we need to have data on the following variables: i) magnitude of extreme floods with a 50-year return period for flood-prone areas; ii) estimates of the life cycle cost (LCC) of different types of water supply schemes in different physical (geology, geohydrology, topography and hydrology) and socio-economic environments, iii) realistic assessment of groundwater demands for irrigation in different agro-climatic socioeconomic conditions; iv) rainfall-runoff relationships of catchments under different hydro-climatic conditions; v) utilizable groundwater recharge in different geological and geohydrological environments and the pattern of occurrence over the year, including the return flows from irrigation and canal seepage; and vi) mapping of the vulnerability of aquifers under different geohydrological environments in Maharashtra .

3 Strategies for Improving Water Quality Surveillance for Source Protection in Maharashtra

The approach for water quality surveillance of any area should be driven by an assessment of the public health risk that water pollution and contamination in an area pose to public health. This basically means that the risk status of an area should be the major criterion for deciding the infrastructure and knowledge requirements of the WQT laboratories and their staffing. Hence, the approach involves mapping the public health risks associated with water contamination and pollution using a robust tool (like the water quality surveillance index that we have developed).

That said, the analytical capabilities of agencies (such as WSSO) primarily concerned with the protection of drinking water sources should be enhanced to map the risk posed by poor quality of source water, periodically. Simultaneously, the sanitary engineers and inspectors should be provided training on the impact of on-site sanitation and sanitary engineering. Further, in areas that face high public health risks from water pollution, capabilities for sanitary surveillance need to be built at the local level by providing proper training to the Jal Surakshaks on how, where and when on-site sanitation impacts the quality of surface and ground water resources. Finally, the analytical capabilities of the Groundwater Survey and Development Agency of Maharashtra, the agency concerned with the development of groundwater-based drinking water sources, need to be enhanced for the processing and interpretation of water quality data.

3.1 Assessing the Infrastructure, Staffing and Knowledge Requirements of WQT Laboratories

Infrastructure and Knowledge Requirements

The Uniform Drinking Water Quality Monitoring Protocol (2019 draft version) mentions that the GPs are to be provided with field testing kits that can analyze water samples for 11 parameters for the presence of bacteria, pH levels, TDS levels, and colour. A visual comparison method is adopted for testing turbidity, the presence of ammonia, phosphate and residual chlorine, and a visual colour comparison is to be used for nitrate and fluoride. The water quality testing capabilities of laboratories would be decided by the administrative jurisdiction of the laboratory (MoDWS, 2019).

The water quality testing capability of any laboratory, irrespective of its geographical position or the jurisdiction it commands, should instead be decided by the water contamination/pollution risks the area is subjected to, in order to reduce the time lag between sample collection and making the test results available to the affected communities to a minimum. The laboratory in an area with a large presence of polluting industries and reported cases of surface or groundwater contamination should possess the equipment and staff to test water samples for complex compounds that are likely to be encountered in industrial effluents. The availability of well-equipped laboratories within a short distance of the pollution hotspots will help carry out quick and periodic water quality surveillance of the area to prevent public health hazards. It is necessary to have all the equipment necessary to conduct tests for all 73 parameters (suggested in the Quality Monitoring Uniform Protocol) in such laboratories.

Further, the 2019 draft protocol recommends that State and District laboratories may monitor Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) in surface water if eutrophication is observed or reported. It also suggests that these parameters may also be of importance at the downstream of industrial areas/discharge of treated/partially treated/untreated sewage from cities and towns. However, the protocol does not recognise the chances of the occurrence of high COD in shallow groundwater areas and areas where industrial sludge is dumped. Further, with numerous pit latrines being constructed in rural areas, there can be a prevalence of high BOD in shallow groundwater. Thus, all laboratories should have the capability of testing water samples for BOD and COD. The laboratories at all levels (state, district and sub-district) need to put greater emphasis on bacteriological tests owing to the widespread contamination of drinking water sources from human and animal waste.

In the event of a health outbreak due to the intake of contaminated water in an area that otherwise is in the safe category (as per the WQSI), arrangements should be made to send water samples to the nearest labs having facilities to undertake advance water quality testing.

In addition, to reduce the response time between sample collection and dissemination of test results, mobile water quality testing facilities also need to be created, along with field test equipment and well-equipped laboratories. The Centre for Affordable Water and Sanitation Technology (CAWST), which is a non-profit organization in Canada, does water quality tests in poor localities using mobile laboratories as well.

Staffing of Laboratories as per the Local Risk Assessments

The 2019 draft Uniform Drinking Water Quality Monitoring Protocol document suggests that the staffing requirements of an effective water quality assessment laboratory should be based on: total work load; schedule of on-site analysis, camp analysis and laboratory analysis; geomorphology/terrain of the area; demographic conditions; size and complexity of the supply system; and distance of sampling points and water supply systems. The protocol suggests 14 staff for the state-level lab, eight for the district labs, and six for the sub-district/block-level lab.

However, the criteria suggested for fixing the staff strength of laboratories miss many important factors that will actually have a significant bearing on the requirements. They are: 1) the nature of water quality problems encountered in the source water of the area coming under the jurisdiction of the laboratory (such as problems of contamination of water from pesticides, heavy metals and radio-active substances); 2) the surveillance requirements as decided by the degree of health risk posed by the water source to the communities in the area due to water contamination or pollution ; and 3) the characteristics of drinking water sources.

Complex water quality problems, generally caused by hazardous chemicals present in industrial effluents, increase the testing requirements vis-à-vis the number of chemical parameters for which water samples are to be analysed. High risk areas demand greater water quality surveillance and a greater frequency of monitoring (with more samples and tests per year) to avert public health hazards. The dominance of mini water supply schemes like hand pumps and individual village schemes in a region increases the sampling requirements and consequently the workload of the laboratory. The reason is that there will be too many drinking water sources in a given geographical area, each supplying water to a limited population (against one large RWS scheme supplying water to several villages), which increases the monitoring requirements as there will be more water points from which samples have to be drawn.

The analysis undertaken by UNICEF/IRAP proposes to have at least nine staff members, including one senior microbiologist/senior chemist/senior water analyst, one microbiologist, one chemist, two lab assistants, one data entry operator, two field assistants and one lab attendant in high-risk areas. The laboratory staff strength can increase to 11 in cases where the area is dominated by mini water supply schemes (like individual village schemes and hand pumps), with additional staff for the posts of Field Assistant and Laboratory Assistant (please refer to Table 6.1). In the rest of the places, the staff strength suggested for block-level laboratories would be adequate.

However, in their job charts, the requirement of some versatility in conducting essential jobs is called for. In addition, each one of the major laboratories should have a laboratory manager, who would work with the chief or the Sr. water analyst.

[8] In the case of state-level labs, it is proposed to have one Chief Chemist/Chief Water Analyst, one Senior Chemist/Senior Water Analyst/Senior Microbiologist, two Chemist/Water Analyst, one Microbiologist/ Bacteriologist, three Laboratory Assistants, two Data Entry Operator, two Lab Attendants, and two Field Assistants (task/need based field staff). In the case of district-level labs, the staff size is one Chemist/Water Analyst, one Microbiologist/ Bacteriologist, two Laboratory Assistants, one Lab Attendant, one Data Entry Operator and two Field Assistants (task/need based field staff).

Table 6.1: Staff composition proposed for areas prone to high pollution risk

Sr. No	Staff Position	Number of Personnel	
		Blocks Dominated by Large (RWS) Schemes	Areas Dominated by Mini Schemes
1	Sr. Chemist/Sr. Water Analyst/ Sr. Microbiologist	1	1
2	Chemist	1	1
3	Microbiologist	1	1
4	Lab Assistants	2	3
5	Lab Attendant	1	1
6	Field Assistant	2	3
7	Data Entry Operator	1	1
	Total	9	11

Source: Based on authors' own analysis

Apart from testing water samples, the laboratories should also be mandated to undertake research that would help leverage actions for improving source water quality and the quality of water during treatment and distribution. The state-level laboratory should undertake a resource planning exercise from time to time to take cognizance of the fact that the appointment of qualified and experienced staff will place further demands on the budget.

3.2 Undertaking a Training on Impact of Onsite Sanitation, and Sanitary Engineering

A review of the international literature suggests that there are three types of factors influencing the human health impacts of poor sanitation viz., physical, socio-economic and cultural. The physical factors include rainfall, climate, soils and geo-hydrology. There is a sufficient amount of international evidence that links these physical factors to the health impacts of poor sanitation, such as open defecation and on-site sanitation. These works include both theoretical and empirical data-based studies. The overarching factor is the climate characteristics, essentially the occurrence of climate extremes.

There is too little appreciation among the professionals working on sanitation issues of how these factors influence the way onsite sanitation impacts public health, i.e., how they increase the 'hazard', i.e., contamination of surface and groundwater bodies tapped for drinking water supply; how they increase the exposure of the communities to the hazard; and how they change the degree of vulnerability of the communities to the problem of exposure to contaminated water. As a result, often stereotyped designs are followed for the construction of toilets for on-site sanitation in rural areas.

While the physical factors mainly influence the hazard, the socio-economic factors influence both exposure and vulnerability. The cultural factors influence the exposure and the 'climate extremes' influence all the other three dimensions of the public health risk associated with water contamination, viz., hazard, exposure, and vulnerability of the communities. The main contents of the training to be imparted to the sanitary engineers and inspectors are discussed in detail below.

Physical Factors

Contamination takes place in the event of a pathway existing between a source, i.e., an on-site sanitation system and a receptor, i.e., a groundwater body. Groundwater pollution due to on-site sanitation systems has been dealt with by many workers (Gerba & Bitton, 1984; Hageton, 1984; Chidavaenzi et al., 2000).

Concern about groundwater pollution due to on-site sanitation systems relates primarily to unconfined and, to a lesser degree, to semi-confined aquifers. If groundwater supplies are drawn from deep and confined aquifers, on-site sanitation does not pose a significant hazard. Recent studies by Lawrence et al. (2001) highlight the role of hydrogeology in determining the degree of contamination of groundwater from on-site sanitation. Studies carried out in the USA on groundwater pollution from septic tank

[9] An index is already developed by IRAP to assess the water quality surveillance requirements at the sub-district/block level based on the pollution hazard, degree of exposure and vulnerability of the community. The value of the water quality surveillance index is being computed for each block to identify the blocks that pose a high degree of public health risk and those that require high surveillance.

effluent have been a major source of information. However, the effect of the difference in the design and construction of septic tank disposal systems and the proposed sanitation systems may be significant. The studies carried out were in Columbia in sand-clayey sand (Kligler, 1921), and in Alabama in fine-sand medium (Caldwell, 1938). Besides, studies were conducted in sandy clay in Texas (Brown et al., 1979) and fractured rocks in Colorado (Allen & Morrison, 1973).

The majority of the field studies were confined mainly to fine-grained sediments, which are of low risk and consequently most suitable for on-site sanitation. There is a need to obtain more information on other soil types. There is a need for a classification of hydro-geological environments in relation to pollution risk. This would be of great value in the appraisal and implementation of on-site sanitation schemes. The factors affecting the pollution of groundwater from on-site sanitation, which are well documented, are as follows: depth to water table; hydraulic loading; the structure and texture of soils in the unsaturated zone; and the presence of fissures in the case of hard rock formations. Their role is discussed below.

1) The chances of contamination increase significantly in geological settings where the water table is very shallow (1-15m).

2) The unsaturated zone represents the first line of defence against aquifer pollution. Soil provides a very effective natural treatment system. It has ability to remove faecal micro-organisms and chemical/biochemical compounds. The nature of the geological strata and thickness of the unsaturated zone determine the risk of pollution. While natural flow rates in the unsaturated zone of almost all formations do not normally exceed 0.3 m/day (Lawrence et al., 2001), they can be more than an order of magnitude higher in the case of fractured formations. Flow rates in excess of 5 m/day may occur in fissured rocks and coarse gravel (Franceys et al., 1992), and the potential for groundwater contamination under these conditions is extremely high. Thus, rock type, especially the grade of consolidation and the presence of fractures, are key factors in assessing the vulnerability of an aquifer to pollution.

3) The key factor in reducing microbiological contamination of groundwater is the maximization of effluent residence time in the unsaturated zone. Many contaminants, especially micro-organisms, are rendered harmless or reduced to low concentrations by natural processes when the movement of the contaminants in the sub-surface is slow. The natural treatment processes, such as filtration, are more efficient in fine-grained, unstructured soils. Structures such as root channels, animal burrows, natural voids and fissures commonly lead to short-circuiting of the unsaturated zone, with a consequent reduction in the residence time and natural treatment. This may lead to a greater risk of groundwater pollution.

4) Clogging of the filtration surface in the latrine pit enhances bacteria and virus removal processes so that the risk of pollution from microorganisms diminishes after the first 100 days or so of pit usage. But it can reduce the infiltration of the effluent, thereby affecting the capacity to reduce the BOD, COD, nitrate, etc.

5) More specifically, the risk of microbiological groundwater pollution will be minimal where more than 2 m of fine unsaturated soils are present beneath the latrine pit, provided the hydraulic loading in the pit does not exceed 50 mm/day.

6) In the saturated zone, pollutants move with the groundwater causing a pollution plume to develop from the pollution source. Contamination removal processes take place in the saturated zone but at a lesser rate compared to the unsaturated zone since groundwater moves more rapidly. Within the saturated zone, dispersion and dilution play an important role in reducing the concentration of the contaminants.

Improper design, construction, operation, or maintenance of on-site sanitation systems can lead to failure due to the loss of infiltration capacity and the consequent surfacing of effluent. Such failures are quite frequently reported. In well-designed septic tanks, the solid matter does not represent a significant hazard, but the soak pit causes both microbiological and chemical contamination. There is a potential threat to groundwater where hydraulic loads are high and they exceed natural attenuation potential in the sub-surface. However, an equally important and more insidious failure is that of inadequate effluent purification.

The organic matter gets filtered while passing through the soil formations. They also get adsorbed and digested through aerobic and anaerobic processes. The microorganisms, such as bacteria, viruses and fungi, get adsorbed.

Adsorption of both viruses and bacteria is highest in soils with high clay content and is favoured by a long residence time-that is, when flow rates of effluent are slow. Since the flow is much slower in the unsaturated zone than in the saturated zone, the contact time is longer between soil and effluent, thereby increasing the chances of adsorption. Adsorbed microorganisms can be dislodged, for example, by flushes of effluent or following heavy rainfall, and may then pass into lower strata of the soil.

Both viruses and bacteria live longer in moist conditions than in dry conditions. Bacteria live longer in alkaline soils than in acidic soils. The bacteria also survive well in soils containing organic material, where there may be some regeneration.

The survival of bacteria and viruses in soils also depends on the temperature. The reduction of polioviruses held for 84 days in loamy sand was less than 90% at 4°C but 99.99% at 20°C. Also, it was found that aerobic inactivation was more rapid under non-sterile versus sterile conditions and that anaerobic conditions led to a reduction in inactivation. In a nutshell, while the formation conditions influence the removal process, the survival of these microorganisms in the formations depends on the temperature, pH value, moisture content, etc. However, the dominant factors for bacteria survival are temperature and moisture (Gerba et al., 1975).

Socio-economic Factors

The socio-economic factors include: the educational status of the families, their income status, whether rich or poor, access to public health infrastructure, and population density. For instance, in the Indian context, a study employing data from NFHS-3 and employing the Concentration Index found that a negative gradient exists between a family's socio-economic status, measured in terms of family asset index, and the prevalence of chronic childhood malnutrition (for children below the age of five) (Kanjilal et al., 2010). In communities that are educated, people are more cautious about the health impacts of poor sanitation facilities and would exercise enough precaution to prevent the negative health outcomes of poor sanitation . Similarly, comparatively rich people would be able to develop immunity to negative health impacts such as diarrhoea and cholera through nutritional intake and by accessing health facilities quickly in the wake of epidemic outbreaks, whereas the poor may fall victim to diseases due to a lack of ability to access medical facilities (Howard, 2002; Hunter, 2003).

People living in congested localities would be more prone to vector-borne diseases, due to the favourable environment for vector breeding and through faster transmission of the disease through vectors (Howard, 2005). People living in remote localities with poor access to transportation networks would be more liable to the risk of mortality from water-borne diseases like diarrhoea than those with a good transportation network.

Cultural Factors

Poor sanitation can be the result of cultural factors too. Cultural beliefs and practices can hinder the introduction of sanitation technologies, systems and practices (Okot-Okumu & Oosterveer, 2010). The cultural factors also include food habits, practices related to personal hygiene and sanitation, the practices of animal rearing, and overall lifestyles. In many rural areas of India, 'hand-washing' with soap or even simple hand-washing after food is not very common. This can also increase human exposure to pathogens.

It is now an established fact that, irrespective of economic status, certain communities show a higher degree of nutritional deficiency than certain other communities-which is not explained by their ability to access nutritional food. One major reason is the social taboo about the non-vegetarian diet (meat, fish and eggs) and the lack of ability to find a dietary substitute with adequate proteins. The community's own perception of hygiene is also important. In some communities, keeping toilets close to the dwelling is considered very inauspicious and unhygienic. In some agricultural communities, keeping cattle, agricultural harvest, etc. close to the dwelling is considered a sign of prosperity.

In the individual context, latent variables (such as attitudes and preferences) can be linked to the choice of sanitation technologies. Now, conclusions can be drawn from cognitive variables associated with an individual's socio-economic and demographic characteristics of his/her individual preferences and attitudes, and causal pathways can be established amongst these variables.

Climate Extremes

The droughts and floods are the over-arching factors. The ways in which droughts and floods can influence the human health impacts of poor sanitation are very complex and not amenable to simple and straightforward analysis (Hales et al., 2003; Kovats, 1999). Floods can cause changes in water contamination by faecal matter and increase the risk of diarrheal diseases (Hales et al., 2003). Contamination can occur via surface conveyance of faecal matter as well as in groundwater as recharge increases.

During floods, contaminated water can also enter open wells commonly present in shallow groundwater areas, especially in coastal zones like the Konkan region.

As temperature and moisture influence bacterial survival in soils (Gerba et al., 1975), prolonged rainfalls can provide a favourable environment for bacterial contamination of groundwater. The health risks can increase due to overall poor health resulting from population displacement, shortage of food supply, etc. (Kovats, 1999). Droughts can increase food shortages and malnutrition, drinking water shortages, and health risks associated with a lack of water for hygiene (Kovats, 1999).

[10] One good example of this is the practice of boiling drinking water from open wells contaminated by septic tanks and leaching type toilets.

3.3 Improving Analytical Capabilities for Mapping Risks from Poor Quality of Source Water

The key to ensuring safe drinking water lies in proper water quality surveillance. If WQS is to be undertaken in an efficient and cost-effective manner, it has to be targeted at areas that pose the highest public health risk.

Target Audience: First of all, the target audience for this is the Water Supply and Sanitation Organization (WSSO) and the officials from different laboratories. A training can have a total of 20-25 participants, including 18-20 participants from the district labs and 2-3 from the state-level laboratories. Each district lab can delegate a minimum of two and a maximum of 3 officials for the training.

Orientation to the Concept of Public Health Risk from Water Contamination: In order to improve the analytical capabilities for mapping the risk associated with exposure to poor quality water, the first thing is to have orientation of the people involved in WQM at WSSO and the laboratories to the concept of public health risk. The public health risk associated with contamination/pollution of source water is a function of three important variables: 1) degree of hazard (which in this case is water pollution); 2) degree of exposure of the water supply system to the hazard; and 3) vulnerability of the communities to the deterioration of the quality of the water supplied by the source.

Training on Development and Application of WQSI: After orientation, the next step should be to train the participants on the concepts and principles underlying the development of the Water Quality Surveillance Index, the composite index that helps us map the variation in public health risk associated with water contamination across the state and identify areas (districts/sub-districts) that require constant surveillance for ensuring drinking water safety and protection of public health. The training sessions will be aimed at explaining the range of factors influencing the pollution hazard, exposure and vulnerability, as well as the manner in which they influence.

Laboratory Work: As part of the training, the officials need to be assigned the task of computing the WQSI for a few sample districts, wherein they would be asked to collect secondary data pertaining to different variables (used for developing the index) for those districts and then compute the values of the index. Since collection and compilation of these data require time, it will be useful if the trainees are intimated well in advance of the kind of data required to be collected. Five to six groups can be formed for the lab work, each having four members.

Validation: The computed values of the index for different districts (around 6 of them) could be reviewed by the lab officials representing those districts to see whether they reflect the situation on the ground-or whether they can be related to the evidence from the field. The reality on the ground can be in the form of reported cases of drinking water contamination or reported incidences of water-borne diseases. The review should be in relative terms in the sense that one should be concerned whether the district with a higher value of the WQSI is showing a higher incidence of waterborne diseases or a larger number of cases of water contamination. If the computed values do not match with the ground realities, then the values considered for the different parameters used in index computation must be revisited. Simultaneously, the data on the reported cases of waterborne diseases, etc., also need to be cross-checked to examine their reliability.

3.4 Building Sanitary Surveillance Skills at the Local Level

Carrying out sanitary surveillance of drinking water sources in rural areas as per the current sanitary surveillance protocol is a highly time-consuming task. One major reason is the large number of drinking water sources (such as hand pumps and bore wells), each one catering to a small portion of the population. Surveillance should be frequent in regions where the public health risk associated with consuming contaminated water is high. This is determined by several physical, socio-economic and cultural factors, with climate extremes (such as droughts and floods) and variability having an over-arching effect in terms of magnifying the impact of these factors on hazard, exposure, and vulnerability.

From the description of factors that actually determine the degree of public health risk associated with contamination of drinking water sources due to onsite sanitation, we can describe areas that require continuous surveillance in terms of physical, socio-economic and cultural features. They are:

- Areas with high rainfall, a cold and humid climate, sandy soils and a shallow water table: A higher risk will be evident when the depth to groundwater table is low, or when the climate is 'colder and humid' and the soil has low clay content.

- Areas where the rural households are very poor and that are entirely dependent on public sources for drinking water supply: First of all, the absence of alternative sources of water supply increases the exposure of the communities to contaminated water from public sources. Secondly, the immunity to diseases is generally poor among poor communities, which increases their vulnerability to water-borne and vector-borne diseases.

- Areas where drinking water sources, such as stand-posts and open wells (unprotected sources), are prone to water logging/ flooding: The water source can become contaminated by flood waters carrying animal waste and also faecal matter if open defecation is prevalent.

- Areas where households do not have individual water connections and depend on common sources that are distant
- Areas where drinking water supply is based on surface sources and where the catchments of the water body are exposed to human excreta from open defecation and use by animals

Further, it is important to remember that in a locality, which generally poses low risk, the chances of contamination of drinking water sources can increase immediately after high rainfall events during the monsoon season or after floods, as top soil gets saturated, the water table rises, and the vertical movement of (microbial and biochemical) contaminants in the faecal matter becomes faster. Furthermore, even in hot and arid (also semi-arid) tropics, the vulnerability of the communities increases or immunity decreases during the rainy season due to increased moisture in air and soil and the prevalence of microorganisms in water, air and soil. The same decreases during the hot summer months. Hence, the frequency of surveillance also depends on the time of the year or season. The ability of the Jal Surakshak to do sanitary surveillance in an effective manner depends on the extent to which he/she is familiar with the above-described issues, apart from their knowledge about the quantitative criteria already adopted as per the current sanitary surveillance protocol.

In order to build sanitary surveillance skills at the local level, the capacity of the Jal Surakshak needs to be enhanced. Building the capacity of the Jal Surakshak for carrying out the work of sanitary surveillance effectively would require imparting training to them on the factors influencing public health risks associated with contamination of drinking water sources due to onsite sanitation. Such training shall be conducted by sanitary engineers or public health engineers who are well versed in knowledge about the impact of onsite sanitation on drinking water quality. Such training would help the Jal Surakshaks independently take decisions on which drinking water sources in the villages require surveillance and therefore frequent monitoring and which ones can be left for routine monitoring.

3.5 Improving Capabilities for Processing and Interpretation of Water Quality Data at the Level of GSDA

The analytical capabilities that the water supply agencies will need in the future for the processing and interpretation of water quality data depend on the kind of information that needs to be generated for water quality management and drinking water safety.

The Groundwater Survey and Development Agency collects water samples from their observation wells and analyze them in the state, district and sub-district level laboratories for 11 water quality parameters once every six months as part of groundwater resource monitoring. They also collect water samples from all drinking water supply sources periodically through their network of district-level water quality consultants and Jal Surakshak and analyze them for a total of 13 water quality parameters.

These data are available in tabular form for different seasons and years. However, they are never analysed on a spatial and temporal scale using a geographical information system. They are also not analyzed in order to understand the dynamics of change in water quality. This approach to analyzing and interpreting water quality data does not provide sufficient warning to the agency before the source is contaminated in order to take preventive measures. The analytical capabilities of the two agencies, i.e., GSDA and WSSO, need to be remarkably enhanced so as to produce the outputs in the following formats for better water quality management and drinking water safety:

- The contaminants/pollutants whose concentration shows a consistently increasing trend as per the maps produced from source water monitoring; the locations where such trends are seen; and the rate at which the concentration is increasing
- To what extent this is caused by the proximity of these sources to potential contaminating/polluting sources (such as industrial effluent disposal sites, or urban wastewater disposal sites)
- Distance between the observation stations that consistently show rising trends from major drinking water sources and the likelihood of future contamination of the sources
- The contaminants/pollutants whose concentration show fluctuating trends--increasing and decreasing trends--and their association with seasonality and rainfall occurrence (such as salinity and fluoride concentrations)
- Pattern of occurrence of bacteriological contamination of groundwater, particularly in terms of its relationship with areas of poor sanitation, climate, rainfall magnitudes, soil characteristics and geohydrological environment
- Areas/locations where new water quality monitoring stations need to be established to better capture water quality variations

For performing the analysis to generate such information, the following technical capabilities are required: 1) understanding of the process of movement of contaminants in soils and groundwater; 2) the process of natural cleaning of wastewater during its vertical movement through underground formations; 3) geo-hydrochemistry; and 4) statistics. Of these four different types of skills, only one is present in the GSDA at present, i.e., knowledge of geo-hydrochemistry. Training will have to be imparted to the technical officers of the GSDA (geologists) to equip them with the first two sets of skills. Training will have to be undertaken by sanitary engineering experts who have specialized in groundwater hydraulics and pollutant transport in soils. For skills in statistics, it is good to hire professionals trained in statistics.

4 Best Practices in Drinking Water Source Protection

In the case of new schemes being planned,

1) Review the situation with respect to water safety: Make a prior review of the public health risks associated with source water contamination and pollution in the area in question at an appropriate scale, and in the case of high risk, ascertain the factors that actually contribute to the hazard and the associated risk.

2) Employ Risk Reduction Strategy: Explore the scope for reducing the pollution threat by altering the values of the related parameters. For example, if the source water is from a shallow aquifer and there is an imminent threat of pollution from on-site sanitation, then the possibility of tapping water from a confined aquifer that is least vulnerable to pollution can be explored. In the event that the measures for mitigating the pollution threat become prohibitively expensive, the alternative option of proper siting of the source shall be explored as below.

3) Proper siting of the scheme: If the area falls in the category of 'high risk' or 'moderate risk', locate the scheme in a safe place, taking cognizance of the potential pollution threat. In the case of groundwater-based schemes, this means that the source water doesn't get contaminated by the pollution load from above (from open defecation, animal waste dumping, onsite sanitation, effluent disposal, etc.). Groundwater-based schemes in flood-prone areas should tap deep, confined aquifers that are not vulnerable. In the case of surface water, this means that the catchment of the source water is free of biological and biochemical waste disposal sites.

4) Capacity ascertainment with respect to WQM and surveillance: Depending on the type of pollution threat (i.e., whether bacteriological or other microbial, chemical, or radioactive), ascertain that the infrastructure and trained personnel are available for the required water quality testing and that a local surveillance mechanism is available for regular water sample collection and surveillance.

In the case of existing schemes and new schemes,

5) Periodic monitoring of source water quality: Closely monitor the changes in source water quality periodically in high risk and moderate-risk areas with respect to the pollutants that are relevant for the area, depending on the polluting source. In an area where open defecation is common, animal waste disposal is rampant, or onsite sanitation systems are common, and if the area has a shallow water table and the WS scheme is groundwater-based, then bacteriological contamination of groundwater is likely to be high. Hence, monitoring should be for the bacterial load in the groundwater.

Increase the frequency of Monitoring: Increase the frequency of monitoring the source water through the collection and testing of water samples during the months of monsoon.

7) Prevent animal waste disposal: Prevent open dumping of animal waste and open defecation in areas that fall under a high- or moderate-risk zone . Environmental sanitation should include the safe processing of animal waste for the production of compost in compost pits.

8) Issuing of warnings: In the event of contamination of the source water being detected, the communities that depend on the source shall be informed immediately so as to take precautionary measures by the local surveillance agency (the Water Supply Committee of the Gram Panchayat and the Jal Surakshaks). However, the measures that the communities would need to take would depend on the type of contamination. In the case of microbial contamination, boiling the water will be sufficient. However, in the case of chemical contamination with high level of nitrate, arsenic, and fertilizer and pesticide residues, the communities should be prevented from using the water, and an alternative source of water shall be prescribed for drinking purposes.

5 Summary

In this section of the report, we first discussed the best practices for planning, technology selection and design of rural water supply systems for ensuring sustainability. They are: 1) realistic assessment of the actual water demands and the likely future growth, including the demand for water for productive water needs; 2) good mapping of all potential water sources that can be tapped from the locality and water that can be obtained through desalination of marginal quality groundwater; 3) realistic assessment of the competing water demands from the potential sources mapped, such as water for irrigation and water for industrial uses; 4) proper quantification of the amount of water that can be supplied by various sources, and the amount of water that will have to be imported; 5) selection of water supply technologies based on proper evaluation of the comparative cost of various combinations of water supply, considering the indirect costs and indirect benefits; 6) considering the life cycle cost (LCC) of the technologies for the region/area under consideration; 7) design of systems for extreme climatic conditions wherever it matters to ensure that they perform at the desired level even in the driest years; 8) design the water supply systems for flood-prone areas by considering the extreme floods of a high return period (T=50 years for large schemes) and their implications for river water levels and groundwater quality; and, 9) selection of sites for the schemes in such a way that they are least susceptible to pollution from onsite sanitation, industrial effluent disposal, etc.

In the second part of this section, we also discussed the approach to be used for assessing the infrastructure, knowledge and staffing requirements of the laboratories in different areas based on the water quality surveillance needs of those areas. One of the recommendations made on the basis of this approach was to have at least nine staff members, including one senior microbiologist/senior chemist/senior water analyst; one microbiologist, one chemist, two lab assistants, one data entry operator, two field assistants and one lab attendant in high-risk areas. The laboratory staff strength can increase to 11 in cases where the area is dominated by mini water supply schemes (like individual village schemes and hand pumps), with additional staff for the posts of Field Assistant and Laboratory Assistant.

Now, for initiating actions for the protection of water sources, it is important to know the way in which poor sanitation influences public health. There are three types of factors influencing the public health impacts of poor sanitation viz., physical, socio-economic and cultural. The physical factors include rainfall, climate, soils and geo-hydrology. There is a sufficient amount of international evidence that links these physical factors to the health impacts of poor sanitation, such as open defecation and on-site sanitation. These works include both theoretical and empirical data-based studies. The overarching factor is the climate characteristics, essentially the occurrence of climate extremes. That said, there is too little appreciation among the professionals working on sanitation issues of how these factors influence the way onsite sanitation impacts public health, how they increase the exposure of the communities to the hazards, and how they change the degree of vulnerability of the communities to the problem of exposure to contaminated water. As a result, often stereotyped designs are followed for the construction of toilets for on-site sanitation in rural areas. In lieu of this, we have identified specific training needs for building capacities at the local level to analyse the impact of on-site sanitation.

Proper water quality surveillance is the key to ensuring drinking water safety. If water quality surveillance is to be undertaken in an efficient and cost-effective manner, it has to be targeted at areas that pose the highest public health risk from water pollution. We have also proposed interventions to improve the analytical capabilities of the Water Supply and Sanitation Organization (WSSO) and the officials of the WQ testing laboratories in mapping risks from poor quality of source water. We have also discussed the strategies for improving the surveillance capabilities of the local communities and the role of the Jal Surakshaks. However, the issue that the members of the local communities often do not know what should be done with the water quality test should not be ignored, as pointed out by two of the senior experts who were at the helm of affairs in a state-level water supply agency.

Now the analytical capabilities that will be required by the state water supply agencies of Maharashtra in the future for the processing and interpretation of water quality data depend on the kind of information that needs to be generated for water quality management and drinking water safety. Keeping these crucial points in mind, in this report, we have discussed ways to improve the capabilities of the GSDA for the processing and interpretation of water quality data. Finally, we also discussed the best practices in planning, technology selection and design of water supply schemes, as well as the best practices for protecting drinking water sources.

That said, there are best practices that can be followed for source protection when new schemes are planned. They include: reviewing the situation with respect to water safety; 2) employing a risk reduction strategy; 3) proper siting of the scheme, by locating it away from the high-risk areas; 4) capacity ascertainment (infrastructure and trained personnel) with respect to WQM and surveillance for regular water sample collection and surveillance.

In the case of existing schemes and new schemes, the following measures can be adopted: 1) Periodic monitoring of source water quality; 2) increasing the frequency of monitoring of source water through the collection and testing of water samples during the months of monsoon; 3) preventing animal waste disposal; and 4) issuing proper warnings on the basis of the degree of risk involved in the event of contamination of the source.

6 Conclusions and Policy Inferences

If we have to design water supply schemes that are physically sustainable, cost-effective, and that result in minimum negative impact on the environment, we have to move away from schemes that tap a single water source (say, groundwater, reservoir water, or river water) to schemes that tap multiple water sources in the locality (groundwater, reservoir water, lake water, and water from local catchments) and that result in optimum utilization of local water sources with minimum dependence on exogenous water and minimum energy requirements for transporting water. This requires a paradigm shift in thinking in policy circles.

On the other hand, source protection requires institutional capacity building at various levels, from equipping the laboratories in areas where pollution risks are high with skilled personnel and equipment to building the analytical capabilities of the agencies concerned with water quality management for risk mapping and water quality data processing, analysis and interpretation, to building the sanitary surveillance capabilities of the local self-governing institutions. What is most important in water quality monitoring and source protection are: when and where monitoring is done; how the samples are analyzed and results interpreted; and finally, what actions are taken on the basis of such reports at the local level.

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Annexure 1: Why a Drinking Water Quality Surveillance Index?

1.0 Why a Drinking Water Quality Surveillance Index?

The inbuilt assumption in the Ministry's approach seems to be that water quality management challenges are uniform. While it specifies the WQ parameters to be analysed by each type of laboratory, it does not make any distinction amongst the sources being monitored in terms of the likely water contamination and pollution challenges they pose and does not assign the types of water quality parameters to be analyzed using samples collected from individual DW sources. However, the reality is that there are certain regions/areas in every state that face inherent contamination problems, especially with respect to groundwater, and there are regions where both surface water and groundwater resources are vulnerable to pollution from a wide range of sources by virtue of their location vis-à-vis their proximity to polluting industries, open defecation and a lack of grey and black water management systems, urban centres, unique characteristics of geological formations that the schemes tap, geohydrology, proximity to the sea, rainfall and climate. Field monitoring of source water quality using test kits, as proposed by the Ministry of Drinking Water and Sanitation, will not be adequate to capture complex pollutants. Instead, in such regions, DW source monitoring for contaminants and pollutants will have to be more stringent and more frequent than that of others. Accordingly, the lower grade (sub-district level) laboratories located in such regions should be equipped with better facilities for water quality surveillance. On the other hand, in regions where serious water contamination problems are very rare, it will not make economic sense from the point of view of public health to monitor a large number of water quality parameters, as every additional parameter considered for water quality analysis increases the human resource, chemicals and equipment requirements and therefore the cost of water quality monitoring (DWI, 2017; USEPA, 2016). However, the current protocol does not recognize the need for differential treatment of regions/areas and the water-testing laboratories located there on the basis of water quality management challenges. An attempt is made to develop a composite index that would provide indications as to where the water supply surveillance, in relation to the quality of water, has to be more frequent to avert any public health hazards, and where regular monitoring of certain basic parameters would be sufficient.

2.0 Development of a Drinking Water Quality Surveillance Index for Assessing the Risk of Drinking Water Sources

The water quality surveillance index uses several of the concepts used in the development of the WATSAN vulnerability index developed for urban areas by Kumar (2014), which is about assessing the vulnerability of communities to problems associated with the lack of adequate quantities of water of sufficient quality and reliability for domestic and productive needs. The theoretical discussions providing the rationale for using several of the parameters considered for assessing 'threat', 'exposure' and 'vulnerability' are provided in Kumar (2014).

The development of the present index considers the factors that determine:

1] The 'threat' to water sources, or the chances of deterioration (through contamination or pollution) of a water source (such as groundwater or surface water), which is captured by a water quality index for the source water

2] The degree of exposure of the drinking water sources to contamination or pollution, which is determined by four key factors, viz., availability of water in terms of quantity & quality; conditions of water supply infrastructure; access to water & sanitation; and climate, flood proneness & population density, and

3] The vulnerability of the communities, which is influenced by two factors, viz., the overall public health status, and institutions and management.

The total risk is computed by multiplying Threat (T) X Exposure (E) X Vulnerability (V).

The maximum value of each sub-index would be 1.0. The value of each sub-index is computed by adding up the values of various factors that influence it and then normalizing to obtain a maximum value of 1.0. For computing the value of the sub-index for 'threat', the 'water quality index' (of the source water), which is the only parameter that influences it, is used. For computing the value of the sub-index for 'exposure', values of variables A, B, C and G are added up and normalized. For computing the value of 'vulnerability' sub-index, values of variables D and F are added up. Lower values of the index mean higher vulnerability. The factors considered for computing the sub-indices also will have equal weightage (measured on a scale of 0 to 1.0) and the sum of their values will have to be normalized so as to obtain a maximum value of 1.0. Here, it is important to reckon with the fact that the values being assigned to the indices and sub-indices used for computing the water quality surveillance index, many of the variables used for computing various indices (say for instance the climate sub-index) are 'discrete distributions', and are NOT "real value functions" of real variables, and this is used because what we have developed is a statistical model for computing the surveillance".

The index is computed separately for groundwater-based sources and surface water-based sources, as two of the parameters, viz., resource vulnerability to pollution/contamination, and water quality index values, are specific to the type of resources under consideration (i.e., whether surface water or groundwater). The index value to be used for assessing the water quality surveillance needs will depend on the situation on the ground. If there are only surface water schemes in an area, then the index corresponding to surface water shall be used. If there are only groundwater-based schemes in an area, then the index corresponding to groundwater must be used. In the case of combined use of groundwater and surface water, the weighted average on the basis of the population served by each type of source shall be used.

Though similar indices are not in use anywhere, in the United Kingdom, a Compliance Risk Index (CRI) is used by the Water Supply Inspectorate to assess the risk associated with non-compliance with the European Commission's regulations on drinking water supply by the water supply companies. The Compliance Risk Index is a measure designed to show the risk arising from treated water compliance failures, and it is in line with a risk-based approach to regulation of water supplies. It tries to quantify the significance of each parameter in deciding the overall risk associated with non-compliance with water quality standards, the proportion of consumers potentially affected and an assessment of the company response. The CRI assists water supply companies in requesting (to the Inspectorate) adjustments to be made to their sampling programme (DWI, 2017).

In the United States, the US Environmental Protection Agency uses the concept of risk assessment of 'source water' for designing the source water monitoring system. This risk assessment is based on likelihood, vulnerability and consequences. Likelihood is the probability that the source water will become contaminated. Its value may be based on previous contamination incidents caused by the source water threat or on projections and models. Vulnerability is the probability that a utility or its customers would be impacted by a source water threat. The vulnerability value is generally based on the ability of the utility to effectively respond to an SW threat, preventing or mitigating consequences to utility infrastructure, operations, and customers. Consequences are the adverse effects of an incident experienced by a utility or its customers (e.g., illness). Where possible, consequences are expressed in terms of monetary damage, providing a standard measure of consequence across all threats (USEPA, 2016).

The various parameters considered for developing the water quality surveillance index, the rationale for considering them, the method for assigning scores for each of the parameters required to compute the value of the index, and the sources of the data corresponding to these parameters are detailed in Annexure 2.

Annexure 2: Water Quality Surveillance Index

No	Parameters	Rationale	Scoring Methods		Data Source
Threat					
A	**Water Quality Index**				
1.0	Water Quality Index (The type of resource to be considered (i.e., whether groundwater or surface water) for the computation of this index should be based on the types of drinking water sources that require surveillance. If the source is a reservoir, only the quality status of the surface water should be considered. However, if the source is a well, hand pump, or tube well, then the overall quality of SW and groundwater must be considered.)	Sources with the degree of water pollution and differentiates the purity and impurity of the water resources	Water Quality Index (Potable = 1.0, Non-potable = 0.0). This is based on the WQI adopted and estimated by the Central Pollution Control Board.		The maximum score of sub index E will be 1.0.
Exposure					
B	**Availability of Water Resources in Terms of Quantity and Quality**				
1.1	Surface water and groundwater availability in the area	When plenty of freshwater is available, the chances of communities resorting to consuming water from contaminated sources are less. A renewable freshwater availability of 1700 m^3 per capita per annum is considered adequate for a region or town, estimated at the level of the river basin in which it is falling.	The value of the index is computed by taking the amount of renewable water as a fraction of the desirable level of 1,700m^3.	The maximum score under sub-index A will be 3.0. It has to be reduced to 1.0 for normalizing.	WRD, Govt. of Maharashtra

No	Parameters	Rationale	Scoring Methods	Data Source	No
1.2	Variability in resource condition	The higher the variability, the greater will be the vulnerability.	The index is computed as an inverse function of the coefficient of variation in the rainfall variability in that basin/sub-basin (1-x/100), where x is the coefficient of variation in rainfall.	The maximum score under sub-index A will be 3.0. It has to be reduced to 1.0 for normalizing.	IMD/ maharani.gov.in
1.3	Seasonal variation of groundwater	In the presence of alluvial aquifers, the vulnerability will be lower, and in the presence of hard rock aquifers, vulnerability will be higher. Also, in regions with sedimentary and alluvial deposits, vulnerability will be medium.	For alluvial areas, the value of this index is considered as 1. For hard rocks, the value is considered as 0.3. For sedimentary and alluvial deposits, the value is considered as 0.65.		GSDA/CGWB
2.0	Vulnerability of the resource to pollution or contamination (Here, in the case of sources based on groundwater, both surface and groundwater resources shall be considered. However, in the case of surface water-based sources, only the vulnerability of SW resources shall be considered.)	Shallow groundwater; river/stream/reservoirs in the vicinity of industries are highly vulnerable.	Shallow groundwater, river/stream/reservoirs in the vicinity of industries are highly vulnerable with sub-index value equal to 0.0; distant reservoir in the remote virgin catchments and groundwater from deep confined aquifers has a pollution vulnerability index of 1.0; shallow groundwater in rural areas (with no industries) to have medium vulnerability with a value of 0.50.		CPCB

No	Parameters	Rationale	Scoring Methods		Data Source
3.0	Pollution from industrial and domestic Sources	Pollution will be high due to the presence of different categories of industries (pulp & paper, distillery, power, tannery, dyeing industry, etc.). Also, a higher population causes wastewater discharge to be high.	Presence of highly polluting industries near rivers/streams with a population greater than 100,000 = 0.0; if industries are absent near rivers/lakes and population is less than 100,000 = 1.0	The maximum score under sub-index A will be 3.0. It has to be reduced to 1.0 for normalizing.	CPCB/HP
C	**Accessibility**				
1.0	% of households with piped water supply having access to treated (tap) water	Reduces chances of contamination of water during collection and storage	Index will be computed based on the % of households having access to piped water supply, estimated as a fraction of total households	The maximum score under sub-index B will be 3.0 and has to be reduced to 1.0 for normalizing.	Census
2.0	Access to sanitation as a % of total households	Reduces the chances of vector borne diseases through food contamination, etc.	% of households with piped water supply having access to treated (tap) water		Census
3.0	% of households depending on public taps/stand post/ and other sources (tanks/lakes, etc.)	Chances of contamination of water will be higher for open spaces (tanks/lakes), as well as during collection and storage	% of households depending on public taps/stand post, the value of which is estimated as an inverse function		Census
D	**Infrastructure Characteristics**				
1.0	% of households covered by the water distribution system	Reduces chances of contamination of water during collection & storage	% of households covered by the water distribution system as a fraction	The maximum score under sub-index C will be 4.0 and has to be reduced to 1.0	WSSO/PHED/ Census
2.0	% of households covered by sanitation system	Reduces chances of vector borne diseases through food contamination, etc.	% of households covered by sewerage system as a fraction		WSSO/ PHED/Census

No	Parameters	Rationale	Scoring Methods		Data Source
3.0	Condition of water supply infrastructure	Older water supply systems are more susceptible to disruption	very good =1.0; good =0.8; average =0.6; poor =0.4; very poor =0.20	The maximum score under sub-index C will be 4.0 and has to be reduced to 1.0	WSSO/ PHED
4.0	Condition of sanitation systems	Older sanitation systems are more susceptible to disruption	very good = 1.0; good = 0.8; average = 0.6; poor = 0.4; very poor = 0.20		WSSO/ PHED
E	**Climate, Flood Proneness, and Population Density**				
1.0	Climate (whether semi-arid/arid/hyper-arid, or sub-humid/humid)	The vulnerability to poor environmental sanitation is a function of climate. It increases from hot & arid to hot & semi-arid to hot & sub-humid to hot & humid to cold & humid.	The value ranges from "0.0" for cold & humid to "1.0" for hot & arid, with increments of "0.20".	The maximum score under sub-index G will be 3.0, and has to be reduced to 1.0.	DPAP/ IMD
2.0	Flood proneness (whether flood-prone or not)	Vulnerability increases with increase in flood proneness.	The value can be "0.0" for flood prone areas and "1" for the rest.		NIDM
3.0	Population Density		Relative index, computed by taking the inverse of the value in relation to the best block		Census
Vulnerability					
F	**Public Health Outcomes**				
1.0	Under-five mortality rate (IMR) (out of 1,000 people),	Undernourishment in general and malnourishment, especially among children, make communities more vulnerable.	A relative index, whose value is computed by taking the inverse of the value in relation to best block $\{IMR_{max}-IMR\}/(IMR_{max}-IMR_{min})$	The maximum score under sub-index D will be 2.0 and has to be reduced to 1.0.	Health Department, Govt. of Maharashtra

No	Parameters	Rationale	Scoring Methods		Data Source
2.0	% of households reporting illness due to WRD (diarrhoea, skin rashes, worm infestation)	When sources have lower biological contamination, WRD will be less.	A relative index, computed by taking the inverse of the value in relation to the best block {WRD_{max}-WRD/ [WRD_{max}-WRD_{min}}.		Health Department, Govt. of Maharashtra
G	**Institutions & Management**				
1.0	Staff: Number of staff per 1,000 connections	Vulnerability reduces with an increase in the number of staff members available to manage a fixed number of connections	Relative index, whose value is computed on the basis of the highest and lowest numbers found across utilities	The maximum score under sub-index F will be 4.0 and has to be reduced to 1.0.	
2.0	Frequency of Complaints	Vulnerability increases with the number of complaints about water supply	Vulnerability increases with the number of complaints about water supply		
3.0	Time Taken to handle complaints	Vulnerability increases with delays in handling complaints	Relative index, computed by considering time taken by the best and worst performing utilities		
4.0	Performance Improvement Measures	a] Leak detection; b] leakage reduction; c] computerization of customer care; d] online payment & complaint registration; e] use of GIS in planning & data management; f] performance rewarding; g] autonomy in hiring & firing staff	The presence of these management measures reduces the vulnerability of the city to poor water & sanitation. The presence of each one of them in the management would earn the utility a score of 1/7. In their absence, the score would be 0.0.		

Annexure 3: Values assigned to various parameters considered in the computation of Hazard, Exposure, Vulnerability and the Final Risk Index

		Variable	Ahmadnagar	Akola	Amrabati	Aurangabad	Bhandara	BID	Buldana	Chandrapur	Dhule	Gadchiroli	Gondiya	Hingoli	Jalgaon	Jalna	Kohlapur	Latur	Mumbai	Nagpur	Nanded	Nandurbar	Nashik	Osmanabad	Parbhani	Pune	Raigarh	Ratnagiri	Sanghli	Satara	Sindhdurgh	Solapur	Thane	Wardha	Washim	Yavatmal
HAZARDS	Natural	Rainfall	2	2	2	2	1	2	2	1	2	1	1	2	2	2	1	2	1	1	2	2	2	2	2	1	1	1	2	2	1	2	1	1	2	1
		Rainfall Variability	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		Aridity	3	2	2	2	2	2	2	2	3	2	2	2	2	2	2	2	1	2	2	2	2	2	2	3	1	1	1	1	1	2	1	2	2	2
		Annual Renewable Water Availability	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	3	2	1	1	2	1	1	2	2	1	1	1	1	1	3	1	1	1
		Flood Proneness	2	2	2	1	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Overall Hazard		**0.67**	**0.60**	**0.60**	**0.53**	**0.53**	**0.60**	**0.60**	**0.53**	**0.67**	**0.53**	**0.53**	**0.60**	**0.60**	**0.53**	**0.60**	**0.60**	**0.60**	**0.60**	**0.60**	**0.60**	**0.67**	**0.60**	**0.60**	**0.67**	**0.53**	**0.47**	**0.53**	**0.53**	**0.47**	**0.60**	**0.60**	**0.53**	**0.60**	**0.53**

EXPOSURE	Natural	Depth to ground water table	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2	2
		Temperature and Humidity	3	1	2	3	2	3	3	3	2	3	3	2	3	2	3	3	3	2	3	2	3	3	2	3	3	3	3	3	3	2	3	2	2	2
		Groundwater stock	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	2	3	3	3
		Occurrence of cyclone with high-speed winds	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	3	3	1	1	3	1	3	1	1	1
	Physical	Characteristics of natural water resources	3	2	1	1	1	3	1	2	1	2	3	2	1	1	2	1	2	2	2	1	1	2	2	2	2	2	1	1	2	2	2	2	2	1
		Condition of the water supply system	1	1	1	1	1	2	1	2	1	1	1	1	1	1	1	1	1	1	1	2	1	1	2	1	1	1	1	1	1	1	2	1	1	1
		Provision of buffer storage of water in reservoirs per capita	1	1	2	3	NA	2	1	2	1	1	1	1	1	NA	1	NA	3	2	NA	2	1	2	NA	1	1	2	1	1	1	1	1	2	1	1

EXPOSURE	Physical	Proportion of HHs covered by tap water supply	2	2	1	2	2	2	1	2	1	2	2	2	1	1	1	1	NA	1	2	3	1	1	2	2	1	2	2	1	2	1	2	1	2	2
		Flood control measures, such as embankments, dykes, dams and water pumping facilities	1	1	3	1	1	1	3	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	1	1	1	3	1
	Socio-Economic	Proportion of people living in low-lying areas	1	1	1	1	2	1	1	2	1	1	1	1	1	1	1	1	NA	1	3	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1
		Proportion of people having access to water supply source within the dwelling premises	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	2	1
	Institutional & Policy	Disaster risk reduction measures available	1	2	2	1	2	1	1	1	1	2	2	1	1	1	1	1	1	2	1	1	1	1	2	1	1	1	1	1	1	1	1	2	2	2
		Existence of a policy to hire private tankers for emergency water supply	1	1	1	1	1	3	1	1	1	3	3	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Provision for tanker water supply in rural areas in terms of number of tankers	2	3	3	1	1	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Overall Exposure		**0.55**	**0.52**	**0.57**	**0.52**	**0.51**	**0.67**	**0.55**	**0.62**	**0.48**	**0.62**	**0.64**	**0.52**	**0.50**	**0.46**	**0.55**	**0.54**	**0.72**	**0.55**	**0.62**	**0.57**	**0.50**	**0.55**	**0.64**	**0.55**	**0.62**	**0.64**	**0.55**	**0.52**	**0.62**	**0.50**	**0.60**	**0.55**	**0.62**	**0.52**

	Variable	Ahmadnagar	Akola	Amrabati	Aurangabad	Bhandara	BID	Buldana	Chandrapur	Dhule	Garchiroli	Gondiya	Hingoli	Jalgaon	Jalna	Kohlapur	Latur	Mumbai
Natural	Rainfall	2	2	2	2	1	2	2	1	2	1	1	2	2	2	1	2	1
	Rainfall Variability	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Aridity	3	2	2	2	2	2	2	2	3	2	2	2	2	2	2	2	1
	Annual Renewable Water Availability	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	3
	Flood Proneness	2	2	2	1	2	2	2	2	2	2	2	2	2	1	2	2	2
Overall Hazard		**0.67**	**0.60**	**0.60**	**0.53**	**0.53**	**0.60**	**0.60**	**0.53**	**0.67**	**0.53**	**0.53**	**0.60**	**0.60**	**0.53**	**0.60**	**0.60**	**0.60**

	Variable	Nagpur	Nanded	Nandurbar	Nashik	Osmanabad	Parbhani	Pune	Raigarh	Ratnagiri	Sanghli	Satara	Sindhdurgh	Solapur	Thane	Wardha	Washim	Yavatmal
Natural	Rainfall	1	2	2	2	2	2	1	1	1	2	2	1	2	1	1	2	1
	Rainfall Variability	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Aridity	2	2	2	2	2	2	3	1	1	1	1	1	2	1	2	2	2
	Annual Renewable Water Availability	2	1	1	2	1	1	2	2	1	1	1	1	1	3	1	1	1
	Flood Proneness	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Overall Hazard		**0.60**	**0.60**	**0.60**	**0.67**	**0.60**	**0.60**	**0.67**	**0.53**	**0.47**	**0.53**	**0.53**	**0.47**	**0.60**	**0.60**	**0.53**	**0.60**	**0.53**

Variable	HAZARDS					
	Natural					Overall Hazard
	Rainfall	Rainfall Variability	Aridity	Annual Renewable Water Availability	Flood Proneness	
Ahmadnagar	2	2	3	1	2	**0.67**
Akola	2	2	2	1	2	**0.60**
Amrabati	2	2	2	1	2	**0.60**
Aurangabad	2	2	2	1	1	**0.53**
Bhandara	1	2	2	1	2	**0.53**
BID	2	2	2	1	2	**0.60**
Buldana	2	2	2	1	2	**0.60**
Chandrapur	1	2	2	1	2	**0.53**
Dhule	2	2	3	1	2	**0.67**
Garchiroli	1	2	2	1	2	**0.53**
Gondiya	1	2	2	1	2	**0.53**
Hingoli	2	2	2	1	2	**0.60**
Jalgaon	2	2	2	1	2	**0.60**
Jalna	2	2	2	1	1	**0.53**
Kohlapur	1	2	2	2	2	**0.60**
Latur	2	2	2	1	2	**0.60**
Mumbai	1	2	1	3	2	**0.60**
Nagpur	1	2	2	2	2	**0.60**
Nanded	2	2	2	1	2	**0.60**
Nandurbar	2	2	2	1	2	**0.60**
Nashik	2	2	2	2	2	**0.67**
Osmanabad	2	2	2	1	2	**0.60**
Parbhani	2	2	2	1	2	**0.60**
Pune	1	2	3	2	2	**0.67**
Raigarh	1	2	1	2	2	**0.53**
Ratnagiri	1	2	1	1	2	**0.47**
Sanghli	2	2	1	1	2	**0.53**
Satara	2	2	1	1	2	**0.53**
Sindhdurgh	1	2	1	1	2	**0.47**
Solapur	2	2	2	1	2	**0.60**
Thane	1	2	1	3	2	**0.60**
Wardha	1	2	2	1	2	**0.53**
Washim	2	2	2	1	2	**0.60**
Yavatmal	1	2	2	1	2	**0.53**

		Variable	Ahmadnagar	Akola	Amrabati	Aurangabad	Bhandara	BID	Buldana	Chandrapur	Dhule	Garchiroli	Gondiya	Hingoli	Jalgaon	Jalna	Kohlapur	Latur	Mumbai	Nagpur	Nanded	Nandurbar	Nashik	Osmanabad	Parbhani	Pune	Raigarh	Ratnagiri	Sanghli	Satara	Sindhdurgh	Solapur	Thane	Wardha	Washim	Yavatmal
VULNERABILITY	Socio- Economic	Population Density	2	2	2	2	2	2	2	1	2	1	2	2	2	2	3	2	3	2	2	2	2	2	2	3	2	1	2	2	1	2	3	2	2	2
		Proportion of people living below the poverty line	1	1	1	1	1	1	1	1	2	1	1	2	1	2	1	1	1	1	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Access to primary health services	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3	3
		Proportion of people who are unhealthy (use infant mortality per 1000 live births)	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		Percentage of children under the age of 5 with stunting (low height-for-age ratio)	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	3	2	2	2	3	3	2	2	2	2	2	2	2	2	2	3	2	2	2

VULNERABILITY				Total Risk	Risk Category
Institutions and Policy			Overall Vulnerability		
Ability to provide relief and rehabilitation measures for floods and cyclones (number of agencies, including overnment, private and NGOs)	Social ingenuity and cohesion	Adequate number of primary and other health infrastructure			
3	2	2	**0.74**	**0.27**	**MODERATE**
3	3	2	**0.78**	**0.24**	**LOW RISK**
3	3	2	**0.78**	**0.27**	**MODERATE**
3	3	2	**0.78**	**0.22**	**LOW RISK**
3	3	2	**0.78**	**0.21**	**LOW RISK**
3	2	2	**0.78**	**0.31**	**HIGH RISK**
3	3	2	**0.81**	**0.27**	**MODERATE**
3	1	2	**0.67**	**0.22**	**LOW RISK**
3	3	2	**0.81**	**0.26**	**MODERATE**
3	1	1	**0.67**	**0.22**	**LOW RISK**
3	3	2	**0.81**	**0.28**	**MODERATE**
3	3	2	**0.81**	**0.26**	**MODERATE**
3	3	2	**0.78**	**0.23**	**LOW RISK**
3	3	2	**0.81**	**0.20**	**LOW RISK**
3	2	2	**0.78**	**0.26**	**MODERATE**
3	2	2	**0.78**	**0.25**	**MODERATE**
1	2	NA	**0.63**	**0.27**	**MODERATE**
3	3	2	**0.78**	**0.26**	**MODERATE**
3	3	2	**0.81**	**0.30**	**HIGH RISK**
3	1	2	**0.74**	**0.25**	**MODERATE**
3	1	2	**0.74**	**0.25**	**LOW RISK**
3	3	2	**0.78**	**0.26**	**MODERATE**
3	3	2	**0.78**	**0.30**	**MODERATE**
2	3	2	**0.74**	**0.27**	**MODERATE**
3	2	2	**0.74**	**0.24**	**LOW RISK**
3	2	2	**0.70**	**0.21**	**LOW RISK**
3	2	2	**0.74**	**s0.22**	**LOW RISK**
3	2	2	**0.74**	**0.21**	**LOW RISK**
3	2	1	**0.67**	**0.19**	**LOW RISK**
3	2	2	**0.74**	**0.22**	**LOW RISK**
3	2	3	**0.81**	**0.29**	**MODERATE**
3	2	2	**0.74**	**0.22**	**LOW RISK**
3	2	1	**0.70**	**0.26**	**MODERATE**
3	2	2	**0.74**	**0.21**	**LOW RISK**

Annexure-4
Site Photographs

A1: Latur District (Hard Rock) LCCA

Field visit in Jewali Village, Latur Block, Latur District: studying the failed bore wells

Field visit in Kanadi Boregaon Village, Latur Block, Latur District, Studying the failed borewell

Field visit in Haregaon Village, Ausa Block, Latur District: Studying a borewell based scheme that was abandoned due to frequent breakdown.

Field Visit in Matola Village, Ausa Block, Latur District: Studying the borewell based scheme which failed

Field Visit in Nandurga Village, Ausa Block, Latur District, Exploring the reasons for the failure of the borewell based scheme

Field Visit in Pangaon Village, Renapur Block, Latur District, Understanding the root cause for the failure of the borewell based scheme

A2: Gadchiroli District Solar Powered Drinking Water Supply

Solar-based drinking water scheme installed under the Jal Jeevan Mission at Kakadayeli Village, Dhanora Taluka, Gadchiroli District

Solar-based drinking water scheme installed under the Jal Jeevan Mission at Usegaon Village, Gadchiroli Taluka, Gadchiroli District

Solar-based drinking water scheme installed by GDSA and an NGO in Gadchiroli District

Solar-based drinking water scheme installed in Pandarsara Village, Kurkheda Taluka, Gadchiroli District

Solar-based drinking water scheme installed by
Gram Panchayat in Usegaon Village, Gadchiroli Taluka,
Gadchiroli District

Defunct Hand Pump at Usegaon Village,
Gadchiroli Taluka, Gadchiroli District

Pump stolen from the well at Sadaktola Village,
Dhanora Taluka, Gadchiroli District

Pipeline leakage in a JJM Scheme in Chatgaon Village,
Dhanora Taluka, Gadchiroli District

A3: Ratnagiri District Cyclone and Flash Floods

Well filled with landslide debris in Katale village,
Guhagarh Taluka, Ratnagiri District

Well filled with landslide debris in Vetoshi village,
Ratnagiri Taluka, Ratnagiri District

Well damaged due to floods in Posare Village,
Khed Taluka, Ratnagiri District

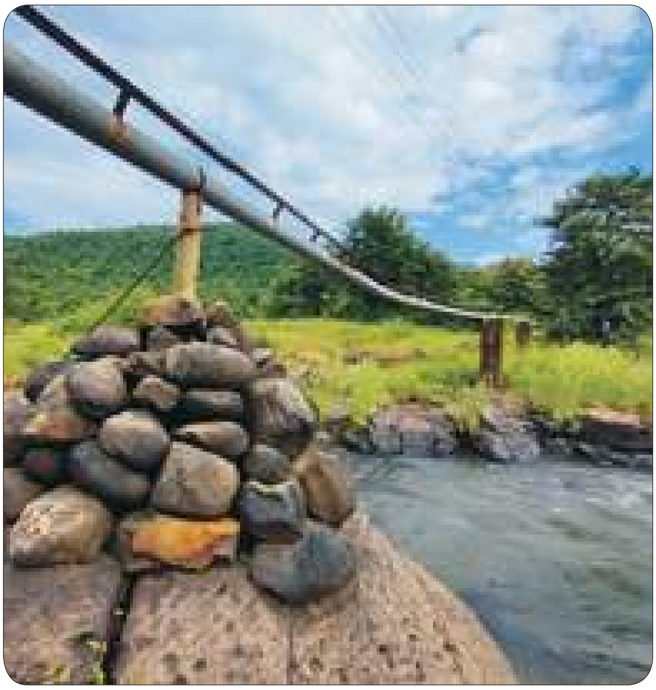
Handpump reinstated after landslide in Posare Village,
Khed Taluka, Ratnagiri District

Covering the well to protect it from plant debris in Aare Village,
Guhagarh Taluka, Ratnagiri District

Construction of new well with modifications in Vetoshi Village,
Ratnagiri Taluka, Ratnagiri District

Construction of new well in Posare Village,
Khed Taluka, Ratnagiri District

Pipelines laid under river bed after floods in Talsar Village,
Chiplun Taluka, Ratnagiri District



Pipeline height raised above the flood level in Talsar Village,
Chiplun Taluka, Ratnagiri District

Newly constructed supply infrastructure in Talsar Village,
Chiplun Taluka, Ratnagiri District

A4: Kolhapur Flood Prone Areas

Water reservoir structure in Kolhapur

Villagers faced electricity supply issues in Kolhapur

Water treatment plant in Kolhapur village

75 HP pump damaged in the flood

Please contact :
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Content:
Institute for Resource Analysis and Policy
& UNICEF Mumbai.

Photo :
UNICEF, India.

Design : Sri Lakshmi Printers, Hyderabad.