
# Improving Small Water System Projects

## Resources and Recommendations for Safe Water Network

## Preface

This report is the final product of the Workshop in Applied Earth Systems Management for the Master of Public Administration in Environmental Science and Policy at Columbia University's School of International and Public Affairs. During the Spring 2013 semester, the workshop team performed research and analysis related to several topics of interest to Safe Water Network, a non-profit organization involved in the development of small water systems in the developing world.

## Acknowledgements

We would like to thank our faculty advisor Shadan Azali for her support this semester. We would also like to thank Safe Water Network for the opportunity to participate in this project, and specifically Ryan Hebert, Amanda Gimble, Bob Stea, and Subhash Jain, who helped provide background information and site data.

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All photos courtesy of Safe Water Network.

# Executive Summary

The need for successful development projects aimed at providing potable water for those without it cannot be understated. Unfortunately, in the developing world the failure rate of such projects is on average quite high (even approaching 80% in some areas). In response to this situation, an increasing number of organizations have stressed the need for project design and management that focus on the long-term economic, social, and environmental sustainability of drinking water projects in the hope of improving the odds of project success.

Since 2006, the non-profit organization Safe Water Network has been involved in building and promoting small community-based water treatment systems in Ghana and India by using a project design and implementation methodology that incorporates both community participation and long-term economic viability. Seeking to further improve their site selection and project design and management efforts, especially in regards to environmental sustainability, Safe Water Network asked that the workshop team further investigate and report on the following areas of interest:

1. **Water Safety and Security Planning**
2. **Groundwater Source Depletion Mitigation**
3. **Reverse Osmosis (RO) Waste Management**
4. **Global Information System (GIS) Data and Tools**

Over the course of the allotted semester, the workshop team performed literature reviews and researched case studies related to groundwater source depletion mitigation and reverse osmosis waste management, gathered and summarized examples of water safety and security plans from governmental and non-governmental organizations, and summarized data resources for future GIS work. The workshop team also demonstrated possible future uses for GIS mapping and analyzing geographically related data pertinent to water treatment project site selection and project management in the state of Andhra Pradesh. Based on the research conducted, the team developed several recommendations for Safe Water Network.

The following page contains summaries of the main findings and recommendations for each area of interest. Safe Water Network can improve the environmental sustainability and overall success of their water treatment projects by using the gathered resources and expanding upon the recommended actions.

## 1. Water Safety and Security Planning

***Main Findings:***

- There has been a shift in planning strategies from relying solely on direct water quality testing (which is expensive and time consuming) to the more holistic and proactive Water Safety Plans of varying complexities.
- Plans formalize and incorporate strategies such as budgeting water, protecting water sources, recharging groundwater, and thoroughly identifying potential water security issues.

***Recommendation:***

- The example Water Safety Plans should be utilized in formalizing and improving Safe Water Network's current water security activities.

## 2. Groundwater Depletion Mitigation

***Main Findings:***

- The determination of the maximum sustainable yield at a given site is necessary for the long-term sustainability of any water project.
- Sustainable yield calculations should include surveys and pump tests of groundwater resources, demographic trend analysis, and environmental variability risk factors.

***Recommendation:***

- Safe Water Newtork should continue to incorporate pump stress tests in their initial community assessments in order to help quantify sustainable yields.

## 3. Reverse Osmosis Waste Management

***Main Findings:***

- There is a growing awareness of the importance of RO concentrate management within both public and private organizations.
- The three main strategies for management include increasing RO efficiency, using alternative disposal methods, and finding reuse opportunities. The last two options require additional community assessment information.
- A thorough report on RO concentrate management in rural India was recently completed by students at the University of Michigan and Sarvajal.

***Recommendations:***

- Incorporate potential opportunities for sustainable reuse of RO concentrate into the initial community assessments.
- Develop an application decision matrix to assist in comparing different concentrate management strategies at a given site.
- Carefully pursue increases in RO efficiency to limit the amount of waste water that requires management.
- Increase water quality monitoring activities to include measurements of the concentrate stream.

## 4. GIS Tools and Data

***Main Findings:***

- Ghana lacks countrywide data and/or access to countrywide data.
- For India, there is a large amount of helpful GIS data that can be utilized in, particularly regarding water contaminant levels. Village level data is not as available.

***Recommendations:***

- For the case of Ghana, use the provided list of data resources as a starting point in an effort to gather, consolidate and enable the sharing of this information.
- For the case of India, use existing data and GIS tools to assist in the site selection process. This may require bringing in outside expertise or creating a new internal position. Once information is consolidated, the database should be continually maintained and additional data sought out and incorporated.

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# List of Acronyms

| | |
|---|---|
| APFAMGS | Andhra Pradesh Farmer Managed Groundwater System Project |
| AWPs | Area Water Partnerships |
| CAD | Computer Aided Drafting |
| CIESIN | Columbia University's Center for International Earth Science Information Network |
| CCMG | Community Change Management Group |
| DDWs | Deep Disposal Wells |
| DDWS | Department of Drinking Water and Sanitation |
| GIS | Geographic Information Systems |
| GPS | Global Position System |
| GWP | Global Water Partnership |
| IWA | International Water Association |
| IWRM | Integrated Water Resources Management |
| km | Kilometer |
| NaDCC | sodium dichloroisocyanurate |
| NFS | National Forest System |
| NGO | Non-Governmental Organization |
| NRDWP | National Rural Drinking Water Program |
| POU | Point of Use |
| POUZN | Point-of-Use Water Disinfection and Zinc Treatment |
| RO | Reverse Osmosis |
| SAR | Sodium Adsorption Ratio |
| SHGs | Self-Help Groups |
| TDS | Total Dissolved Solids |
| UIC | Underground Injection Control |
| USDA | United States Department of Agriculture |
| VOCs | Volatile Organic Compounds |
| WHO | World Health Organization |
| WSP | Water and Sanitation Programme |

# Introduction

## The Need for Sustainable Water Projects

Access to safe drinking water remains one of the key issues in development. Approximately 783 million people (11% of the global population) remain without access to an improved source of drinking water (United Nations, 2010). Globally, the effort to provide access to drinking water is comprised of a mix of government policy and aid, programs from international governing organizations, and projects funded by non-governmental organizations. Awareness of water issues has steadily increased, and the General Assembly at the United Nations (UN) recently recognized access to water and sanitation as a human right. Moreover, the UN claims to have helped 1.3 billion people gain access to drinking water during the decade of International Drinking Water Supply and Sanitation from 1981 to 1990 (United Nations, 2010).

While the increased focus on water projects is helpful, there has been and continues to be a high failure rate of water sector development projects in the developing world. The Water Institute at the University of North Carolina at Chapel Hill states the average failure rate of water and related sanitation projects in the developing world is 35%, and in the most difficult areas upwards of 80% (The Water Institute, 2013). These numbers suggest that part of the underlying problem is not only the lack of projects, but also importantly the lack of good projects that are sustainable over the long term.

## Safe Water Network and Increasing the Odds of Success

In response to the lack of successful projects, many water development organizations have started focusing on the importance of economic, social, and environmentally sustainable project design and implementation. Safe Water Network was founded in 2006 and is involved in designing and implementing drinking water projects in areas of the developing world that incorporate these three sustainability goals in the hope of shifting the odds away from project failure. Safe Water Network works extensively in both Ghana and India and incorporates the following aspects into their projects (Safe Water Network, 2012):

**Field Initiatives:** Design, launch and management of water purification stations and rainwater harvesting programs to provide safe water to those in need.

**Market Development:** A fact-based approach to measure outcomes and models, as well as develop scale propositions.

**Networking:** Collaborative activities, best practice approaches, and action-oriented programs that apply partner expertise to field work and scale development projects.

**Technical Assistance:** On-site consultation to other organizations, as well as support through training materials, manuals, and on the job training.

In Ghana and India, Safe Water Network has developed locally owned and operated Safe Water Stations. These innovative stations not only provide water to numerous village members, but they do so within a site selection and project management framework that emphasizes economic feasibility and continued production. This allows local communities to not only provide water to themselves but also the ability to create new and independent revenue streams. Another point of emphasis in both Ghana and India is community participation, from site selection meetings to the support of financial, technical, and health training. In their work, Safe Water Network also puts emphasis on the ability to identify and scale up good practices.

Safe Water Network is currently seeking to further improve their site selection and project design and management efforts, especially in regards to environmental sustainability. To this effect, Safe Water Network asked the workshop team to further investigate and report on the following areas of interest (the first three areas were focused on India, and the last area was focused on both Ghana and India):

1. **Water Safety and Security Planning**
2. **Groundwater Source Depletion Mitigation**
3. **Reverse Osmosis Waste Management**
4. **Geographical Information System (GIS) Tools and Data for Site Selection**

The goal of this partnership was to help enable Safe Water Network to increase the odds of project success through improved site selection and project implementation and maintenance that is based on the resources and recommendations contained in this report.

## Methodology and Report Structure

Over the course of the semester, the workshop team performed literature reviews, gathered case studies, contact information, and GIS data sets, and developed recommendations related to the four areas of interest as described above. Some analysis of Safe Water Network site data was performed and ArcGIS was used to create demonstrative maps.

This report is divided into four main sections, each dedicated to one of the four areas of interest. Due to the nature of this project, a large amount of additional information and resources related to these areas can be found in the References and Resources section and in the Appendices.

# I. Water Safety and Security Planning

## Introduction

Access to clean drinking water is essential for development because water is the crucial component for human health, social and economic growth, and general well-being. However, in many regions of the world, this finite resource is depleting faster than it can be replaced. Surface water pollution, climate change, rapid growth and expansion of cities, and groundwater over-extraction have all contributed to a disparity in drinking water access. Additionally, natural contaminants in groundwater (e.g., fluoride and arsenic) further reduce the availability of safe drinking water.

## Current water crisis in India

Of India's 1.19 billion citizens, roughly 97 million do not have access to clean drinking water (WHO Facts, 2012). The Ministry of Rural Development and the Department of Drinking Water and Sanitation both define water security as having "adequate safe drinking water for drinking, cooking, and other basic needs with safe water readily and conveniently accessible at all times." India's water resources are depleting at an alarming rate and despite three trillion cubic meters of annual rainfall, only 18% is utilized due to poor storage infrastructure (UNICEF, 2002).

Surface water accounts for 80% of India's water needs. Major rivers and tributaries, fed by monsoon rains and glacier melt, supply 85% of India's surface water and also help recharge groundwater (Raj, 2010), Agricultural runoff, pollution from industrial processes, poor hygiene and cleaning methods, and over usage are causing rivers to run dry and/or become heavily contaminated so the water is no longer potable. Additionally, changing weather patterns and erratic monsoon seasons have further stressed water availability, resulting in long dry periods. In turn farmers and other inhabitants must rely on groundwater extraction. Groundwater extraction has become the preferred method to access water due to subsidized electricity and relatively low drilling costs. However, poor groundwater management has drained local resources and led to farmers to drill deeper bore wells to meet their needs.

The Government of India's Ministry of Drinking Water and Sanitation has been trying to provide water safety and security to its people. Although water access is provided to over 80% of the population, this is often limited to drinking water for a few hours a day. Due to the urgency of the water crisis, the Indian government is working with several independent organizations at the communal, regional and national levels to piece together a framework for water safety and security in India.

## Water Safety Plans Framework

It should be noted that the emphasis of water safety and security strategies has changed during the decade. Previously, international strategies tended to increase the number of parameters associated with water quality standards by increasing the number and type of water sample tests. However, this approach does not adequately protect locals because it is very time consuming and many pollutants present immediate risks to human health. Moreover, many developing nations lack the equipment, personnel, and well enforced protocols needed for this method of water testing (WSP, 2008).

To create a new approach for increasing water safety and security, water experts developed the concept of Water Safety Plans that have direct and indirect outcomes. A direct outcome of these efforts was the report "The Bonn Charter for Safe Drinking Water", written by the International Water Association (IWA) in 2004, and an indirect outcome was the important third edition of the report "Drinking Water Guidelines", written by the World Health Organization (WHO) in 2006, both of which helped delineate the new strategy. The key principle of this new strategy is to map the entire supply chain of water (i.e., from source to consumption) and then conduct an analysis to identify where hazards occur and how to mitigate them (WSP, 2008). Water Safety Plans attempt to incorporate comprehensive risk management and assessments from the entire supply chain to ensure "safe drinking water that has the trust of the consumers" (IWA, 2004).

IWA is credited with developing the modern concept of Water Safety Plans to address water safety and quality issues. IWA is an independent non-profit organization that works with water experts around the world. They organize conferences and workshops, and also conduct research to investigate and understand all facets of the water cycle.

IWA's report "The Bonn Charter," written in 2004, was one of the first documents to pioneer the development of Water Safety Plans. The Charter promotes similar objectives as the WHO's "Guidelines for Drinking-water Quality", and sets the principles of the water quality management framework as well as the responsibilities of key parties. This document defines the consumers' outcomes as the key principles of the analyzed approach, and describes Water Safety Plans and their verification methods. Also, in this report IWA describes how stakeholders should be involved assigning roles and responsibilities from the perspective of governments, water suppliers, regulatory authorities, and consumers. Figure 1.1 depicts a diagrammatic representation of the framework developed and presented in the Bonn Charter.


**Figure 1.1: Diagram of Bonn Charter framework (IWN, 2004).**

According to IWA, Water Safety Plans provide a framework that incorporates a preventative risk-based approach and provides the proactive, systematic, and effective management of drinking water supplies. The successful implementation of Water Safety Plans can improve drinking water quality, accrue operational efficiencies, and provide an important framework to better investments capital in more sustainable projects.

In addition, WHO has also been an important player developing the framework of Water Safety Plans. WHO is a specialized agency of the United Nations concerned with international public health issues. They consider safe drinking water essential to health and have published four editions of the *Guidelines for drinking-water quality* reports (1983-1984, 1993-1997, 2004, and 2011). Figure 1.2 presents a framework of how WHO organized these guidelines in the most recent two editions. In these editions the WHO included the concept of Water Safety Plans, which, as mentioned earlier, are part of the modern approach to water strategies that many organizations are adopting.

The core of this framework includes three main components. First, WHO analyses the health-based targets, where they set the main water quality targets for single and long-term exposure. Second they develop the concept of Water Safety Plans (analyzed in further detail below), and finally WHO considers a system of independent surveillance that verifies the above framework parameters are operating properly.

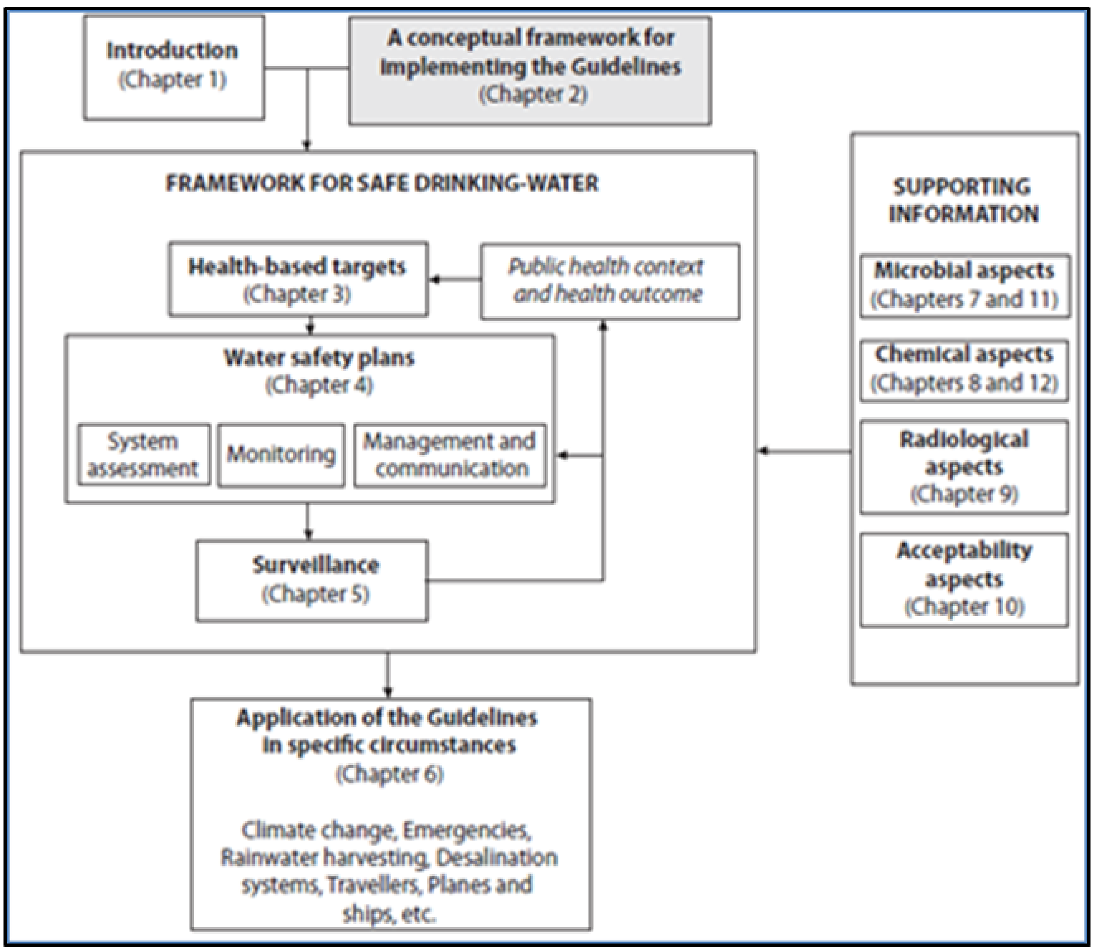



**Figure 1.2: WHO framework for safe drinking-water (WHO, 2011).**

The Water Safety Plan is a powerful tool for drinking-water suppliers aiming to manage safe water supplies. According to WHO, Water Safety Plans are the most effective way to consistently ensure the safety of drinking-water supplies because they consider the entire supply chain and use a comprehensive risk assessment and risk management approach.

Water Safety Plans vary in complexity and only some of the possible parameters will be applied to enhance water quality, depending on the system type and the associated hazards. The main objectives of a Water Safety Plan are: (a) the minimization source water contamination, (b) the reduction or removal of contamination through treatment processes, and (c) the prevention of contamination during storage, distribution and handling of drinking-water. These objectives are applicable to all drinking-water supplies, independently of the size and complexity of a system.

Under WHO guidelines, Water Safety Plans have to consider at least three key components, which are listed below:

- System assessment: to determine if the drinking water supply chain as a whole is capable of supplying water of sufficiently high standards to meet regulatory targets;
- Operational monitoring: to identify control measures in the drinking water system; and
- Management plans: to document the system assessment, describe actions taken during various operational conditions and define monitoring and communication plans.

It is beyond the scope of this report to detail how to implement a Water Security Plan. However, an overview of the key steps in developing a Water Security Plan is presented in Figure 1.3. For a better understanding of how to implement Water Safety Plans, review the “Water safety plan manual: Step-by-step risk management for drinking-water suppliers” developed by WHO and IWA in 2009.

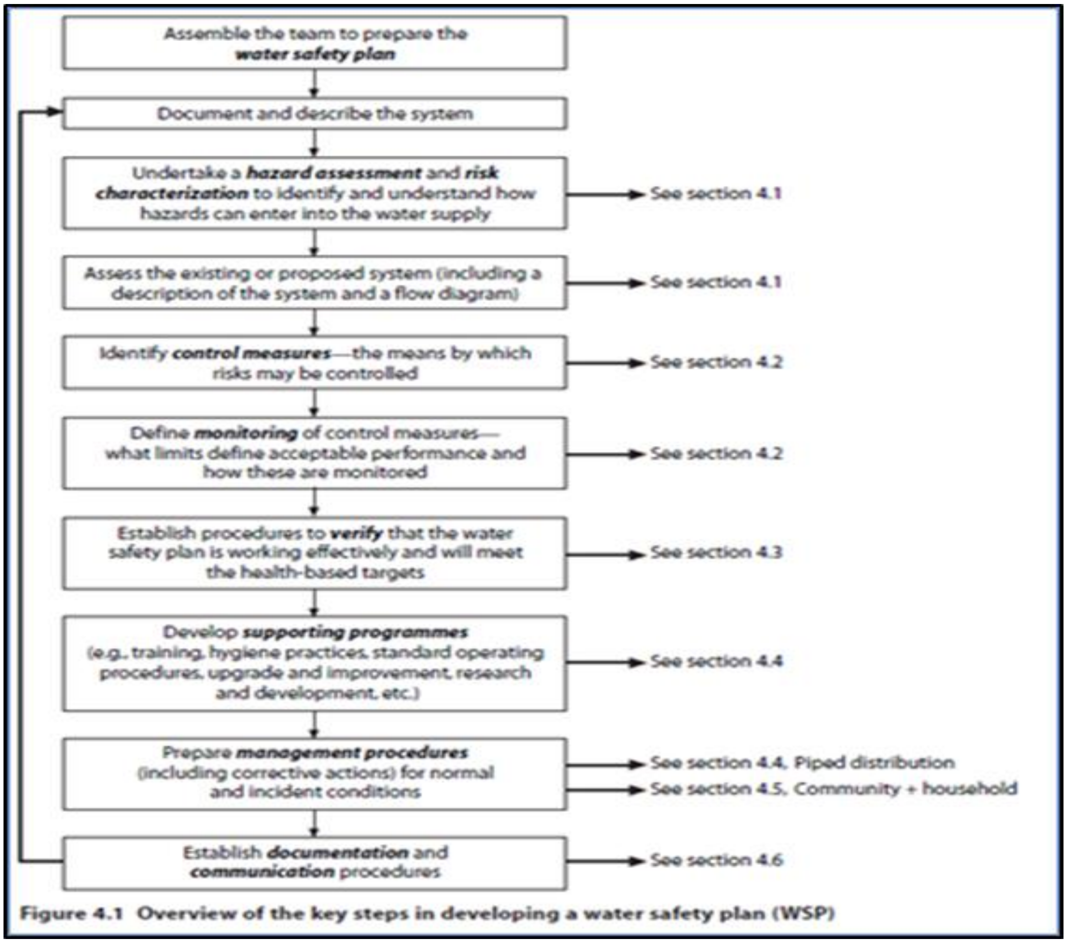



**Figure 1.3 Overview of the key steps in developing a water safety plan (WHO, 2011).**

Another contribution of IWA and WHO regarding water safety and security is the creation and management of "The Water Portal" (http://www.wsportal.org). This web page is co-managed by both organizations and contains tools, case studies, and other relevant information related to the management of drinking-water supplies. It also provides practical guidance and includes regional networks supporting the implementation of Water Safety Plans.

In addition to the contributions of the WHO and IWA, the following organizations were also researched:

1. Water and Sanitation Programme (WSP)
2. Global Water Partnership (GWP)

Full summaries of these organizations' methods of identifying, quantifying, and computing the extent of water scarcity and their solutions for water security can be found in Appendix A.

## Government of India Approaches to Water Safety and Security

The national government of India has been working to improve the access to and the quality of drinking water through its Department of Drinking Water and Sanitation (DDWS). This section will focus on the DDWS's handbook for *gram panchayats* (i.e., village self-governments) that contains guidelines for how to implement, operate, maintain, and manage drinking water security issues. In 2012, the DDWS published this handbook based on the National Rural Drinking Water Program (NRDWP) guidelines. The NRDWP identifies five phases to ensure "Drinking Water Supply", which are: (a) preparation, (b) planning, (c) implementation, (d) operation and maintenance, and (e) monitoring, audit and reporting. Following is a summary of the issues addressed during each phase:

a) Preparatory Phase (Timeline: Maximum of two to three months)
   - What assistance will the national and local government provide?
   - How are Village Water and Sanitation Committees formed?
   - What training is available and from whom?
   - How can community participation be encouraged and harnessed?

b) Planning Phase (Timeline: Two to three months annually)
   - How can information for our water source and system be accessed?
   - How can this information be used to plan?
   - What should a proposal to the district government contain?

c) Implementation Phase (Timeline: Six to twelve months)
   - What is an annual action plan?
   - How can materials and contractors be procured?
   - How can good quality work be ensured?

d) Operation and Maintenance Phase (Timeline: The entire project lifecycle)
   - What are the key operating functions for each part of the water supply system?
   - How can the finances be managed?
   - How can the assets be managed?

e) Monitoring, Audit and Reporting Phase (Timeline: The entire project lifecycle)
   - What is a social audit?
   - How can our progress and performance be reported?

## Additional Organizational Approaches to Water Safety and Security in India

To Increase access to potable water and combat health problems rural India, many grassroots organizations and larger NGOs are developing their own strategies. Several important organizations in India researched were:

1. The Centre for Excellence and Change's Community Change Management Group (CCMG)
2. Pratinidhi
3. Gram Vikas

For these international organizations, full summaries of these organizations' methods of identifying, quantifying, and computing the extent of water scarcity and their solutions for water security can be found in Appendix A.

In general, strategies employed by these organizations are along the lines of the government framework. They include identifying water sources as well as threats facing these sources. Once the sources are identified, water is budgeted and usage measured so the withdrawal amounts do not exceed the replenishing rate. By involving communities in initiatives, organizations ensure the support and labor for these projects. Certain organizations work only in villages where the entire community agrees to work and contribute not only time and knowledge but also financially to the project before they commence work there.

While some organizations work on protecting and maintaining the water source, others work on treating available water. This second method is likely to meet opposition, as studies have shown that communities are less likely to spend the initial investment for water purifiers and are highly suspicious about chemical additives. By incorporating strategies suited to the organization and the operation sites, these groups are making the programs efficient and realizing their goal of water security and safety in rural communities.

## Summary

The above section has examined different approaches employed by organizations working towards water safety and security in India and other developing countries. Strategies include budgeting water, protecting water sources, recharging groundwater, identifying potential water security issues, and using coping mechanisms to reduce water stressors. Additionally, government and international organizations such as WHO and WSP have elaborate, large-scale Water Safety Plans that identify hazards and risks to water security. These frameworks explain how programs monitor, assess and manage available water to ensure water security and safety.

The Water Safety Plan is a useful tool for organizing and formalizing the water security actions of organizations working on water issues. Water Safety Plans can promote the practice of water quality and quantity assessments and by extension, better informed water management decisions. Setting up and improving upon a Water Safety Plan establishes a model framework that can be replicated across locations and improve operations. The tool is also useful in streamlining the program by allocating resources efficiently, identifying areas where costs can be reduced and ensuring an overall smooth operation and the long-term success of the program.

## Recommendations

While Safe Water Network is currently implementing many activities promoting water security at their sites, the example frameworks presented above should be utilized in organizing these actions into a more formalized system. A sample stepwise description of the process towards preparing a Water Safety Plan is shown below (this process is presented in more detail in the "Training Manual for Village Water Safety Planning" developed by the Ministry of Drinking Water and Sanitation Program of India). This plan was developed by referencing and incorporating strategies from the case studies described above:

**STEP 1: Assemble the team to prepare a Water Safety Plan (Timeline: 2-4 months)**

In order to establish this plan, Safe Water Network needs to first identify and assign a team to create a framework for assessing water quality and quantity. This team should consist of a team leader, local government water engineers, and subject matter experts who can construct the framework. The team also needs training staff to teach the framework to each of the sites.

**STEP 2: Community mapping to describe the water system (Timeline: 4-6 months)**

This important step aims to involve the entire community in the process of understanding how the particular water system works. Knowledge is shared between participants, and community members have an opportunity to express their ideas and expectations for improvements. The final deliverable of this step is the creation of a map depicting sources, systems, and households involved in the water supply chain. Additionally, awareness of water security issues should increase during this phase and commitment to take positive-action is expected from the entire community.

**STEP 3: Walk the system from "source to mouth." (Timeline: 2 weeks to collect data and map the water supply chain, 2 months to identify solutions)**

It is necessary to verify the conditions of the system "in the field" so team members must physically walk along the water system to identify sources of contamination. Upon completion, the team will have reviewed the entire system, identified hazards at each part of the supply chain, and created possible solutions to mitigate these hazards.

**STEP 4: Prepare the Water Safety Plan (Timeline: 2-4 months)**

Based on the information collected in Step 3, the team is now able to create the Water Safety Plan, which will include:

- Possible threats to water quality and quantity (e.g., animal defecation, river washing and bathing), including resulting health hazards.

- Water assessments conducted according to government standards specified by the Ministry of Drinking Water and Sanitation.
- Control measures (e.g., building a fence around the source, separating sanitation and drinking water facilities).
- Assigning roles to members, assessing what needs to be done, who does it, and who confirms each task has been completed.
- Specific action to take if remediation controls fail (e.g., chlorination of water sources).
- Determining the cost of clean water and setting up water pricing and fee structure. The personnel and operational costs are also determined in this step.
- Problems and constraints with the Water Safety Plan implementation (e.g., lack of funds).

**STEP 5: Operationalize the Water Safety Plan (Timeline: 6 months)**

For each operational step along the supply chain, Safe Water Network must monitor the success of key operations and whether responsibilities assigned for each component are carried out successfully. Then Safe Water Network can make necessary changes, both logistic and financial, that make the system more efficient. During this step, village water and sanitation committees will receive additional training in areas such as handling finances and operational management. After this step, the community will have a good idea of the specific improvements they need to implement to achieve water safety and security.

**STEP 6: Prepare a proposal to submit to the district authorities for financing (Timeline: 2 months)**

As an additional step, Safe Water Network can suggest the team prepare an improvement plan that can be submitted to the district authorities for financial assistance.

# II. Groundwater Depletion Mitigation

## Introduction

Many of the world's fresh water suppliers are currently overstressed and many rivers now run dry during parts of the year. India has the highest volume of annual groundwater overdraft of any nation in the world (Gopalakrishnan, 2001). In most parts of the country, falling water tables have caused 95% of the wells owned by small farmers to dry up, reducing the irrigated area in the country by half over the last decade (Gopalakrishnan, 2001).

As India develops, demand for goods and energy will increase and place additional stress on already strained natural resource supplies. This is especially true in rapidly growing urban areas that are reaching farther for water resources and affecting nearby rural areas. Without proper management and mitigation it is likely India's rapid development could lead to a tragedy of the commons scenario regarding its water. The ultimate result would be the failure to maintain a sustainable yield of water, the limiting of economic development, an increase in waterborne diseases, and irreversible harm to the natural environment.

Safe Water Network is committed to ensuring the sustainable development of water resources. Its market driven practices are specifically designed to ensure the community receiving outside investment will not only be able to increase their access to potable water, but that this increase will be done in a sustainable manner. This is why the Safe Water Network mission necessitates the design, adaption, and integration of a proven model to effectively manage and mitigate the depletion of groundwater resources. The following section will highlight examples of strategies that could be integrated into a standard operating procedure used at each Safe Water Network project site.

## Literature Review and Discussion

This literary review assessed the public, non-profit, and private sectors to determine each stakeholder's beliefs regarding the optimum strategy for water management and depletion mitigation in India. Below is a brief synopsis of the findings with regard to each sector.

The available literature from the public sector reflects the need for an overhaul of national water policy, specifically to combat water depletion. It is imperative the Indian government at the local and state level implement enforceable policies to stop or reverse the overuse of water resources. In addition, the current state of policies requires greater national and state level policy integration to increase effectiveness. Corroboration between state and national policy, if successful, represents a boon for water resource management in India. The nationwide adoption of best state practices and decentralized water depletion mitigation policies must feed into an overarching national water policy in order to halt water resource depletion.

The view from the non-profit sector reflects the micro problem and solution dynamic of the industry. Having the inability to directly set national and state level policy, the work from this sector focuses on economically feasible and sustainable solutions to water depletion. The range of these solutions spans traditional techniques to modern construction projects. Both of these methods aim to harvest rainwater more effectively and supplement natural ground water recharge. While most of this sector is involved with similar solutions, some advocate the greater usage of scientific and statistical techniques to improve existing depletion mitigation, with a focus on measurement and tracking of water withdrawals. Tracking the rate of change in a water system will allow for better management. The analysis of this sector points to successful replication of micro solutions across the country as a viable means of achieving critical mass in water depletion mitigation.

Lastly, the private sector offers its own set of market driven strategies. The usage of water as a critical process input drives certain industry players to perform local water recharge. Companies can utilize private capital to secure the sustainability of public water resources when the need to protect water resources creates the necessary economic conditions. Other private sector participants advocate the privatization of water with the responsibility of water purification and pollution abatement left to the instruments of the private sector. While literature does exist on successful implementation of water privatization, there are cases where the private sector fails in delivering water sustainably and instead exacerbates water problems.

## Case Studies

### Technical Guide to Ground Water Resource Management_ USDA- Tonto National Forest Case Study

**Location:** Tonto National Forest, AZ
**Timeline:** Published May 2009
**Type of Document:** Case Study
**Summary Data:**

**Location 1:** Miami, AZ
**Environment:** 3,700 feet above sea level, mountainous, semiarid
**Water Requirements:** 590 - 850 gallons per minute
**Location 2:** 52 mile tract from Payson to Heber, AZ
**Environment:** Atypical Mediterranean
**Water Requirements:** 180 gallons per minute

**Background/Description:**

This technical report provides guidance for implementing the United States Department of Agriculture (USDA) Forest Service national groundwater policy. It describes hydrological, geological, and ecological concepts, as well as the managerial responsibilities that must be considered to ensure the sustainable use of groundwater resources within National Forest System (NFS) lands.

The particular case study evaluated in this report is the groundwater development project in Arizona's Tonto National Forest. A major transferable theme with regards to water management is the use of well pump stress tests to calculate the sustainable yield of ground and surface water resources. Other useful sections of the parent paper include technical guidelines and techniques for different specialties, along with highlighted best practices and several other case studies.

**Summary:**

Ground and surface water resources were measured and quantified in two different locations for their eventual use in independent industrial and recreational applications. The case study detailed how each site was monitored, the results, possible alternatives for gathering the same information, and conjunctive use. Pump tests were conducted in the withdrawal areas along with some selected sites downstream over a period of approximately 30 days. The results were then used to establish a baseline quantity and/or rule out possible extraction areas. Projects can successfully be completed and water withdrawal yields sustained over the long-term by establishing proper baselines, conducting pump stress tests and quantifying the results (barring any large climate or hydrological abnormalities). Possible alternatives to collect data besides stress tests include; collecting local water bills, data from already dug water wells, and if available, possible water usage logs.

*Strengths*

- Proven examples of how to monitor and evaluate ground and surface water systems.
- Alternative data collection methods to be used under tight budget constraints.
- Structured diagrams and flowcharts of water resource management systems, along with examples of how to correct or mitigate water resource problems.
- Places strong value on sustainability and best practices.

*Weaknesses*

- Focuses on many U.S. government regulations and processes that fall outside the scope of Safe Water Network projects.
- Assumes greater budgetary resources than may be possible.
- Gives little credence to impact of climate change.

*Lessons Learned/Applicability to* Safe Water Network *Projects:*
Proper monitoring and quantification of water resources include many variables and so can be expensive and time consuming. Evaluations can take up to a month, include areas downstream, and require multiple monitoring wells and test stations to be drilled. However, these additional analysis help to reduce associated costs and ensure the vitality of water withdrawal projects over the long term.

**References:**

United States Department of Agriculture. (2007). *Technical Guide to Managing Groundwater Resources.* Retrieved from: http://www.fs.fed.us/biology/resources/pubs/watershed/groundwater/ground_water_technical_guide_fs-881_march2007.pdf

## Water and Population Dynamics: Case Studies and Policy Implications

**Location:** Chikkanayaknahali taluk, Karnataka, India
**Timeline:** Published May 1998
**Type of Document:** Case Study
**Summary Data:**

**Population:** 193,419 (1991)
**Area:** 112,998 hectares
**Average Rainfall:** 600 mm/year

**Background/Description:**
This case study aimed to collect data on water consumption and respective demographics in a small region of Karnataka, India. The authors relied on basic questionnaires, local census reports, and reports from the local water board. In-depth interviews provided household level data and village records. These data were then used to analyze trends between developing demographics and water consumption habits.

**Summary:**
The examined population increased at an average overall rate of 14.3% over a two-decade period, although this growth slowed by almost half during the second decade (this decrease was mostly attributed to migration of workers to cities). Economic development allowed food consumption to increase 43% and plantation land grew by 81% as a small percentage of farmers shifted from staple food crops to cash crops. These factors contributed to a clear shift from surface water to groundwater, which caused water consumption to increase by 45% and many water tanks, bore wells and mini-water supplies to go dry. Per capita water availability dropped from 3,594 $m^3$ in the 1980s to 1,669 $m^3$ in 1991, while localized population growth also decreased (although growth rates were still overall positive). The study projected per capita water availability to continue to decrease to a projected 1,346 $m^3$ in 2010.

*Strengths*

- Includes a systematic approach for the collection and evaluation of water consumption and demographic data.
- Presents trends between population, specific demographics, and water consumption rates.

*Weaknesses*

- Area examined is not within Safe Water Network's current project range.
- The study is from 1998 so certain information (e.g., demands on local water resources and personal habits) may be outdated.

*Lessons Learned/Applicability to* Safe Water Network *Projects:*

This case is a good example of the complexity of populations, demographics and water consumption relationships. As Safe Water Network increases water availability, economic development and population may also increase. While this is beneficial, it must be considered when calculating the optimum sustainable yield associated with each safe water stations. If the demographic shift is not properly projected, population growth can lead to higher than anticipated water consumption rates and an eventual overuse and depletion of the underlying resources needed for the Safe Water Stations.

**References:**

Malhotra, K. C., Raghuram, S., & Pais, M. (1998). Water and population dynamics in a rural area of Tumkur District, Karnataka State. *161*, 235-61A.,

## Water and Population Dynamics: Case Studies and Policy Implications

**Location:** Jadavpur University
**Timeline:** Published February 2013
**Type of Document:** Scholarly Paper
**Summary Data:**

**Hydrological Model:** HEC-HMS
**Baseline:** (1961-1990)
**Time Slices:** (2010-2040),(2041-2070), and (2071-2100)
**Calibration error range:** 0.2%-20%
**Inputs:** River runoff, water availability, virtual water availability, water footprint, green water availability, and the Gini coefficient

**Background/Description:**

This study was conducted to assess the impact of climate change on river basins in India with regard to domestic, industrial, agricultural and hydropower scenarios. This study used hydrological baseline data from 1961-1990 and established formulas to examine three different scenarios in order to predict the effects of climate change, trade laws, and emission regulations on Indian water resources.

**Summary:**

The modifying of the different inputs lead to moderately different scenarios but in all three scenarios, industry production, runoff, erosion and Gini coefficient (i.e., the amount of income disparity equality) all increased. All variables are strongly influenced by population growth and effective land use management or other government policies can mitigate some factors. This projection ultimately predicts more water runoff, though there is less temporal certainty about when this runoff will occur.

*Strengths*

- Uses multiple established hydrological data sets and modeling software.
- Demonstrates trends between different hydrological processes and industrial sectors.

*Weaknesses*

- Further in-depth analysis of model is lacking.
- As with all models, dynamic climate conditions could cause the baseline used to provide inaccurate results.

*Lessons Learned/Applicability to* Safe Water Network *Projects:*
The most relevant variable examined was the increase in projected water run-off that could lead to more raw water resource availability. However, the temporal variability will be largely unpredictable leading to a possible problem with water storage and sustainable production yields.

**References:**
Roy, P. K. & Mazumdar, A. (2013). Water resources in India under changed climate scenario. *Water Resources*, *3*(1), 954-961

## Recommendations

To mitigate the depletion of water resources Safe Water Network should integrate into its current site selection criteria information regarding: the sustainable yield of the sites' hydrological systems, the potential for increased per capita consumption that follows economic growth from changing demographics, and the possible variation to sustainable yield with regards to local seasonal climate variability. This assessment should be completed at least a month before a project is started to ensure the project is both environmentally and economically sustainable.

The initial assessment should continue to include a survey and pump tests of the water resource to be utilized in order to estimate the sustainable yield at a particular location. A detailed survey to determine previous, current and future demographic projections should be done alongside the initial hydrological assessment. These data will be used to not only predict the possible increases in water consumption but could also be incorporated to determine economic potential. The final task should be the inclusion of an environmental variability risk factor to the sustainable yield, which will likely be the most challenging variable to calculate and fell outside of the scope of this project. However, this factor might be managed by the incorporation of storage facilities or by allowing a fixed amount of additional resource production capacity to be held in the case of poor production seasons. It is recommended that this factor be further researched and quantified.

If these assessments are not done, Safe Water Network risks investing in a project that might ultimately fail due to unsustainable water withdrawal rates. Failure to conduct an assessment could also lead to increased production costs as yields fall and alternative costlier extraction methods are needed.

Additionally, dynamic demographics can lead to unforeseen increases in demand that can outstrip the natural recharge rates of the area, especially without a known target yield rate. Moreover, climate variability could lead to a functional site losing its market niche as unknown variations lead to lower production yields. However, many of these risks can be mitigated with the adoption of a comprehensive groundwater mitigation strategy that should be part of the overall Water Safety Plan.

# III. Reverse Osmosis Waste Management

## Introduction

Safe Water Network has successfully used reverse osmosis (RO) water treatment technology to help improve community health in villages in the Indian states of Andhra Pradesh and Uttar Pradesh. While RO usage requires electricity and is somewhat more expensive than other small-scale water purification technologies, RO systems are very effective at reducing certain water contaminants (e.g., total dissolved solids (TDS) and fluoride) that exist in the feed (source) water of many of the communities Safe Water Network works with. RO systems use electrical pumps and filtering membranes to remove contaminants from feed water and create two output streams: a permeate stream of treated potable water, and a concentrate stream that contains the removed contaminants (labeled in the literature as concentrate, brine, waste, or reject water). Due to the nature of the RO process, this concentrate stream contains water pollutants at levels exceeding the originally contaminated feed water. One of the issues Safe Water Network faces and will increasingly face is the proper management of this concentrate waste stream in order for their RO-based systems to be environmentally sustainable.

According to Safe Water Network, current practice at all of their Safe Water Stations (SWS) is to dispose of the reject water by releasing it into the village sewers (public drains). Safe Water Network considers this method to be environmentally safe, as the total quantities of concentrate produced are low and the pollutant concentrations in the concentrate stream are not highly elevated. However, Safe Water Network expressed that this is a potential concern for the future of their treatment centers and requested information on the best ways to manage these waste streams so as to limit the potential negative effects if any on surrounding human and environmental systems, and to ensure compliance with Indian water effluent regulations at the national and state levels.

In order to assist Safe Water Network in this effort, this section of the report was created based on the workshop team's previous literature review that examined sustainable RO system waste management in small developing communities. This section of the report is organized into three sections: the first section contains a discussion of pertinent source availability and a summary of content; the second section presents a presents case studies; and the third section summarizes a set of recommendations for Safe Water Network.

## Literature Review and Discussion

### Methods

In order to perform this literature review, Columbia University Library and electronic database searches were conducted for relevant information. Additional organizational and water quality data was provided by Safe Water Network. Some of this water quality data was then used to calculate the concentrations of pollutants in the concentrate stream for comparison with government standards.

### General

Since several of the original issues that limited adoption of membrane technology were solved in the 1970's, RO systems have been increasingly utilized for a variety of water treatment purposes. Major municipal applications for RO technology have been the desalination of seawater and brackish water and the treatment of wastewater and other contaminated waters in preparation for either reuse or proper disposal. RO technology has also been widely used for water treatment in industrial settings, including in the production of soft drinks. Due to the resource demands of RO technology (in terms of energy, materials, and required personnel expertise), most research and case studies examine the planning, design, management, and operation of RO systems in industrial settings and developed nations. However, research has more recently focused on the use of small-scale RO treatment systems for community and/or private water supply in the developing world, particularly in India.

### RO Concentrate Management

The majority of literature and detailed case studies found regarding the management of RO waste streams were for large municipal and industrial systems in the developed world. This literature reveals a consensus that RO systems further inland have greater environmental risks because systems in coastal regions can redirect the RO concentrate stream into a large salt water body and therefore dilute the contamination. This is true for strict desalination plants, but also applies to several applications where the contaminants of interest are other naturally occurring salts. Most available research on concentrate management for inland areas suggests either increasing the efficiency of RO systems (thus decreasing the quantity of concentrate produced) or finding sustainable alternative disposal or reuse applications in order to avoid direct discharge into surface fresh water bodies. Several sources included in the annotated bibliography summarize the advantages and disadvantages of various methods for either increasing efficiency or using alternative disposal and reuse strategies, some of which may be applicable to smaller-sized systems.

While more information exists for large-scale RO systems, research and case studies do exist for RO applications to purify drinking water in developing communities including those in India. Research and case studies related to the specific issue of RO waste management in small developing-world communities was not readily available; although many reports state the importance of concentrate management, they do not expand upon possible solutions. An exception to this is a 2012 report from the University of Michigan, which may prove to be an extremely valuable resource for Safe Water Network. The following section provides a summary of this key report.

### University of Michigan/Sarvajal (Water for All) Report

The recent University of Michigan report entitled, "Water for All: Sustainable Solutions for Reducing and Utilizing Sarvajal's Reverse Osmosis Brine in Northwestern India" is the result of a year-long collaboration between masters students at the School of Natural Resources and Environment and Sarvajal/Piramal Water Private Limited, a social-enterprise startup that works on water projects in India. Sarvajal is responsible for setting up small owner/operator RO water treatment franchises in several parts of India, though the majority of their sites are within the states of Rajasthan and Gujarat in the Northwest of the country. The students' role was to perform literature reviews, an analysis of available data, and in person visits to a number of the Sarvajal franchise for interviews and testing purposes. While the report does not discuss each case study in detail, out of 22 sites visited 17 of them were trying or had tried to reuse the RO concentrate for other applications.

As can be inferred from the report title, the underlying concerns and information needs of Sarvajal are very similar to those of Safe Water Network. Based on information provided in the Water for All report and by Safe Water Network, the system sizes (500 - 1000 liter per hour) and RO system efficiencies (40-50%) are comparable between the two organizations. The current practice of discharging RO concentrate (referred to as brine in the Water for All report) to sewers, oceans, and other surface waters is also the same.

The report contains a large amount of information that Safe Water Network should find useful, including the following:

- A general summary of strategies aimed at increasing RO system efficiency.
- Detailed summaries of alternatives for the disposal, treatment, or reuse of RO concentrate including discussion of specific benefits and barriers for implementation (see Appendix H of the Water for All report).
- The development of a utility matrix for comparison of the various alternatives based on economic, social, and environmental impacts (see Appendix G of the Water for All report). Figure 3.1 found on the next page of this report shows a summary of the utility matrix results taken from the Water for All report.
- Case studies related to several Sarvajal franchises that are currently reusing the RO concentrate, or have attempted to in the past (a sample of which are presented again in this report).
- A set of recommendations for further data collection, increased efficiency, additional communication, and implementation of alternative strategies, some of which are discussed in the recommendation section of this report.

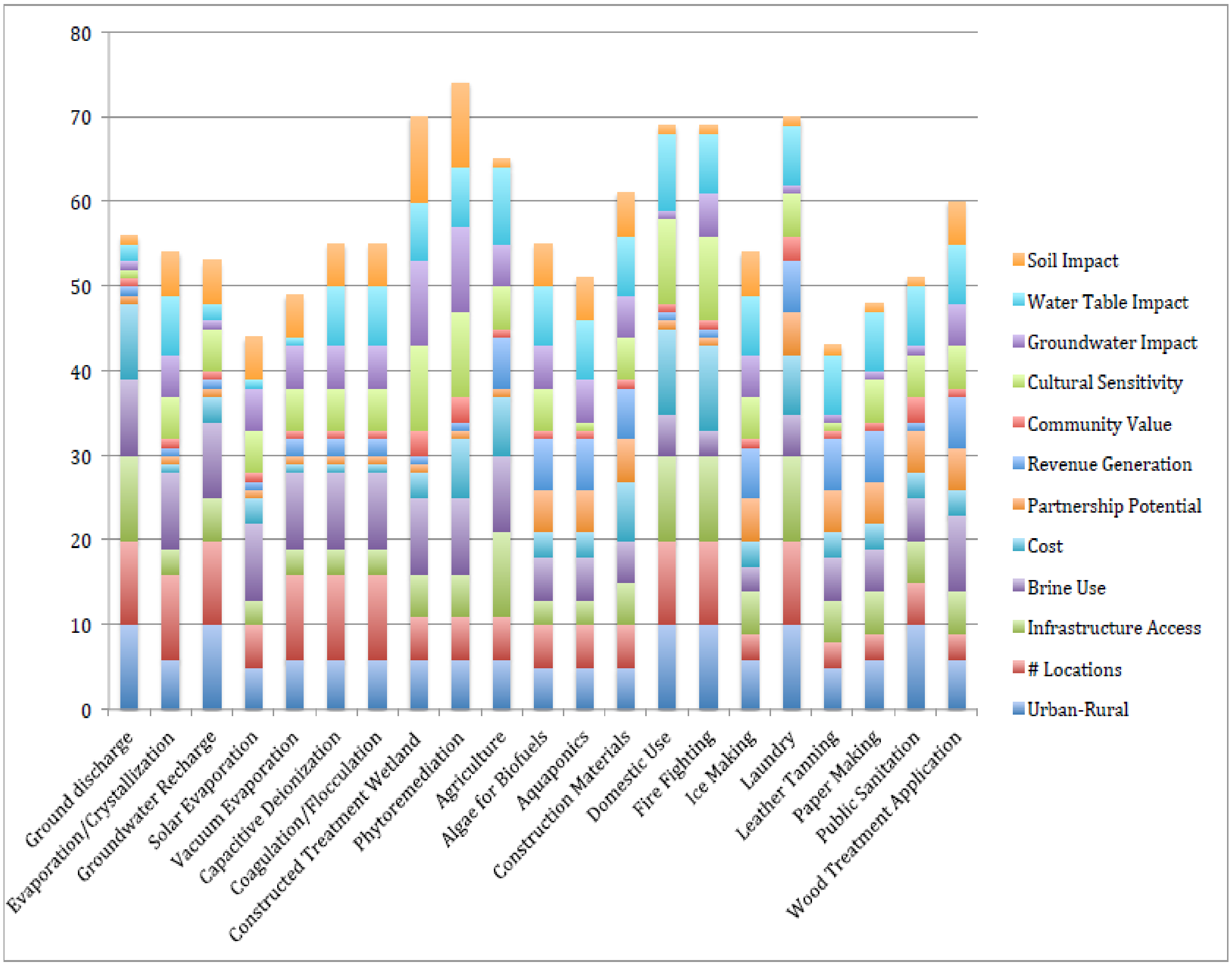



**Figure 3.1: Summary of utility matrix analysis taken from the Water for All report. This chart helps compare different concentrate management strategies based on scores given in the various categories located along the right side of the chart. A similar analysis is recommended for Safe Water Network's sites.**

## Case Studies

As discussed in the preceding section of this report, it was difficult to find complete case studies describing the proper disposal of RO concentrate in small developing world community settings. The exception to this is the University of Michigan's Water for All report that presents several case studies of projects in the Gujarat and Rajasthan regions. Therefore, this section of the report provides the following: a comparison of two case studies found in the Water for All report, and a summary of a case of poor waste management in the Bathinda area of Punjab State.

## RO Concentrate Reuse at Sarvajal Franchises in Rajasthan

**Background:**
The two summarized RO systems described above are operated as Sarvajal franchises by local owners and are both located in the same area of India. Both locations were visited by the authors of the Water for All report.

**Summary:**
**Location 1:** Ramgarh, Rajasthan
**Type of RO Concentrate Disposal:** Reuse as input to brick and cement making applications.
**Population Served:** 230
**Efficiency of RO system:** 40%
**TDS of Input Water:** 1,600 ppm
**Pollutants of Source Water:** Total dissolved solids (TDS) and fluoride
In Ramgarh, the RO system owner originally attempted to use the concentrate for brick and cement making projects. However, the bricks and cement were of poor quality due to the high salt content of the concentrate. Attempts were made to dilute the concentrate using source water for brick and cement making, but the results were not reported.

**Location 2:** Jaipur, Rajasthan
**Type of RO Concentrate Disposal:** Reuse as input to laundry business.
**Population Served:** 200
**Efficiency of RO system:** 40%
**TDS of Input Water:** 550 ppm
**Pollutants of Source Water:** N/A
In Jaipur, the neighbor of the RO system owner is successfully using the concentrate for his laundry business. At the time of the University of Michigan students' visit, the concentrate was being used successfully in this man

**Lessons Learned/Applicability to Safe Water Network Projects:**
These case studies present several lessons for current and future Safe Water Network projects. They demonstrate a variety of local ways exist to reuse RO concentrate and success partially depends on the type of operation and the chemical characteristics of the concentrate. These cases suggest that collecting additional economic activity information about the local community may be helpful if Safe Water Network wants to promote concentrate reuse at its facilities.

**Reference:**
Berent, Lauren et. al. (2012). *Water for All: Sustainable solutions for reducing and utilizing Sarvajal's Reverse Osmosis brine in Northwestern India.* Retrieved from University of Michigan, Department of Natural Resources and the Environment website:
http://deepblue.lib.umich.edu/handle/2027.42/89963

## Reject Water Mixing with Source Water in Punjabi Facilities

**Location:** Village Balluana, Bathinda, Punjab
**Type of RO Concentrate Disposal:** Mixing with feed water
**Population Served:** 2,000
**TDS of Input Water:** 4,050 ppm
**Pollutants of Source Water:** Arsenic salts and sulfur

**Background/Project Description:**
There are high levels of groundwater contamination in the area of Bathinda, Punjab where many RO systems have been set up. The average TDS of villages in this area is around 4,000 mg/liter, which is 4 times higher than the World Health Organization's WHO's acceptable limits. RO systems are used to remove elevated levels of TDS as well as arsenic and other chemicals.

**RO Concentrate Disposal Process Summary:**
An RO project in the Bathinda area was properly installed with standard components and is reported to be run effectively, except for the disposal of drain line waste product (reject water). At many sites the reject water was unintentionally mixing directly with the source water due to poor construction, which caused an increasing deterioration of product water quality. A simple simulation based on regional data (e.g., average TDS levels) and RO system efficiency revealed that after the sixth process cycle the water quality deteriorated below the norms set by the WHO. In other words, if the common water tank capacity is sufficient for whole community's drinking water demand for 10 days, the water tank will fail to provide safe drinking water after 60 days of operation.

**Lessons Learned/Applicability to Safe Water Network Projects:**
The Bathinda case studies highlight the problems resulting from insufficient separation of reject water from source water in an RO system. These cases also stress the contaminant concentration in the reject water can be sufficiently large enough to deteriorate water quality downstream. Both of these points should be taken into consideration by Safe Water Network, as there are appears to be a history of poor reject water management in some parts of India. In the discussion of the Bathinda cases, evaporation strategies are presented as possible solutions to the RO reject water problem.

This discussion also included several suggestions that may be applicable to Safe Water Network's work if evaporation strategies are to be taken into account:

1. People in the community must be educated to use the RO system. Some villages, which share common land, should jointly use that land to construct seepage-free ponds to facilitate the natural evaporation of residual waste.

2. The use of residual chemicals in the concentrate stream (e.g., sulfur, nitrogen, etc.) could be used to manufacture fertilizers. Though the cost-benefit analysis must be conducted based on individual cases, the relevant chemical analysis should be completed before disposing of RO treatment reject water.

**References:**


Udaybir Man. (2011). *RO System Failure in Punjab.* Jago Punjab-Jago India. Article retrieved from: http://jagopunjabjagoindia.com/ro-system-failure-in-punjab-critical-analysis-by-nri-student-16584

Amita Bhaduri. (2010). *Reverse Osmosis plants for rural water treatment in Gujarat - A study by CAREWATER.* Carewater INREM Foundation.http://www.indiawaterportal.org/node/11938

Tribune News Service (2013). *NRI points out faulty working of RO plants.* Article retrieved from http://www.tribuneindia.com/2013/20130213/battrib.htm

Bartels, C., Franks, R., & Andes, K. Operational Performance and Optimization of RO Wastewater Treatment Plants. Retrieved from http://www.membranes.com/docs/papers/New%20Folder/Operational%20Performance%20and%20Optimization%20of%20RO%20Wastewater%20Treatment%20Plants.pdf.

## Recommendations for Safe Water Network

Based on the research and literature review performed, the following recommended actions should be taken by Safe Water Network to help ensure the proper management of RO concentrate streams:

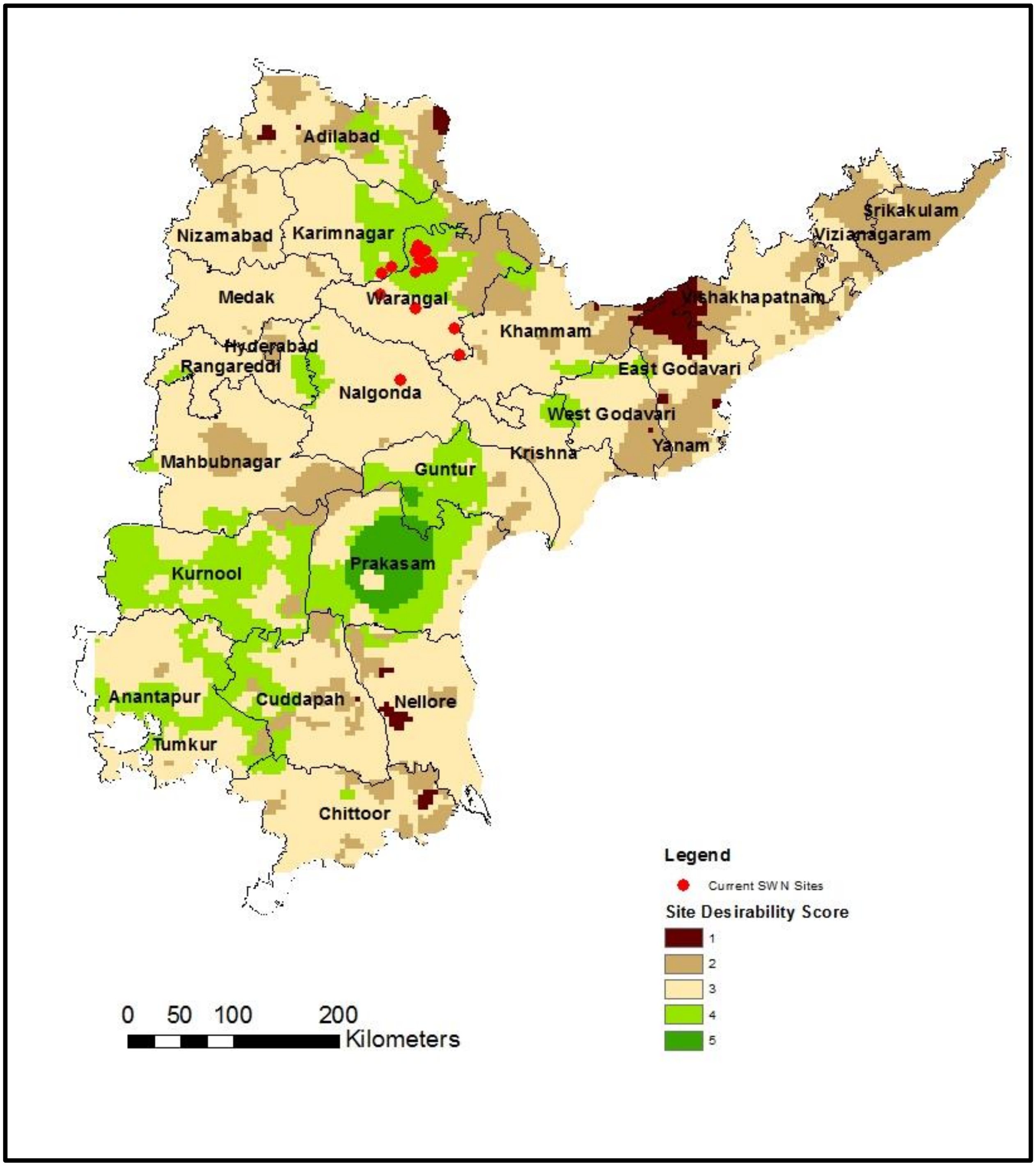
1. **Collect water quality data on the concentrate streams at each current site and plan to do the same at future sites**. As suggested in the Water for All report, water quality and quantity data related to source and concentrate waters are important factors when determining proper management strategy. This is especially critical when considering reuse applications, as the concentrate becomes an input into another specific industry and also potentially salable.

2. **Integrate RO concentrate management into site selection process.** As Safe Water Network potentially expands into more arid regions and/or areas of higher population, an analysis of local disposal or reuse options should occur prior to starting any new projects. To help determine these options, data on local industries, businesses, and other activities should be collected. Safe Water Network may be able to incorporate the collection of this type of socio-economic information in their preliminary site assessments.

3. **Consider using and/or developing an application matrix for comparing alternatives.** The University of Michigan report presents an application utility matrix to help compare various disposal and reuse alternatives. A similar process could be used to create a matrix for each Safe Water Network site, since local economic, physical, environmental, and social conditions will be different. This may help in both decision-making and in communicating strategies to the operators and community as a whole.

4. **Increase RO system efficiencies.** If the amount of concentrate created is reduced, there is less that requires proper disposal and/or reuse. Creating less waste also creates less pressure on the local watershed and groundwater supply, which is especially important in arid areas. The resources presented in the bibliography summarize several ways in which efficiencies can be increased and should be consulted. Since one way to increase efficiency is to run a double RO system, Safe Water Network may also want to consider investigating how the modular nature of their RO systems could be adopted to increase efficiency. The drawback of this approach is its high costs in terms of energy, materials, and both capital and operational costs. Increasing RO system efficiency also increases the concentration of pollutants in the concentrate stream (to the point where government regulations become a concern), and therefore should be promoted in tandem with waste management strategies.

# IV. GIS Data and Tools



## Geographic Information Systems

Geographic Information Systems (GIS) capture, maintain, and represent data containing spatial parameters. GIS has several potential benefits. Software such as ArcGIS (or even mapping tools as common as Google Earth) can help visualize and communicate large amounts of spatial data in a way that traditional charts and spreadsheets cannot. Furthermore, GIS software is equipped with tools to analyze spatial data, some of which could be very helpful for Safe Water Network selecting new sites and monitoring existing sites. Interpolation tools enable the organization to use a finite number of measured observations to infer characteristics of areas that are not observed directly. In Safe Water Network's case, if water quality measurements were given at certain locations, ArcGIS could predict measurements of these parameters at other locations. Higher quantity and wider geographical range of observations increase the predictive power of the model.

Overlay tools synthesize different types of data over the same geographical area. For instance, if one dataset had population data, another had electricity access information, and another had groundwater fluoride levels, one can overlay these "layers" assigning desired weights of importance to each of the parameters to produce a final categorization or ranking of different areas. If Safe Water Network specified a desired population range, electricity capacity, and fluoride range for site selection, GIS could produce a map and table of suitable locations, either in binary terms (i.e., suitable vs. unsuitable) or on a scale (i.e., 10 is most suitable, 1 is least suitable).

Safe Water Network could also use GIS to monitor information at existing sites, but the effective development of any type of tool on a countrywide scale would require more comprehensive water quality data. Building its GIS capacity would help Safe Water Network to scale up its operations by making site selection and site management (e.g., optimizing supply distribution networks) more efficient.

This section of the report describes two GIS research projects. The purpose of the first was to develop a summary of reliable data and resources on water contamination in Ghana. The purpose of the second project was to review GIS data for India and to demonstrate how GIS could be used with these datasets for site selection purposes.

## Ghana

### Methodology

As expected, data on many of the site selection criteria in Ghana are not as readily available on the internet or other public domains as they might be in developed countries. The team conducted a thorough web search for data on relevant groundwater contaminants (e.g., arsenic, fluoride, chlorine, pH, etc.), perhaps the most difficult set of data to obtain. Common engines such as Google, Google Scholar, and Columbia University's library system and e-journal database were used. The team also looked in common environmental databases, such as the United States Geological Survey and the Environmental Data Center, as well as at several Ghana government institutions, such as the Water

Resources Commission. In many cases, individuals were emailed directly and web inquiries were submitted.

### Findings

The team found considerable relevant and useful data on specific districts and areas, but was unfortunately unable to gain access to a countrywide dataset of water quality measurements for tje desired GIS tool within the time constraints of this study. It is likely that more countrywide datasets exist even though they have been difficult to track down, especially without physical interaction or strong rapport with the institutions that likely house such data. Despite sending multiple requests to potential institutions and, in some cases, receiving helpful responses with additional leads, some of the desired data could not be obtained. However, given Safe Water Network's physical location, reputation, and status as an ongoing stakeholder in the water sector in Ghana, it is likely Safe Water Network can gather the needed data and use it to further the organization's mission.

### Notable Resources

While the attached list represents a more comprehensive review of existing and potential data sources, there are several water quality resources worth highlighting. Sandow Mark Yidana, who is affiliated with the University of Ghana, has written several informative journal articles on groundwater quality in various regions of the country. One article in particular, *Hydrochemical Characterization of Aquifers Using Sequential Multivariate Analyses and Geographic Information Systems in a Tropical Setting*, summarizes and analyzes groundwater quality parameters measured throughout Ghana. The data underlying this article and others would be very valuable to Safe Water Network's site selection tool. Also, the Ghana Water Resources Commission and the Ghana Community Water and Sanitation Agency appear to have cogent data, though the team was unfortunately unable to obtain this information in the allotted timeframe.

The team was able to obtain some basic information on population, infrastructure, and geology that would be helpful for any future mapping project. If Safe Water Network can establish a rapport with and gain access to the Ghana Statistical Service's census data, then any subsequent site selection tool would become much more robust.

### Summary and Recommendations

This examination has highlighted the need for collaboration in the water service sector and the large-scale sharing of relevant data between government and non-government entities. Similarly, Safe Water Network can likely improve its organizational performance and health by consolidating internal information – whether it be operational data, contact and donor lists, site coordinates, best practices, or project workflow – into one centralized, user-friendly platform.

### Annotated Bibliography, Contacts, and Maps

In the references and resources section of this report, there is an annotated bibliography that focuses on Ghana, which can serve as a roadmap of relevant geographical information. This section contains articles, reports, and resources of interest found by the team. Appendix B contains a set of maps containing relevant information. Included in the descriptions are explanations of the contact with certain key individuals and institutions. The underlying GIS data for the maps are available and can be sent to Safe Water Network once the organization builds more GIS capacity (either internally or through external connections).

## India

### Introduction

Similar to the work collecting data for a GIS tool in Ghana, the second GIS project focused on developing a tool to help Safe Water Network select potential sites for its Safe Water Stations (SWS) and monitor existing SWS in India. In contrast to the minimal GIS data for Ghana, a significant amount of data for India on population, administrative boundaries, groundwater availability, water contamination levels, annual rainfall, and land use were located.

### Methodology

Data were obtained from online GIS databases and scientific journals. Searches were conducted on Google and using the Columbia University library system. Due to time constraints, there was little attempt to contact with individuals in attempts to gather data; further effort is warranted in areas that the team did not find data (e.g., electricity usage).

After gathering, cleaning, and consolidating data, the team used Esri's ArcGIS software to produce a number of maps of Andhra Pradesh displaying information that might be useful for Safe Water Network in site selection and monitoring. A hypothetical analysis of Andhra Pradesh was performed to rate the desirability of locations for potential SWS sites. Methodologies behind the individual maps are explained in more detail in the Maps section.

Maintaining a GIS platform and more regularly incorporating geographical data into its decision making would require Safe Water Network to establish more long-term technical capacity in the area. That said, the team will share the data underlying its maps with Safe Water Network in the coming weeks and, time permitting, try to find a way for Safe Water Network to display some this data visually using either a free ArcGIS Online public account or Google Earth KML files.

### Data Findings

While the Indian census website offers data on the state and district levels, much of its sub-district data from the last two censuses (2001 and 2011) does not match up with the overarching district data. The team was unable to find an internally consistent census dataset on the municipal or sub-district level so opted to use the population density grid or "raster" instead. These raster data are higher resolution than district-wide population counts and were found from Columbia University's Center for International Earth Science Information Network.

The Irrigation and CAD water report offers substantial hydrological data, such as rainfall, land use, and groundwater availability, on the district level.

The India Ministry of Water Resources' online Ground Water Information System was very helpful in obtaining water quality data. Measurements for numerous groundwater parameters are provided at over 1,000 wells throughout the districts of Andhra Pradesh. Data are available for multiple years through 2011, and the team opted for the 2010 data as it was the most complete data set. While the government does not readily provide much metadata on these measurements (latitude and longitude, for instance), the team used the GPS Visualizer's free online batch geocoder to assign coordinates based on the municipality listed for the wells.

The team used administrative and inland water layers from DIVA-GIS. Safe Water Network provided water quality parameters and coordinates for Safe Water Stations separately at different points in the semester.

## Maps

### *1. Administrative Maps*

The first map (Figure 4.1) shows Andhra Pradesh, India, its districts, sub-districts, population density, and the location of existing Safe Water Network Safe Water Stations. Administrative boundaries of districts and sub-districts were obtained from DIVA-GIS and population density in persons per square kilometer was obtained from Columbia University's Center for International Earth Science Information Network (CIESIN). Population density data are from 2000, which is considerably earlier than some of the other water quality and hydrological data included in this report. The map also shows a magnified view of the existing Safe Water Stations (SWSs) and the location of Andhra Pradesh within India.

The second map (Figure 4.2) shows Andhra Pradesh's districts, rivers, streams, lakes, reservoirs, and existing SWSs. Again, this map provides a detailed view of SWSs and Andhra Pradesh's location within India. All layers were obtained from DIVA-GIS.

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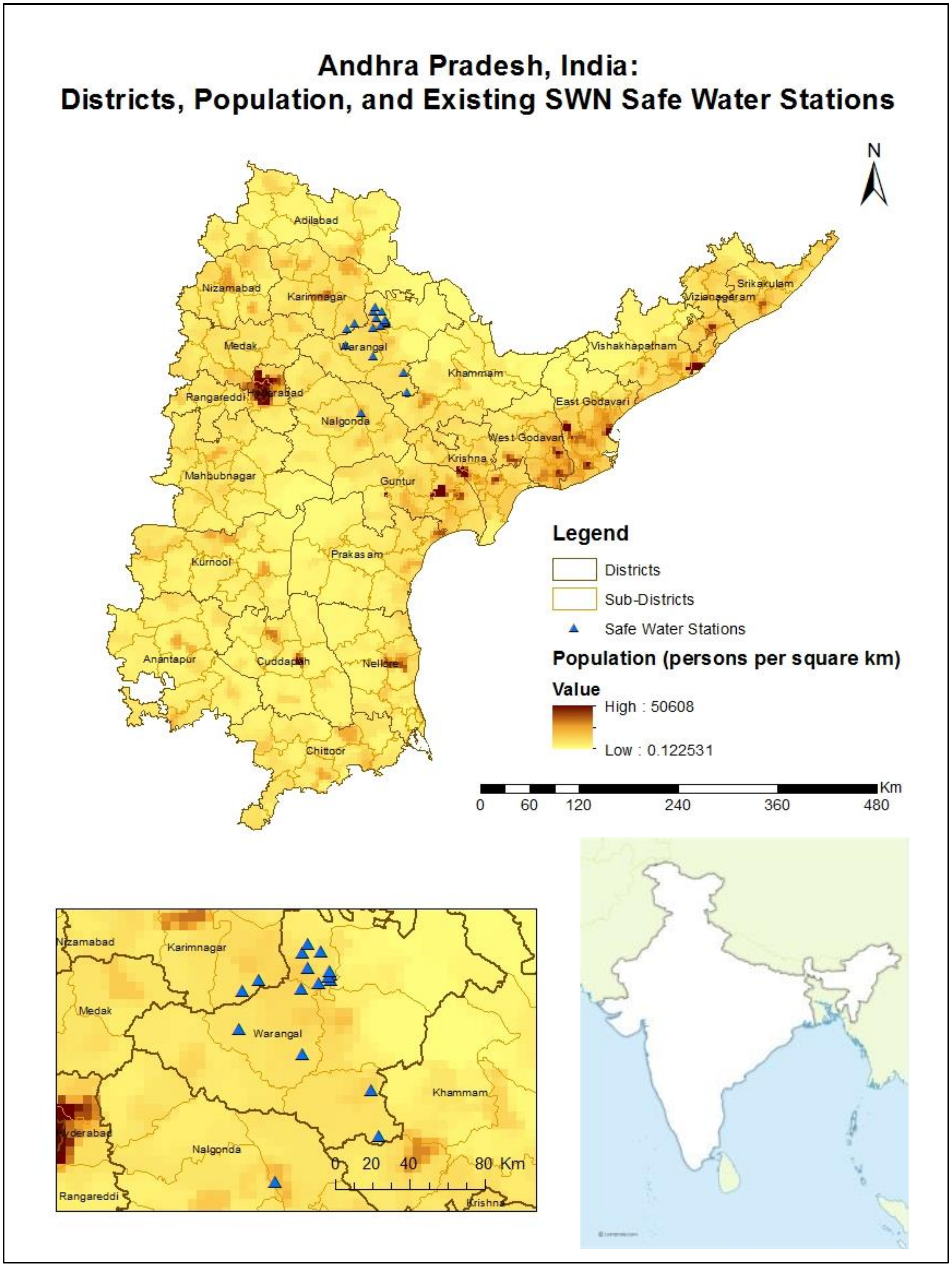


**Figure 4.1: Populations in Andhra Pradesh. Inset shows Safe Water Stations.**

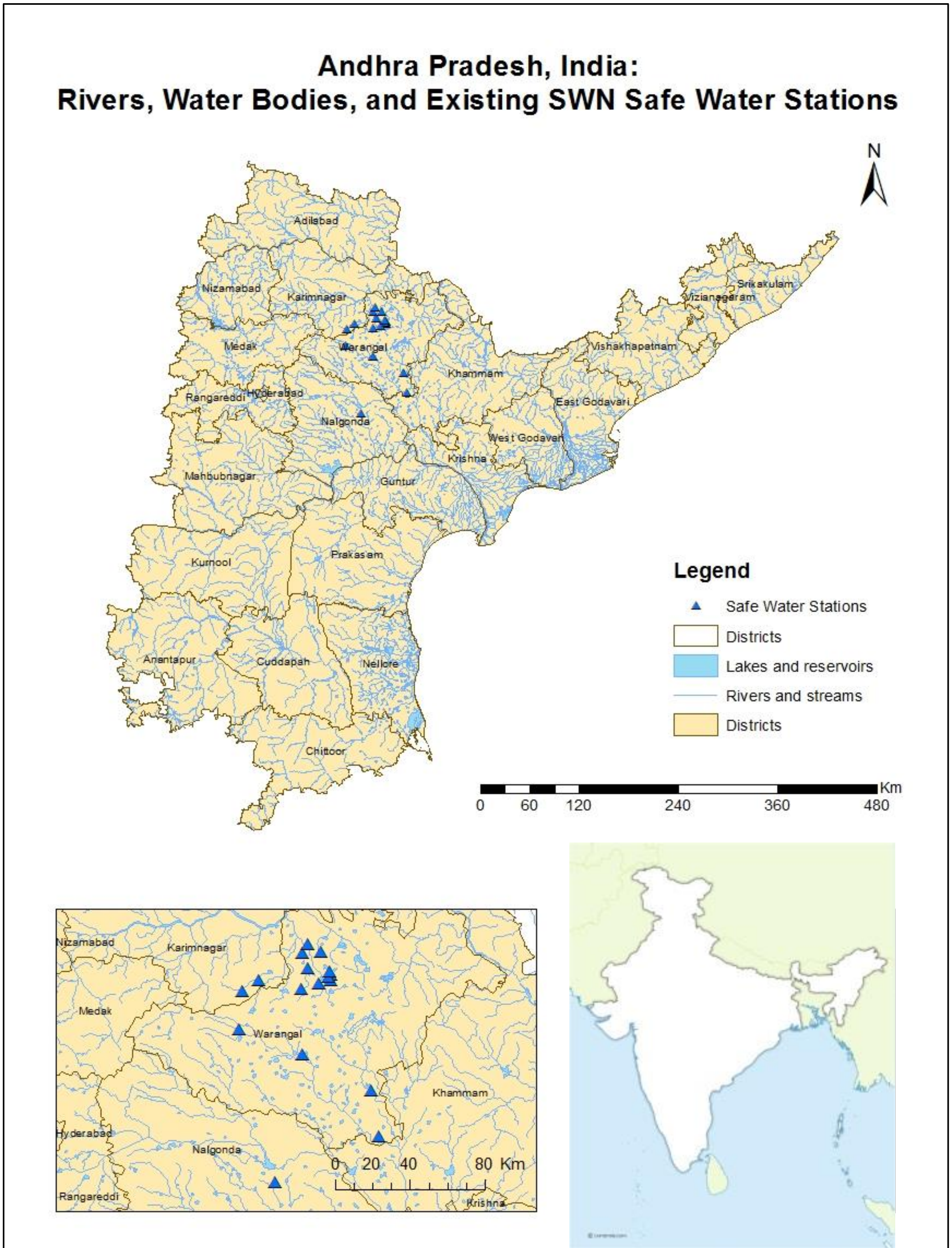


**Figure 4.2: Inland water bodies in Andhra Pradesh.**

***2. Hydrological & Groundwater Availability Data Maps***

Hydrological characteristics of the region represent an important consideration for site selection. The seasonal and annual variation in rainfall affects water availability, groundwater recharge rates, and land use. Measures of groundwater availability are equally if not more important for site selection because the groundwater characteristics of the region can determine the need for groundwater purifying water systems. These data are divided into “command” and “non-command” areas as categorized by the state of Andhra Pradesh. According to the Government of India law department, a command area is “an area irrigated or capable of being irrigated either by gravitational flow or by lift irrigation or by any other method, under an irrigation system, project or source and includes every such area whether it is called ‘ayacut’ or by any other local name in any law in force in the State.” The data for this section was obtained from the 2010 The Irrigation and CAD water report, and the maps for this section can be found in Appendix C.

***3. Land Use and Irrigation Characteristics Maps***

Land use and irrigation paints a broad picture of the state, providing insight into the activities of districts. These data can be analyzed and represented visually for site selection. The data for this section were obtained from the 2010 The Irrigation and CAD water report. The maps for this section can be found in Appendix C.

***4. Andhra Pradesh Water Quality Maps***

Using the 2010 Ground Water Information System quality measurements from the Indian government’s Ministry of Water Resources fluoride, chloride, pH, and sodium adsorption ratio (SAR) interpolation maps for Andhra Pradesh were created. Administrative boundaries were obtained from DIVA-GIS.

After geocoding the measurement wells, we performed statistical interpolations for each of the four parameters using the Ordinary Kriging method. Interpolation is a mathematical method that uses measured values at a set of locations to predict unknown values of the same parameter at interspersed locations between the known values.

One can quantify the uncertainty of an interpolation model by comparing the actual measured values to the predicted values at those same locations, thus obtaining a set of predicted errors, which can then be averaged. ArcGIS computed the following mean predicted errors for the Andhra Pradesh interpolations are as follows: fluoride (-0.0019), chloride (0.0549), pH (-0.0042), and SAR (0.0001).

This quantification is by no means comprehensive, as it does not take into account predicted values at other locations. One must exercise discretion when using interpolation models, as parameter values may fluctuate heavily over short geographic distances due to geology, pollution, etc. Hydrogeological expertise should be consulted when constructing predictive parameter models.

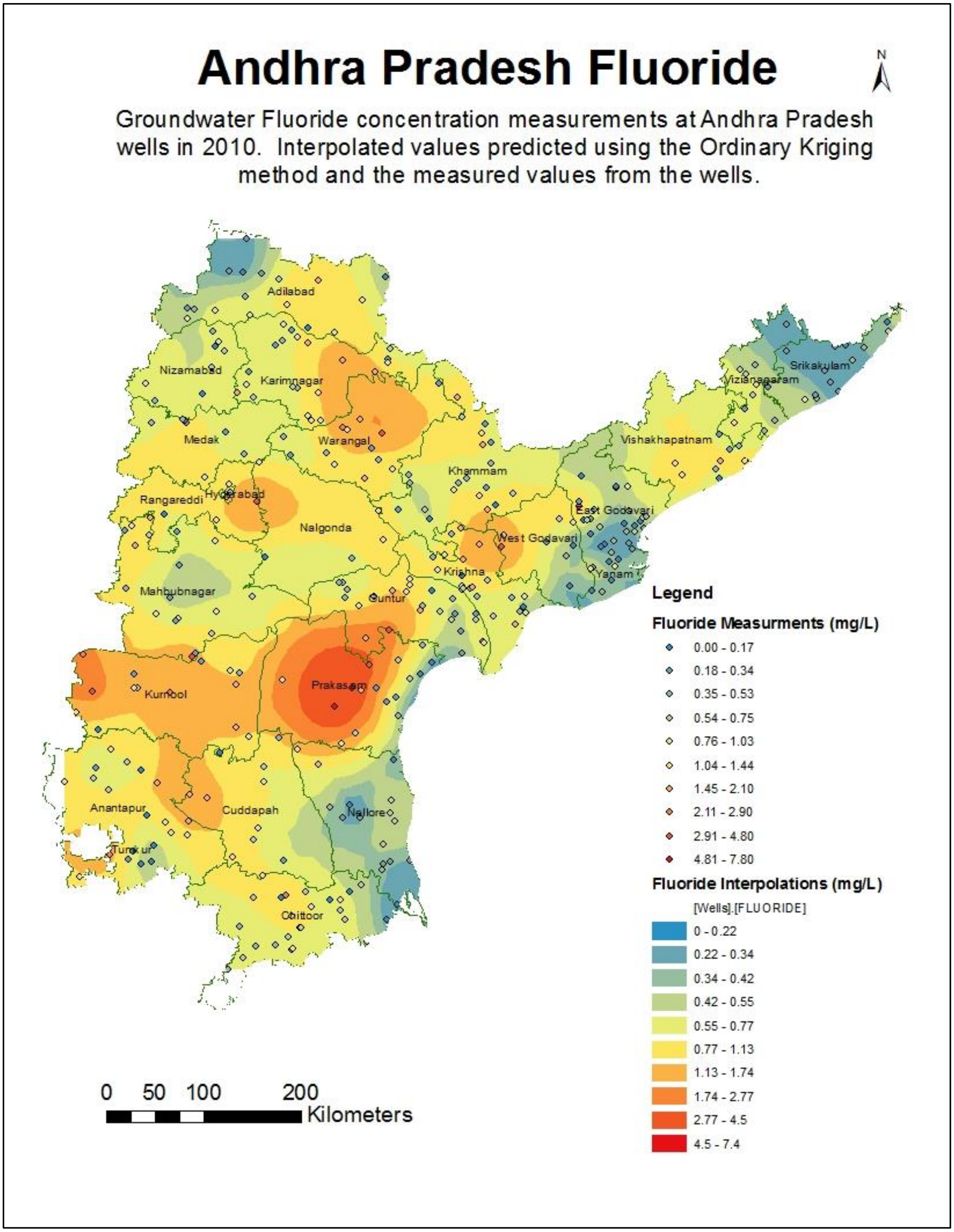


**Figure 4.3: Fluoride interpolations values in milligrams per liter.**

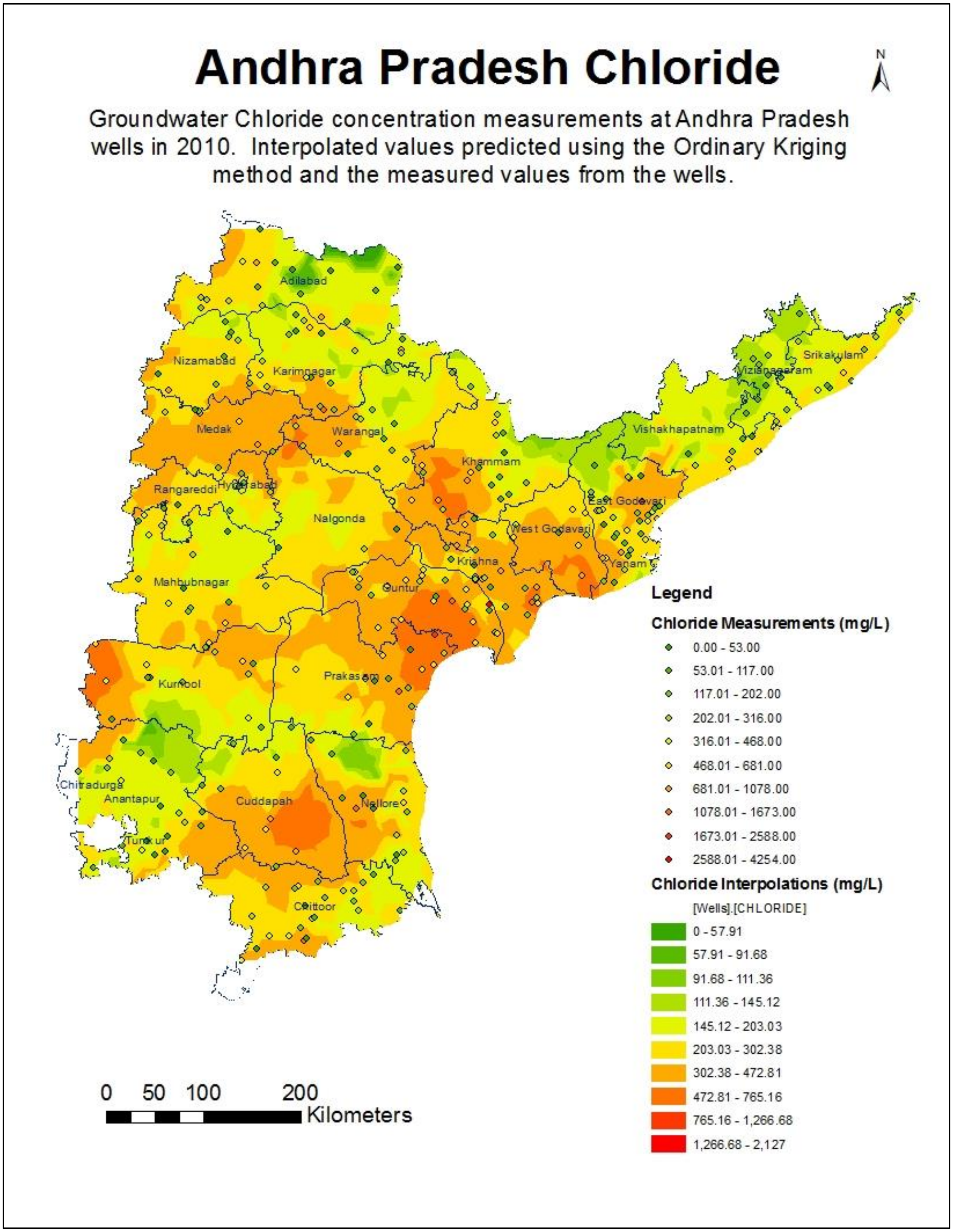


**Figure 4.4: Chloride interpolation values in milligram per liter.**

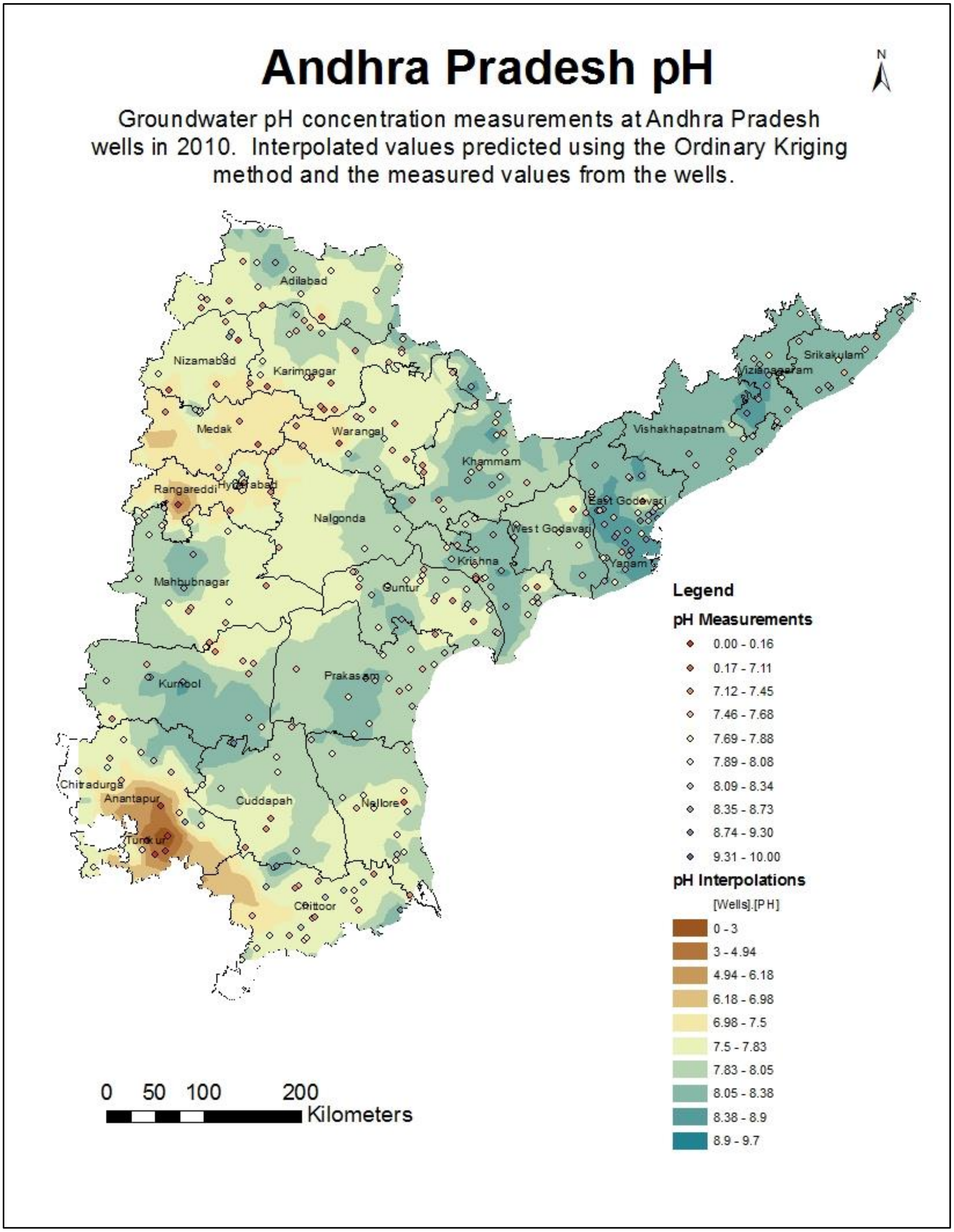


**Figure 4.5: Interpolation values of pH levels.**

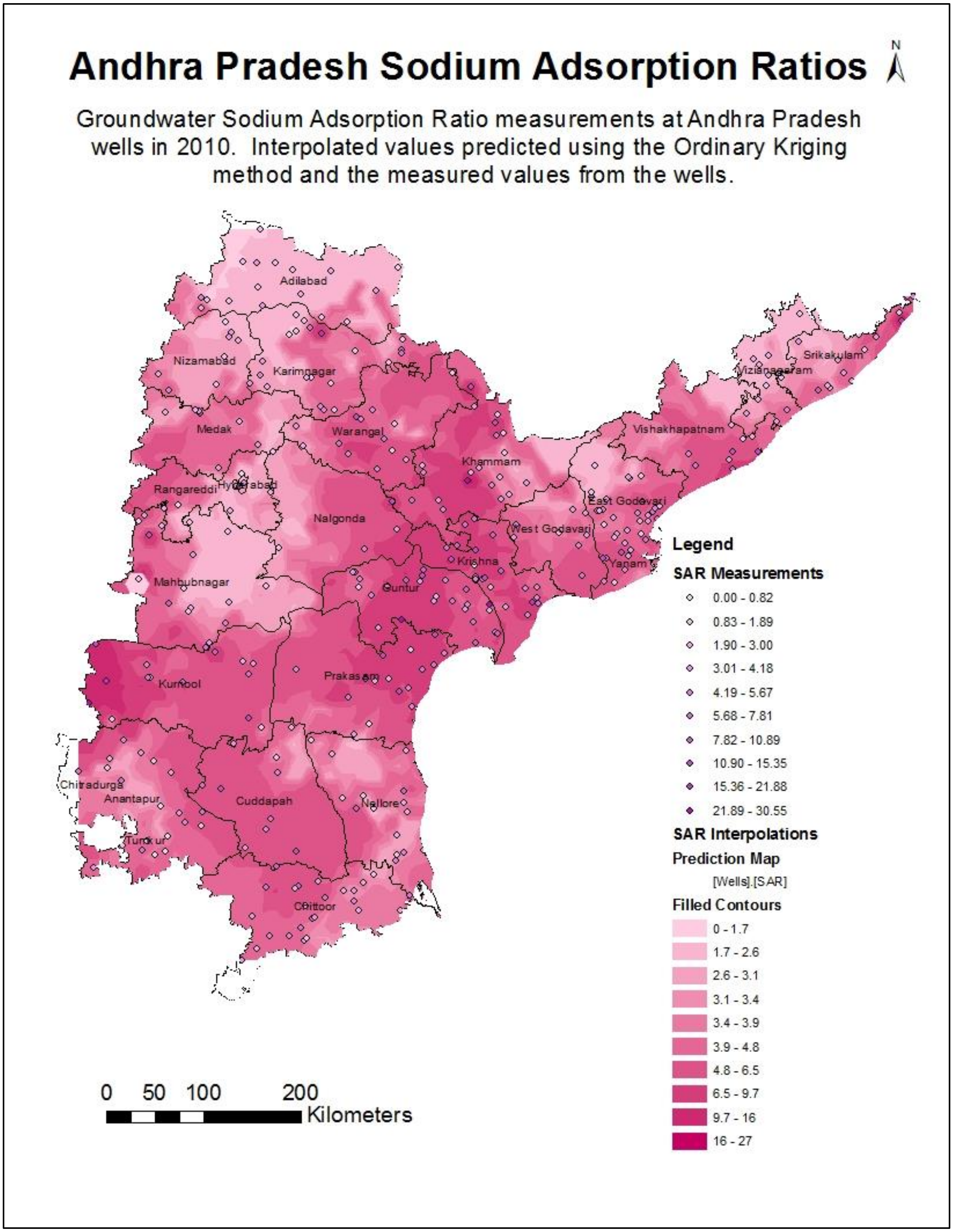


**Figure 4.6: SAR interpolation values.**

### *5. Local Safe Water Station Water Quality Maps*

The team used two datasets provided by Safe Water Network, one with station coordinates and one with water quality data for pre-treated, treated, and reject water at or near the stations. By joining these two tables, the team could map these coordinates with their respective parameter levels. Please see the Reverse Osmosis section of the report for more details on how average contaminant levels were calculated.

The map included in this section shows sites color-coded by reject water fluoride levels and an interpolation of groundwater fluoride levels using pre-treated fluoride levels. The team only used sites for which both coordinates and relevant fluoride measurements were provided. The interpolation model was made using the Ordinary Kriging method and the mean standard error for the interpolation was -0.01803. As was the case with the statewide maps, one must consider hydrogeological factors when using a model like this to inform site selection and analysis.

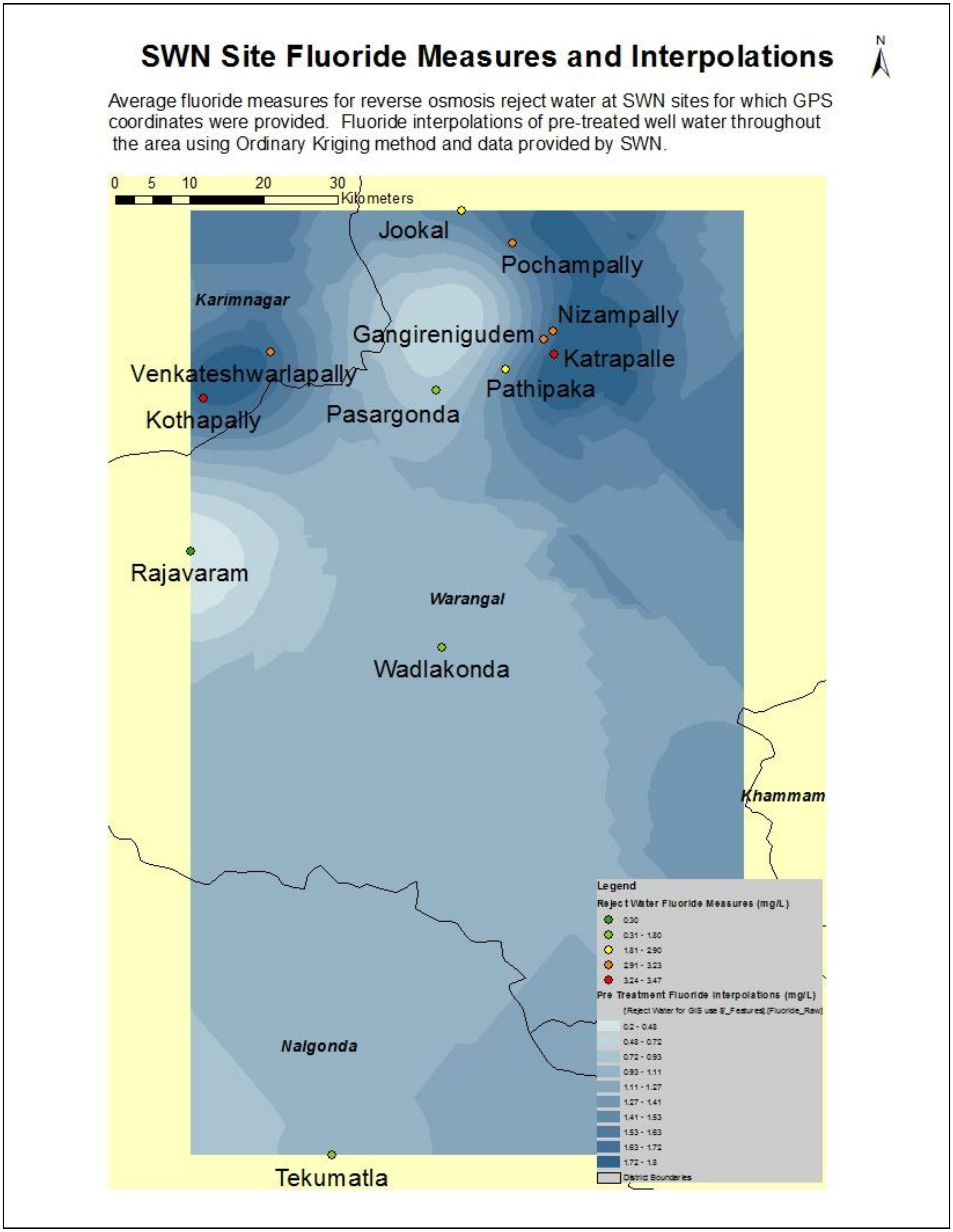


**Figure 4.7: Safe Water Stations and fluoride interpolation values.**

## Demonstration of Weighted Overlay for Site Selection

To demonstrate how Safe Water Network can use GIS for future site selection in India, the team completed a simple "weighted overlay" analysis, which analyzes information from multiple layers based on specified criteria. The team used the collected data of fluoride levels, population density, and groundwater availability to show how Safe Water Network can identify areas with the most need for new Safe Water Stations. By "overlaying" these three data sets, assigned areas across Andhra Pradesh "site desirability" scores, with 5 being the most desirable and 1 the least desirable.

Safe Water Network should refine these example parameters as needed in order to make more accurate recommendations. The weighted overlay should be used more as a demonstration of how GIS data can be useful to Safe Water Network rather than a final, deterministic tool for placing sites.

In the analysis, the team placed the most emphasis on interpolated measurements of fluoride contamination in mg/L, giving this a weighted importance of 50%. It was determined that areas with the highest levels of fluoride would be the most important, and therefore most desirable, to treat.

Next, based on conversations with Safe Water Network regarding the importance of population density the team gave this a weighted importance of 40%. Per the Safe Water Network toolkit, the ideal population for a new SWS is an area with at least 4,000 people in a 4 kilometer (km) radius of a village as the target population is within a rural area, but a high enough population must exist to maintain the station. This number is calculated to be roughly 79 people per $km^2$ and it was decided that the most desirable areas would be 79-150 people per $km^2$, followed by 150-500 per $km^2$, with population densities greater or less than the stated values being much less desirable.

Finally, groundwater availability was weighted with an importance of 10%. The datasets provided district-wide data only, so it was determined that the data were not specific enough to provide more weight compared to contamination levels and population density. Ideally, locations would have the highest amount of available groundwater.

### Recommendations

If Safe Water Network decides to scale up its operations, building GIS capacity could be very helpful, particularly for site selection and monitoring. Cost permitting, Safe Water Network should seek to integrate geographical and other forms of data from all aspects of its operations and manage this information onto one centralized platform.

With GIS capability, Safe Water Network can refine and add to its site selection tool through adding regularly updating data, adding more nuanced demographic data, and creating map layers with information on electricity infrastructure, sustainable water production yield, and climate variability. Elevation and detailed watershed data would help Safe Water Network better manage its reverse osmosis reject water as well.

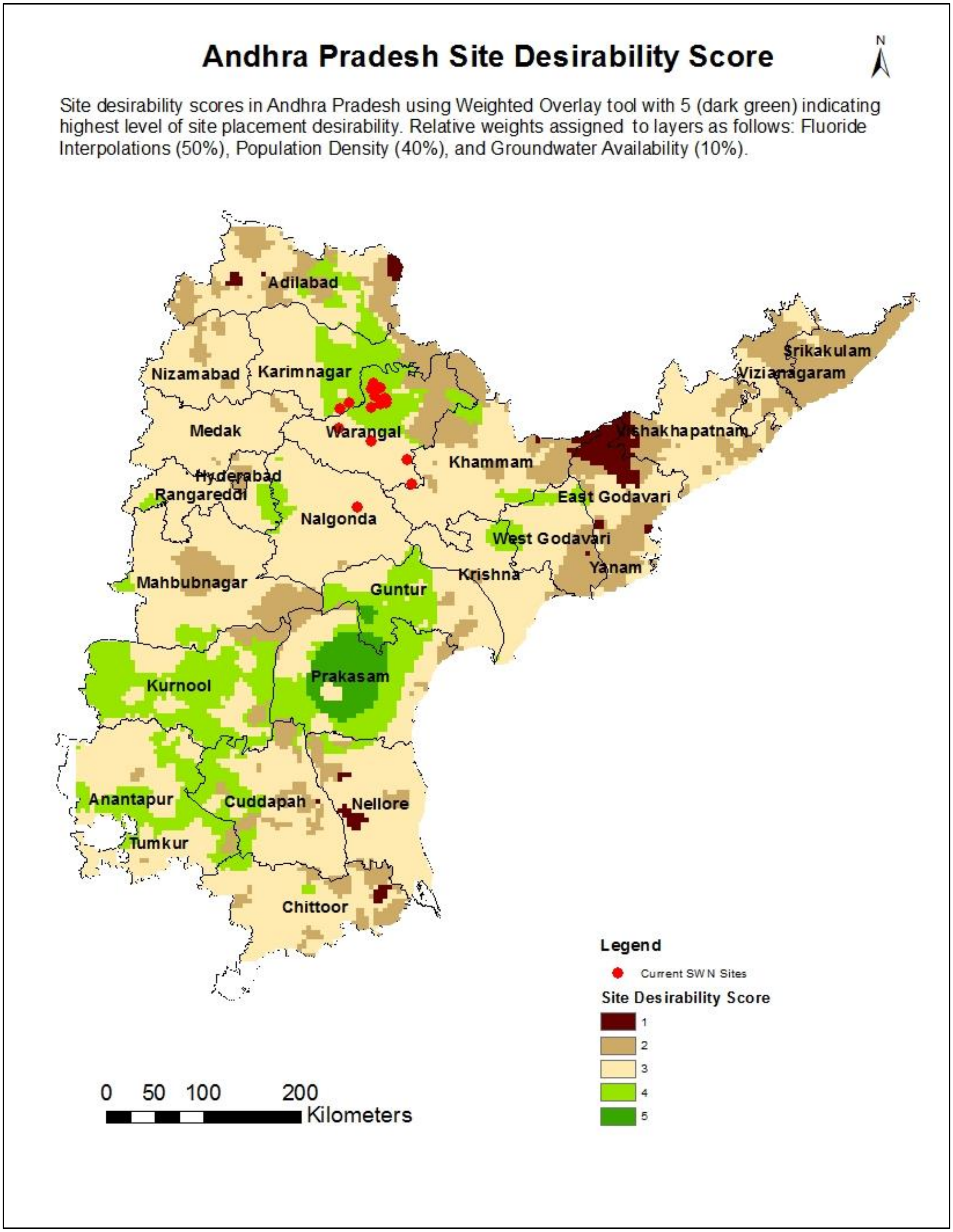


**Figure 4.8: Hypothetical weighted overlay depicting site desirability in Andhra Pradesh.**

# Conclusion

## Summary of Main Findings and Recommendations

### 1. Water Safety and Security Planning

***Main Findings:***

- There has been a shift in planning strategies from relying solely on direct water quality testing (which is expensive and time consuming) to the more holistic and proactive Water Safety Plans of varying complexities.
- Plans formalize and incorporate strategies such as budgeting water, protecting water sources, recharging groundwater, and thoroughly identifying potential water security issues.

***Recommendation:***

- The example Water Safety Plans should be utilized in formalizing and improving Safe Water Network's current water security activities.

### 2. Groundwater Depletion Mitigation

***Main Findings:***

- The determination of the maximum sustainable yield at a given site is necessary for the long-term sustainability of any water project.
- Sustainable yield calculations should include surveys and pump tests of groundwater resources, demographic trend analysis, and environmental variability risk factors.

***Recommendation:***

- Safe Water Newtork should continue to incorporate pump stress tests in their initial community assessments in order to help quantify sustainable yields.

## 3. Reverse Osmosis Waste Management

***Main Findings:***

- There is a growing awareness of the importance of RO concentrate management within both public and private organizations.
- The three main strategies for management include increasing RO efficiency, using alternative disposal methods, and finding reuse opportunities. The last two options require additional community assessment information.
- A thorough report on RO concentrate management in rural India was recently completed by students at the University of Michigan and Sarvajal.

***Recommendations:***

- Incorporate potential opportunities for sustainable reuse of RO concentrate into the initial community assessments.
- Develop an application decision matrix to assist in comparing different concentrate management strategies at a given site.
- Carefully pursue increases in RO efficiency to limit the amount of waste water that requires management.
- Increase water quality monitoring activities to include measurements of the concentrate stream.

## 4. GIS Tools and Data

***Main Findings:***

- Ghana lacks countrywide data and/or access to countrywide data.
- For India, there is a large amount of helpful GIS data that can be utilized in, particularly regarding water contaminant levels. Village level data is not as available.

***Recommendations:***

- For the case of Ghana, use the provided list of data resources as a starting point in an effort to gather, consolidate and enable the sharing of this information.
- For the case of India, use existing data and GIS tools to assist in the site selection process. This may require bringing in outside expertise or creating a new internal position. Once information is consolidated, the database should be continually maintained and additional data sought out and incorporated.

## Opportunities for Further Integration

As with all complex system components, the four areas of interest researched in this report are related and there are opportunities for further integration. This is especially true of the GIS resources, which can be used to help analyze and more effectively communicate the issues and data involved in the development of Water Safety Plans, the formation of RO waste management strategies, and the analysis of the sustainable yield in specific areas. Water Safety Plans can and should include potential threats to source waters posed by the unmanaged waste products of treatment facilities upstream.

Using the resources and considering the recommendations presented in this report, it is hoped that Safe Water Network will be able to continue to improve its success rate, the success of other projects through informational exchange, and the overall health and wellbeing of the communities they work in.

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Gopalakrishnan, S. (2001). *Tamil nadu at a glance: Area and population*. Directorate of Census Operations. & Ministry of Home Affairs. Retrieved from http://www.census.tn.nic.in/.

Malhotra, K. C., Raghuram, S., & Pais, M. (1998). Water and population dynamics in a rural area of Tumkur District, Karnataka State. *161*, 235-61A.,

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## Reverse Osmosis Waste Management

Adham, S. et. al. (2007). Dewatering Reverse Osmosis Concentrate From Water Reuse Applications Using Forward Osmosis. Water Reuse Foundation, Alexandria, VA.

This report discusses the lack of effective disposal solutions for concentrate waste in inland areas. The report reviews several larger scale options such as evaporation ponds and deep-well-injection, but then focuses on Forward Osmosis as an option for minimizing concentrate volume. Advantages of FO include lower electrical requirements and lack of pump usage and maintenance, while disadvantages include the need for better membrane technology and more complicated chemical processes

Berent, L. et. al. (2012). Water for All: Sustainable solutions for reducing and utilizing Sarvajal's Reverse Osmosis brine in Northwestern India. Retrieved from University of Michigan, Department of Natural Resources and the Environment website: http://deepblue.lib.umich.edu/handle/2027.42/89963.

This is the University of Michigan/Sarvajal Water for All report discussed in more detail in the Reverse Osmosis section of the report (see page 25).

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Escobar, I. & Schafer, A. (2010). Sustainable Water for the Future: Water Recycling versus Desalination. Elsevier B.V, Amsterdam, The Netherlands.

This report discusses methods for increasing RO process efficiency and reusing concentrate waste. Options discussed include using a secondary RO system to help concentrate brine coupled with a solids separator to enable the solid concentrate to be sent to a landfill. The authors state that in order to reuse concentrate salts, a market for the salts produced must exist and the RO system must be able to separate different types and qualities into purified salts. The report also discusses additions and alternatives to RO including capacitive deionization, thermal separation, freezing separation, and Forward Osmosis.

Ghosh, P.K. (n.d.). Reverse Osmosis: India. Central Salt and Marine Chemicals Research Institute (CSMCRI).

The publication outlines the most successful methods of integrating water treatment into rural Indian communities. The article also suggests nonconventional power sources for RO membranes (e.g., animal labor) and compares costs between these methods and traditional RO membranes, which depend on unreliable electricity supplies. Another major challenge is explaining the technology to locals and the authors note caution must be used when attempting to implement chemical purification methods due community distrust

Lauer, W. (2006). Desalination of Seawater and Brackish Water. American Water Works Association, Denver, CO.

This report addresses the need in the United States of finding alternative water treatment methods because of environmental regulations that limit waste discharge to surface waters. The report discusses the option of disposing waste to sewers but cautions that the effectiveness of this approach depends on sewer treatment capacity. There is also a discussion detailing how increasing RO efficiency leads to elevated concentrations in the effluent concentrate and additional fouling of membranes.

Saleth, M. R. (1996). Water institutions in India: Economics, Law, and Policy. Commonwealth Publishers, New Delhi.

This source discusses in detail the history of water institutions in India, mostly from an economic perspective. Important characteristics of Indian water laws are mentioned in reference to communal and property rights, religious values of water, and dynamic legal structures.

Sethi, S. et. al. (2006). Existing and Emerging Concentrate Minimization and Disposal Practices for Membrane Systems. Claremont, FL: Florida Water Resources Journal. Retrieved from: www.fwrj.com/TechArticle06/0606%20FWRJ%20tech1.pdf

This report presents an overview and some details regarding a wide range of methods for both increasing the efficiency of the RO process and properly disposing or reusing the concentrate. The report discusses the general background difficulty (economic, regulatory, and political) of finding inland disposal or reuse applications and the importance of increased efficiency. It also lists issues with increased efficiency such as additional scaling of equipment and higher electrical costs. This is a US-centric discussion, but some examples may be applicable in India.

Shannon, M.A., Bohn, P.W., Elimelech, M., Georgiadis, J.G., Mariñas, B.J., & Mayes, A.M. (2008). Science and technology for water purification in the coming decades. *Nature* 452, 301-310.

This source is a comprehensive overview of water purification issues facing communities in the coming decades that outlines positives, negatives, and uncertainties associated with disinfection, decontamination, re-use and reclamation, and desalination technologies. Dozens of methods are discussed by the authors, making this article a very useful reference.

## GIS Data and Tools – Ghana

Abavana, C. G. (n.d.). *Electricity Access Progress in Ghana*. Presented by Noxie Consult.

Table 1 in this report shows electricity access rates by region as of 2010. This data is important for site selection.

”Africa Infrastructure Knowledge Program. (2011). *ARC GIS Map Files*. Retrieved from

http://www.infrastructureafrica.org/documents/tools/list/arcgis-shape-files?page=4.

This ArcMap data library, which is affiliated with the African Development Bank Group, includes layers on the Ghana Electricity Transmission Network (medium and high voltage lines > 10 kv), Ghana power plants (total generating capacity > 10 Mw), and Ghana roads (includes highways and other arterial roads). Our team used each of these layers, which can help Safe Water Network assess the accessibility and suitability of potential sites.

Apambire, W. B., Boyle, D. R., & Michel, F. A. (1997). Geochemistry, genesis, and health implications of fluoriferous groundwaters in the upper regions of Ghana. *Environmental Geology*, *33*(1). Retrieved from http://link.springer.com.ezproxy.cul.columbia.edu/content/pdf/10.1007%2Fs002540050221.

This journal article presents detailed data on fluoride and many other parameters for a small portion of Upper East Region of Ghana. Fluoride levels are of particular concern this far north in Ghana. Averages and a map of sites are provided. The article lacks exact coordinates, but it may be possible to use averages to assign contaminant levels for the entire study area. However, caution should be used as fluoride deposits depend on underlying geological formations so using this method may yield results of varying accuracy.

Armah, F. A., Luginaah, I., & Ason, B. (2012). Water Quality Index (WQI) in the Tarkwa Gold Mining Area in Ghana. *The Journal of Transdisciplinary Environmental Studies*, *11*(2). Retrieved from http://www.journal-tes.dk/vol_11_no_2_page_19/no%201%20Frederick%20A%20Amah2.pdf.

This study focuses on the Tarkwa mining area in Ghana's Western Region. The study provides a wide range of parameters, latitudes, and longitudes of groundwater sampling locations, making this data usable albeit for a small area. Many of the other studies cover the eastern and northern portions of the country, so this data from western Ghana could be helpful. Also, WQI scores are very high here, meaning contaminant levels are significant. The results imply that further investigations of contaminant levels surrounding current or past mining areas would be very useful.

Banoeng-Yakubo, B., Yidana, S. M., Emmanuel, N., Akabzaa, T., & Asiedu, D. (2009). Analysis of groundwater quality using WQIs and conventional graphical methods: the Volta region, Ghana. *Environmental Earth Sciences*. doi:10.1007/s12665-009-0082-9.

This examination of groundwater quality in the Volta Region overlaps with some of the other attached studies and was included because Table 6 provides a list of communities and their respective

WQI scores. Each community received a WQI score in the "Excellent" category so the Volta data are less relevant for Safe Water Network 's site selection. However, WQI methodology is described in detail in this article and will be useful for Safe Water Network.

Banoeng-Yakubo, B., Yidana, S. M., & Nti, E. (2009). Hydrochemical Analysis of Groundwater Using Multivariate Statistical Methods - The Volta Region, Ghana. *KSCE Journal of Civil Engineering*, *13*(1), 55–63. doi:10.1007/s12205-009-0055-2

The groundwater hydrochemical analysis covers the northern Volta Region. Identifiable community names are given for a couple dozen sites, but site-specific data is only provided for silicate weathering, carbonate weathering, and precipitation rather than our principal contaminants of interest. The sites were grouped together into three main clusters using Hierarchical Cluster Analysis. Average values of pH, and fluoride and chloride ion parameters are given for the clusters but not the specific sites. The underlying data with relevant parameters for each site would be helpful for a GIS tool, but Dr. Yidana could not be reached despite multiple tries. One possibility would be to simply assign each of the participating communities the average parameter values for their overarching clusters, though this would yield relatively crude data.

Cobbina, S. J., Nyame, F. K., & Obiri, S. (2012). Groundwater Quality in the Sahelian Region of Northern Ghana, West Africa. *Research Journal of Environmental and Earth Sciences*, *4*(4), 482–491.

The authors present findings from a groundwater study in the Sawla-Tuna-Kalba district of the Northern Region. The article contains mean, range, and standard deviation of pH, turbidity, total dissolved solids, arsenic, fluoride, chlorine, and a number of other parameters. However, these parameters are only given for the entire district rather than for specific sites/villages within the district. The article contains decent district-wide data, though more refined site selection would require obtaining the underlying coordinates for this research.

Ghana Community Water & Sanitation Agency

We contacted Emmanuel Gaze, Director of Technical Services, whose name we were given by Vida Duti from International Water and Sanitation Center, and posted on the organization's website, but did not receive a response.

Ghana Public Utilities Regulatory Commission. (2008). *Public Utilities Regulatory Commission Annual Report 2008*. Retrieved from http://www.purc.com.gh/purc/sites/default/files/annualreport8.pdf

Pages 25-29 show region-wide water quality data for pH, Cl, and *E. coli* regarding treated water. These parameter medians, ranges, and percentages of compliance levels can be used as proxies for the variation in water infrastructure by region. Although some of these data could be helpful, they should not be confused with pre-treatment groundwater or surface water quality readings.

Ghana Statistical Service. (2013). *Data request page*. Retrieved from http://www.statsghana.gov.gh/DataRequest.html.

The Ghana Statistical Service is an autonomous, independent public service that provides national surveys, including the census, economic, and social statistics relating to the country. This is the single biggest source of census data in Ghana and will be a crucial source of relevant GIS data Attempts were made to request relevant data from the 2010 census, but the service has a formal data request process and did not respond.  It may be more helpful to contact the Statistical Service in person to request access to census data. Population data for individual municipalities would greatly assist Safe Water Network's site selection process.

Ghana Water Resources Commission. (2011). *Water Resources Commission Annual Report 2011*. Retrieved from http://doc.wrc-gh.org/pdf/WRC%20Annual%20Report%202011.pdf.

Page 54 lists surface WQI ratings for locations throughout Ghana. Ghana's WQI (WQI) in this report appears to be different than the international WQI used in some of the other scholarly articles reviewed. Latitudes and longitudes are not provided, but this may be discerned individually via additional search. Page 12 lists the entities that have provided technical assistance to the Ghana Water Resources Commission (WRC). The most notable contribution here seems to be that of the Canadian International Development Agency (CIDA), which helped build a database on water quality for three regions in northern Ghana. James Racicot from CIDA responded to our correspondence and put us in touch with Enoch Asare from WRC. After multiple attempts, Enoch Asare responded, notifying us that the data from this project would be made available for Safe Water Network 's site selection tool. However, he has yet to follow up on our reply with the specific water quality parameter requests.

Hijmans, R. (2013). *Free Spatial Data*. Retrieved from DIVA-GIS: http://www.diva-gis.org/Data.

DIVA-GIS is a service that provides free spatial information for use in mapping. Our team used several basic layers, including administrative boundaries, population, roads, and inland water layers to help create our map of Ghana's population and electricity access. GIS shapefiles of land cover and elevation are also available for Ghana.

International Water and Sanitation Center.

We contacted Vida Duti, Ghana Country Director, who responded but did not have any relevant data.

Johnson, A. (2013, March 22). *Water resource quality*. Retrieved from http://www.eawag.ch/forschung/qp/wrq/index.

Eawag is a world-leading water sector research institute based in Zurich, Switzerland. The institute combines a wide range of natural and social scientists, allowing widespread research on water issues globally. Our contact point in Eawag, Dr. Annette Johnson (annette.johnson@eawag.ch), currently works on modeling risk of geogenic contaminants in drinking water. She has expressed keen interest in discussing a potential data study in Ghana as part of Eawag's future plans. A follow-up is required to discuss the details of this proposition.

Kortatsi, B. K., & Jorgensen, N. O. (2001). *The Origin of High Salinity Waters in the Accra Plains Groundwaters*. Essaouira, Morocco: First International Conference on Saltwater Intrusion and Coastal Aquifersó Monitoring, Modeling, and Management. Retrieved from http://www.olemiss.edu/sciencenet/saltnet/swica1/Kortatsi-Jorgensen-paper.pdf.

This paper, written by two scientists from the University of Ghana and University of Copenhagen, contains groundwater quality parameters from 17 different boreholes in the Greater Accra area. Village names are listed as the locations and parameters include pH, chloride, fluoride, and conductivity. Latitude and longitude are not provided, but a handful of coordinates could likely be discerned by village name. Other location names are ambiguous. Given the year of publication, this data may no longer be reliable. Furthermore, the report concludes conductivity (in this case, a measure of salinity) varies significantly within close ranges, such as the Accra Plains area. This finding suggests that large-scale interpolation of salinity values (and perhaps other contaminants) is untenable.

McIntosh, A. (2012, August 17). Graduate Student Maps Fluoride Contamination in Rural Ghana. *Water & Wastes Digest*.

This article provides a synthesis of a project undertaken by Katherine Alfredo, a graduate student at the University of Texas at Austin, in rural Ghana. Intending to map the extent of fluoride contamination in the Bongo District of Ghana, Alfredo measured the pH and fluoride concentrations of several boreholes, recording the concentrations and coordinates of each. After reviewing the article, our team contacted Ms. Alfredo, who was unable to share her data because the findings have yet to be officially published. She has, however, shared her report with Safe Water Network and has asked it not be circulated.

Republic of Ghana, Ministry of Water Resources, Works and Housing. (2009). *Water and Sanitation Sector Performance Report*. Retrieved from http://wsmp.org/downloads/4d8ca15ec1a12.pdf.

Page 39 shows an overview of WQI rankings for two dozen surface water locations throughout Ghana. The source is the Water Resources Commission, which we attempted to contact without much success. Knowing how WRC compiled this quality index and latitudes and longitudes would be very helpful additions. Page 76 shows the percentage of rural communities covered by drinking water services by region. Although this information is very general, it can provide a rough idea of water service level in each region. Page 80 shows a similar graph for percentage of urban communities covered in each region. However, total coverage for urban is exactly the same as total coverage for rural, indicating the urban-rural distinction is unreliable.

Rural Water Supply Network. (n.d.). *Dgroups*. Retrieved 3 14, 2013, from http://dgroups.org/rwsn.

The Rural Water Supply Network's mission is to provide equitable access to safe and reliable drinking water in rural communities. In addition to providing scholarly resources, RWSN strongly emphasizes the importance of networking between global professionals and hosts online forums to facilitate the sharing of information. These forums specifically address the expansion of sustainable drinking water supply sources and technological tools for sustainable groundwater development. Our group posted on the discussion boards of the Sustainable Groundwater Development group and the Water Point Mapping group, and found the online community to be more than willing to provide additional contacts and resources for our project.

Smedley, P. (n.d.). *Arsenic in groundwater in Ghana*. Retrieved from http://www.csir-water.com/.

The British Geological Survey studied the water quality implications of gold mining in the Ashanti region in Ghana. The results of the study indicate that arsenic contamination has been exacerbated by mining pollution. Attempts were made to obtain the underlying data for GIS usage, but without success. The data seem to be of high quality so future inquiry would be worthwhile.

Smedley, P. (n.d.). *Fluoride in groundwater*. Retrieved from http://www.bgs.ac.uk/research /groundwater/health/fluoride.html.

Fluoride contamination is one of the biggest problems for groundwater consumption in Ghana. In a similar vein to the study of arsenic contamination, this study explores the extent of fluoride contamination in groundwater in East Africa. Attempts were made to contact Dr. Smedley for data for GIS use, but to no avail.

SNC-Lavalin and Universite du Quebec. (2006). *Hydrogeological Assessment of the Northern Regions of Ghana - Preliminary Assessment of Available Electronic Databases.* Retrieved from http://www1.ete.inrs.ca/pub/rapports/R000409.pdf.

This 2006 report presents a comprehensive review of available data on groundwater in northern Ghana. The findings in this article provided leads for our research efforts. However, many of the datasets referred to directly in the article were not suitable for our purposes.

U.S. Central Intelligence Agency. (2013). *The World Factbook: Ghana*. Retrieved from https://www.cia.gov/library/publications/the-world-factbook/geos/gh.html.

The CIA Factbook provides information on areas of conflict within a given country. Conflict districts in Ghana were denoted in one of our maps.

Volta Basin Authority. Germany Federal Ministry of Education and Research. (2013). *GLOWA Volta Project Geoportal*. Retrieved from http://131.220.109.2/geonetwork/srv/en/main.home.

The Global Change in the Hydrological Cycle (GLOWA) Volta Project seeks to analyze the geophysical and socioeconomic determinants of the hydrological cycle in the Volta Basin. The Volta Basin Authority comprises the six countries that lie partially within the basin including Ghana. The Project's Geoportal is a useful collection of different geographical data and our team used layers with geological and town data from the portal. The portal also contains several files that could be relevant to Safe Water Network 's site selection in Ghana, but these are not publically accessible. To pursue sharing requests, the appropriate contact information is linked to the metadata sections of these layers.

Water Research Institute *(WRI)*. (2011). Retrieved from http://www.csir-water.com/.

The Water Research Institute is one of 13 government-funded scientific research institutes in Ghana and has led and funded several studies on groundwater quality. In its objectives statement, the organization specifically mentions the desire to undertake commercialized water research, working with private and non-government partners. Further inquiries regarding available data are warranted.

WHO/UNICEF Joint Monitoring Programme (JMP), Water Supply and Sanitation.(2012). *Estimates for the use of improved drinking-water sources*. Retrieved from website: http://www.wssinfo.org/fileadmin/user_upload/resources/GHA_wat.pdf.

This comprehensive report details the evolution of drinking water coverage in Ghana and also provides census-centric water access statistics. Chief amongst these statistics is the proportion of population having access to improved water sources. The report contains other statistics on water access type, household access to piped water and other public health indicators. Unfortunately, the underlying data was not available for use in a GIS setting.

World Gazetteer. (2012). *Ghana: largest cities and towns and statistics of their population*. Retrieved from http://www.world-gazetteer.com/wg.php?x=1361938491&lng=de&des=wg&geo=-85&srt=npan&col=adhoq&msz=1500&men=gcis&lng=en.

This document contains extrapolated 2012 population data for the top 80 cities in Ghana using historical census data. We used this data as a polygon layer in our maps to help indicate areas of high and or dense population. Note that the smallest city on this list is >5,000 individuals and smaller cities (i.e., between 5,000-10,000) seem to be underrepresented. This is unfortunate given that many of the smaller towns would be potential Safe Water Network sites. The World Gazetteer does not provide adequate metadata or specify whether values apply to municipal boundaries or metropolitan/town areas. Thus, data from these layers, while potentially helpful, must be used with precaution.

Yidana, S. M. (2008). The hydrochemical framework of surface water basins in southern Ghana. *Environmental Geology*. doi:10.1007/s00254-008-1357-2

Yidana examines surface water (rather than groundwater) contamination levels in southern Ghana. Overall average parameters are provided, but without specific latitudes and longitudes so this report will not be particularly useful for our site selection tool. Yidana was contacted but did not respond.

Yidana, S. M. (2010). Groundwater Classification Using Multivariate Statistical Methods: Birimian Basin, Ghana. *Journal of Environmental Engineering*, *136*(12), 1379–1388.

This looks at relevant groundwater parameters for the Birimian formations of Ghana. Averages for the entire formation are provided, as are measures for four clusters obtained through Hierarchical Clustering. However, latitudes and longitudes of sites are not included. The country-wide geological formation map may be somewhat useful.

Yidana, S. M. (2011). Hydrochemical Characterization of Aquifers Using Sequential Multivariate Analyses and Geographic Information Systems in a Tropical Setting. *Journal of Environmental Engineering*, *137*(4), 258–272.

This journal article discusses groundwater throughout Ghana rather than in one particular region. Maps of major groundwater basins and geological formations are provided, though their resolution is likely too low to use them as layers for the GIS tool. Eight hundred and sixty six measurements for a number of parameters, including pH, chloride, and fluoride, were taken throughout the country. Summary data is provided for these measurements, but gaining access to the underlying data (with latitudes and longitudes) would be extremely valuable for the GIS site selection tool as this appears to be the most reliable, comprehensive collection of groundwater data on Ghana.

Dr. Yidana (smyidana@ug.edu.gh, yidanas117@gmail.com) was contacted multiple times, but our team did not receive a response. Hierarchical cluster analysis was conducted on all of the sites and groundwater parameter for each the 17 selected clusters are included in the report, but no information is provided regarding which specific sites/villages are within each of these clusters. Even a map of the 17 clusters would be very useful; our team would be able to assemble rough country-wide interpolations for pH, chloride, and fluoride. The article's conclusions are worth noting: mineral weathering dominates groundwater chemistry inland; seawater intrusion dominates in coastal areas; and effects of fertilizers and associated chemicals dominate in the Keta Basin and northern parts of the country where aquifers are shallow and agricultural use is high.

Yidana, S. M., Ophori, D., & Banoeng-Yakubo, B. (2008). Groundwater Quality Evaluation for Productive Uses— The Afram Plains Area, Ghana. *Journal of Irrigation and Drainage Engineering*, *134*(2), 222–227.

Yidana et al. explore fluoride contamination in the Afram Plains, the area west of Lake Volta. The authors used a Kriging interpolation to predict F levels at unmeasured location, the same method our GIS team would use. But while maps of the interpolations are provided, the underlying measurements that the interpolations are based off do not appear in the study. Again, our team did not receive a response from the author.

Yidana, S. M., & Yidana, A. (2010). An assessment of the origin and variation of groundwater salinity in southeastern Ghana. *Environmental Earth Sciences*. doi:10.1007/s12665-010-0449-y

The hydrochemical study of southeastern Ghana covers several of the major geological systems of the region including Voltaian aquifers, Keta Basin, Cape Coast granites, Upper Birimian, and Lower Birimian. Mean, median, standard deviation, and range are provided for measurements of these systems for a number of parameters. The article explains:

"Four distinct categories of groundwater have been identified: low salinity, low pH waters which have the tendency of leaching heavy metals, and are identified mainly among the Birimian and Togo series aquifers; low salinity, moderate pH waters which are suitable for most uses and identified mainly within the Voltaian and Buem aquifers; very high salinity groundwaters which are not suited for most domestic purposes on account of high concentrations of nitrate and fluoride, and identified among aquifers of the Keta Basin; intermediate salinity waters which consist largely of samples from the Keta Basin with minor contributions from the other terrains. The quality of groundwater deteriorates as salinity increases to extremely high levels toward the coast, largely due to seawater intrusion."

The broad geological system data could be somewhat useful as a very crude predictor of groundwater quality parameters. If equipped with suitable geological knowledge, Safe Water Network could use this data (or the geological data provided by GLOWA Volta) to select geological formations that typically coincide with poor groundwater quality in order to narrow down the site selection process.

## GIS Data and Tools - India

Center for International Earth Science Information Network (CIESIN), Columbia University, & Centro Internacional de Agricultura Tropical (CIAT). (2005). *Gridded Population of the World Version 3 (GPWv3): Population Density Grids.* Retrieved from http://sedac.ciesin.columbia.edu/gpw

DIVA-GIS. (2013). *India Country Level Data*.

Government of Andhra Pradesh Irrigation & CAD Department. (2010). *Water Resources Statistical Abstract, Andhra Pradesh*.

Government of India, Ministry of Home Affairs, Office of the Registrar General & Census Commissioner. (2011). *Census of India*. Retrieved from http://censusindia.gov.in/

Government of India, Ministry of Water Resources, Central Groundwater Board. (2010). *Ground Water Information System, Water Quality Data*. Retrieved from http://gis2.nic.in/cgwb/Gemsdata.aspx

Jagannadha, R. (1984). Government of India, Law Department. *The Andhra Pradesh Irrigation Utilisation and Command Area Development Act.* Retrieved April 12, 2013, from http://faolex.fao.org/docs/pdf/ind119056.pdf

Safe Water Network. (2013). *Safe Water Station Coordinates and Water Quality Measures*.

Schneider, A. (2013). Geocoder. *GPS Visualizer*. Retrieved April 1, 2013, from http://www.gpsvisualizer.com/geocoder/

# Appendix A: Additional Approaches to Water Safety and Security Plans

## International Organizations

**<u>1. Water and Sanitation Program (WSP)</u>**

**Location: Worldwide with a focus on rural India**
**Timeline: 2010-2012**

The Water and Sanitation Program (WSP) is a trust fund administered by the World Bank with the objective to improve water access and sanitation for the poor. WSP provides technical capacity and creates partnerships with governments to build capacity at the local level. Because WSP has worked extensively with the Indian government, reviewing their water safety and security policies and actions should be very helpful for Safe Water Network.

In 2010, WSP published the report *"Water Safety Plans for Rural Water Supply in India: Policy Issues and Institutional Arrangements,"* which presents the key principles of water safety planning in rural locations of India. Broadly, the report supports the Water Safety Plans approach (introduced by WHO and IWA) using it as background information for policy development recommendations. The main objectives of this report are (a) to examine policies to enhance drinking water quality, (b) to introduce a risk management framework for drinking water safety that can be incorporated to existing institutional frameworks, and (c) to suggest an implementation approach for policies and the risk management framework. The report discusses five key policies,, being the most important the implementation of Water Safety Plans as the basis of managing drinking-water quality. The other four emerge from adopting the framework of Water Safety Plans. The five key policies are:

1. <u>Adopting Water Safety Plans for drinking water</u>: This is ultimate goal and key policy issue. WSP recommends placing strong emphasis on good operational management strategies with controls based on risk assessment from source to consumption. Although sampling and analysis of drinking-water is important, it is not an effective way to control water quality in rural locations due to the lack of testing facilities and long waiting time for results of analyses.

2. <u>Establishing roles and responsibilities</u>: The successful establishment of roles and responsibilities depends on two key two parameters for the successful development of pilot studies into large-scale projects: planning coordination and training. Plans must be considered by the district authorities and then managed at the district level for logistical considerations. On the other side, training is critical for the implementation of Water Safety Plans and this parameter will be further examined in this report's Indian government section (page 13). The different roles required for framework implementation and possible responsibilities in India are presented in Table A1 on the following page.

3. <u>Water Safety Plans as a basis for investment</u>: During the development of Water Safety Plans improvements, several improvements at differences parts of the water supply chain will become apparent. Some of these improvements will require little or no funding, while others will require monetary investment. Water Safety Plans can be combined with technical and financial tools to identify information needed for an Operation Plan (i.e., a report that includes key operating functions, proposed staff and maintenance costs, and estimated finances), and a Service Improvement Plan (i.e., a summary of improvement measures, proposed remedies, estimated costs, and initial prioritization or timeframe for implementation).

4. <u>Setting performance targets to reflect health objectives</u>: According to a WHO study, the benefits from investment in water and sanitation in developing countries greatly exceed the costs. The study also concluded that establishing simple operational targets can achieve health improvements and provide a powerful support tool for evidence-based decision making.

5. <u>Policies on interventions</u>: Water Safety Plans for drinking water should also identify needed improvements at each stage of the supply chain. Examples of such imrpovements include better protection of resources, improved removal of microbial and/chemical contaminants, distribution system protection, and prevention of contamination in households.

WSP has also developed other documents in coordination with the Government of India. Notable reports include "Towards Drinking Water Security in India: Lessons Learned from the Field" and "A Handbook for Gram Panchayats," the latter of which includes guidelines for how to implement, operate, maintain, and manage drinking water security issues (see the "Government Strategies" section of this report for more information).

**Table A.1: Functions and possible organizational responsibilities for India (WSP, 2010).**

| Functions | Organization Level | | | | | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | National | State | District | Block | GP/ VWSC | State Training Institute | CBO/ SHG | NGO/ SO | |
| Overall policy guidelines, and standards | ✓ | | | | | | | | As per NRDWP and BIS10500 |
| Policies and programs | | ✓ | | | | | | | State policy including adoption of DWSPs |
| Incentive schemes | ✓ | ✓ | ✓ | | | | | | e.g., Sajal Gram Puraskar |
| Annual reporting on management of drinking water quality | | | ✓ | | | | | | DWSMs |
| Audit by states | | ✓ | | | | | | ✓ | NGOs could be given a role here |
| Planning coordination of DWSPs | | | ✓ | | | | | | Management of programs by DWSMs |
| Establishing current state of source water and delivered water as input to DWSPs | | | ✓ | ✓ | | | | | District and sub-divisional laboratories; BRCs should support |
| Training | | | | ✓ | | ✓ | | ✓ | SIRD, BRC, NGOs, and other SOs |
| Training on checks on operation of DWSPs | | | | ✓ | | ✓ | | ✓ | |
| Quality and health awareness training | | | | ✓ | | ✓ | | ✓ | |
| Management of water supply systems | | | | | ✓ | | | | GPs/VWSCs should contract a trained operator |
| DWSP preparation | | | | ✓ | ✓ | | | ✓ | BRCs support GPs/VWSCs |
| Conversion of DWSPs into operational procedures | | | | ✓ | ✓ | | | ✓ | This can also be the basis for operator contracts |
| Checking operation of DWSPs | | | | | ✓ | | ✓ | | Day-to-day checks on operational controls—does not involve analysis |
| Verification of drinking water quality | | | ✓ | ✓ | | | | | District and sub-divisional laboratories |

## 2. Global Water Partnership (GWP)

**Location: Maharashtra, Andhra Pradesh, India**
**Timeline: 2008**

Good stewardship of water resources is a key factor to water security. The Global Water Partnership (GWP) works with organizations throughout the world to establish water security through "development and management of water, land and related resources in order to maximize economic and social welfare without compromising the sustainability of ecosystems and the environment" (Global Water Partnership, 2008).

GWP strives to reach its goal of water security by focusing on the social, economic and environmental dimensions of development. The organization identifies water issues in specific countries by using a water matrix (Table A2) to position countries based on water stress severity and coping capacities (both financial and governmental). Once the identification process is complete, GWP works with national governments to establish Integrated Water Resources Management (IWRM) initiatives through Area Water Partnerships (AWPs). AWPs are local grassroots organizations that engage with local stakeholders and government officials to work towards alleviating water security issues.

**Table A.2: Global water security matrix developed by GWP for identifying areas of water stress (GWP, 2008).**

| Water Stress | Coping Capacity | |
|---|---|---|
| | LOW | HIGH |
| LOW | Low water stress/low coping capacity<br><br>Water security issues:<br>• Vulnerability to floods<br>• Pollution<br>• Increasing need for water and sanitation services (mainly to large cities)<br><br>Increasing water security through:<br>• Development of an appropriate stock of infrastructure (storage, flood control, etc.)<br>• Proper legislation and adequate institutions<br>• Integrated and comprehensive water planning | Low water stress/high coping capacity<br><br>Water security issues:<br>• Mitigate for past, present and future pollution<br>• Ecosystems need for water<br>• Legal frameworks ensuring access for all<br><br>Increasing water security through:<br>• Effective legal frameworks at a range of scales<br>• Economic incentives<br>• Ethical management |
| HIGH | High water stress/low coping capacity<br><br>Water security issues:<br>• Water demand growing fast<br>• Water availability falling to crisis level<br>• Overexploitation of groundwater<br>• Shortages compounded by pollution<br>• Low efficiency of irrigation<br>• Vulnerability to floods/droughts<br><br>Increasing water security through:<br>• Optimal mix of increasing supply and managing demand<br>• Strengthening the institutional capacities and adopting a more cohesive and integrated legal framework<br>• Developing appropriate mechanisms for intersectoral water allocation | High water stress/high coping capacity<br><br>Water security issues:<br>• Declining water resources<br>• Pollution abatement<br>• Environmental requirements<br>• Conflicts of use<br><br>Increasing water security through:<br>• Water conservation and reuse<br>• Sustainable policies and legal frameworks and institutions for water management and dispute prevention and resolution<br>• Strengthening waste water and pollution control through enforceable legal and institutional mechanisms |

Following are two specific examples of GWP strategies in India:

- The Puran River Basin in Maharastra, India has several problems though the most pressing issue is agricultural runoff increasing salinity, which affects over 300 nearby villages. To combat these problems, the Puran Area Water Partnership worked with local stakeholders to incorporate their needs and opinions into a water resource management plan. This collaboration enabled communities to identify better uses of brackish water (e.g., fish farming for additional income) and encouraged locals to use rainwater harvesting and less water intensive farming methods. Over time, the actions increased groundwater recharge rates, lowered groundwater harvesting, and ultimately reduced river water salinity in the region.

- Groundwater depletion is a major problem in India and severely affects the states of Andhra Pradesh, Karnataka, Maharashtra, Punjab, and Tamil Nadu. Since 2003 the Andhra Area Water Partnership has collaborated with local farmers to establish the Andhra Pradesh Farmer Managed Groundwater System Project (APFAMGS). Through this initiative, farmers are engaged in all aspects of the project from data collection and analysis to understanding the dynamics of groundwater. The farmers also create water budgets using the collected rainfall and groundwater data. By personally budgeting water usage and learning simple water saving techniques, groundwater usage has decreased while the long-term health of groundwater aquifers have improved. However, a downfall of this initiative is that the improvements have resulted from strict enforcement by the authoritative leadership of profit seeking farmers and not due to altruistic collective action, which makes the initiative harder to replicate across other regions.

## Indian Non-Governmental Organizations

**<u>The Centre for Excellence and Change's Community Change Management Group (CCMG)</u>**

**Location: Tamilnadu, South India**
**Timeline: February 2013**

Due to recurring droughts and dwindling groundwater resources, the southern Indian state of Tamilnadu faces acute water shortages most of the year. Local water prices have drastically increased and the local government is no longer able to provide water for the rural population. To find long-term solutions to these water problems, a group of engineers and officials from the Tamilnadu State Water Department founded the Centre of Excellence for Change and its Community Change Management Group (CCMG). CCMG is now mainly comprised of community volunteers and has spread to over 140 villages throughout Tamilnadu.

Under the CCMG program, democratization of water resources is used as a means of transferring water resource ownership from the local government to the village. The "change management" principle is a three phase strategy implemented by CCMG towards water security. Phase One is to change individual attitudes regarding accountability, responsibility and response to problems in order to improve these actions at the individual, organizational and community level.

After an initial introductory session, the CCMG program group identifies participants that will become core CCMG members in phase one of the program. These participants comprise of community panchayat members (i.e., the tribal leaders), women entrepreneurs, teachers and also experts from the Centre for Excellence and Change who act as consultants. Phase Two involves the education of community members through three-day workshops that explain how to calculate and budget local water resources. Through these workshops, village water managers can re-examine water resource usage in order to plan long-term water availability. Once this is complete, the community then learns resource conservation and management techniques for local water body maintenance. The next step is for the community to work with the regional chief engineer to develop a Joint Action Plan for maintaining and improving water resources.

Provided below in Figure A1 is a sample workshop plan provided by Centre of Excellence of Change. This provides a detailed breakdown of what is expected of the community in each phase of the program. It is good example of a structural approach to the water crisis in the region.

The program has increased water access, repaired water bodies, and improved water quality in several local districts. Moreover, agricultural practices have become less water intensive, more villages are adopting rain harvesting systems for drinking water usage, and groundwater recharge rates have increased. By educating locals to use water budget and management tools, CCMG has enabled communities to foresee and plan for their future water needs.

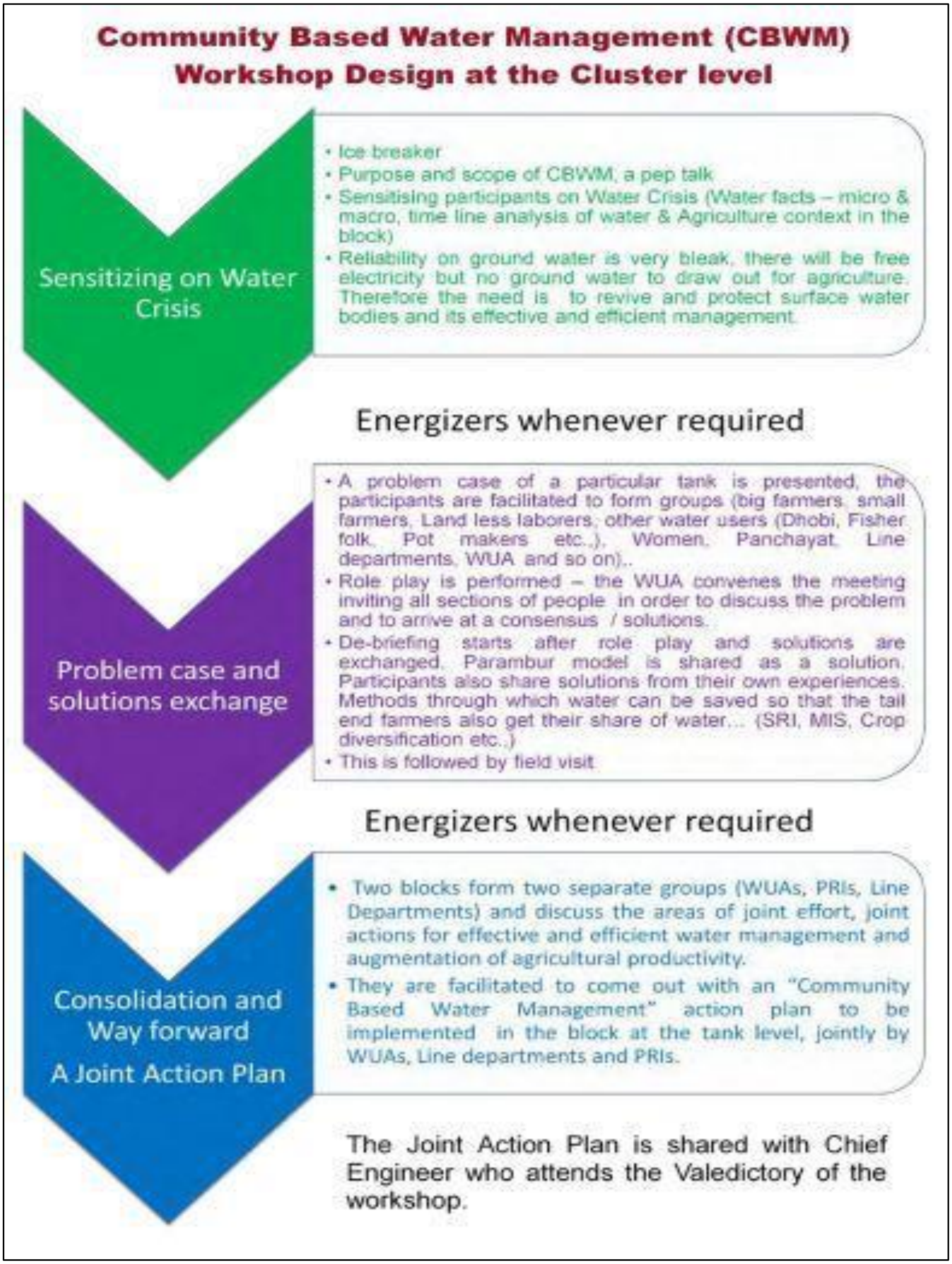



***Figure A.1: Community Change Management Group Workshop plan (Centre of Excellence for Change, 2013).***

**<u>Pratinidhi (meaning "representative" or "proxy")</u>**

**Location: Uttar Pradesh, North India**
**Timeline: 2012**

Pratinidhi is a civil society organization operating in both rural and urban areas of Uttar Pradesh in northern India. The group formed in 1993 and works to not only improve water quality problems for over 100,000 residents, but also the livelihoods of local farmers and women. Pratinidhi achieves the latter by working with farmers to encourage sustainable growing methods and with women to increase employment through teaching and building skills. The organization also promotes participation in local government decisions, which has caused increased community influence in environmental issues.

According to Pratinidhi, most water sources in India become contaminated by sewage and/or agricultural runoff and illnesses (e.g., Hepatitis A, diarrhea, intestinal worms, etc.) are rampant. To combat pollution and disease, Pratinidhi promotes Point of Use (POU) water purification methods while also raising awareness about the relationship between hygiene and health. The organization has targeted 52 slums in the Aliganj area of Lucknow, Uttar Pradesh and is currently using social marketing to raise funds for water purifiers. Additionally, community residents are applying for microloans from Pratinidhi and other independent groups so they can directly purchase the appliances and water treatment chemicals themselves.

Pratinidhi mainly uses two types of chemical treatment methods: Aquatabs and Safewat. Aquatabs are tablets that kill the microorganisms that cause cholera, typhoid fever, dysentery, diarrhea, and other water borne illnesses. These tablets have a shelf-life of 3 years (when stored in tubs) or 5 years (when stored in foil strips) and are composed of NaDCC(sodium dichloroisocyanurate). NaDCC is a compound that releases low concentrations of chlorine at a constant rate in order to safety and effectively treat water. Safewat, a water disinfectant composed of 0.5% sodium hypochlorite, is more commonly used but had to be redesigned to become more user-friendly. Originally, Safewat had a short shelf-life and required 13-14 drops per liter of water for effective treatment, which caused confusion amongst users. After reformulation, Safewat is now 2.5% sodium hypochlorite and requires only 1 drop per liter for treatment. USAID supports Pratinidhi's major projects, namely the Point-of-Use Water Disinfection and Zinc Treatment (POUZN) project and the POUZN Diarrhea Management project. The first project targets roughly 480 slums in Lucknow, Uttar Pradesh and aims to increase the use of POU water purification methods through self-help groups (SHGs). Although the size of these groups is not known, 67% of members were convinced to adopt chlorination techniques for water treatment and 27% of members regularly use POU devices. This is particularly notable because northern communities are traditionally very distrustful of chemical treatment methods, which is worsened when education is lacking. Pratinidhi credits its success to meeting with SHGs, individual group members, and individual households (i.e., door-to-door canvasing of neighborhoods) to discuss financing methods and sanitation education. Moreover, many of the canvasing members were doctors, aid workers, and volunteers already familiar with the area and knew many of the residents personally.

The POUZN Diarrhea Management Project uses completely different methods to promote zinc treatments and combat child diarrheal deaths. Each year an estimated 400,000 children younger than five years old die from diarrhea, which is in large part because doctors and chemists do not properly treat the illness. Pratinidhi calls and personally meets with over 150 doctors and chemists to promote zinc therapy and have convinced over 100 to prescribe zinc in diarrhea cases. This program is active in the Lucknow, Barabanki, and Lakhimpur Kheri regions.

**Gram Vikas (meaning "village development")**

**Location: Orissa, East coast of India**
**Timeline: 2011**

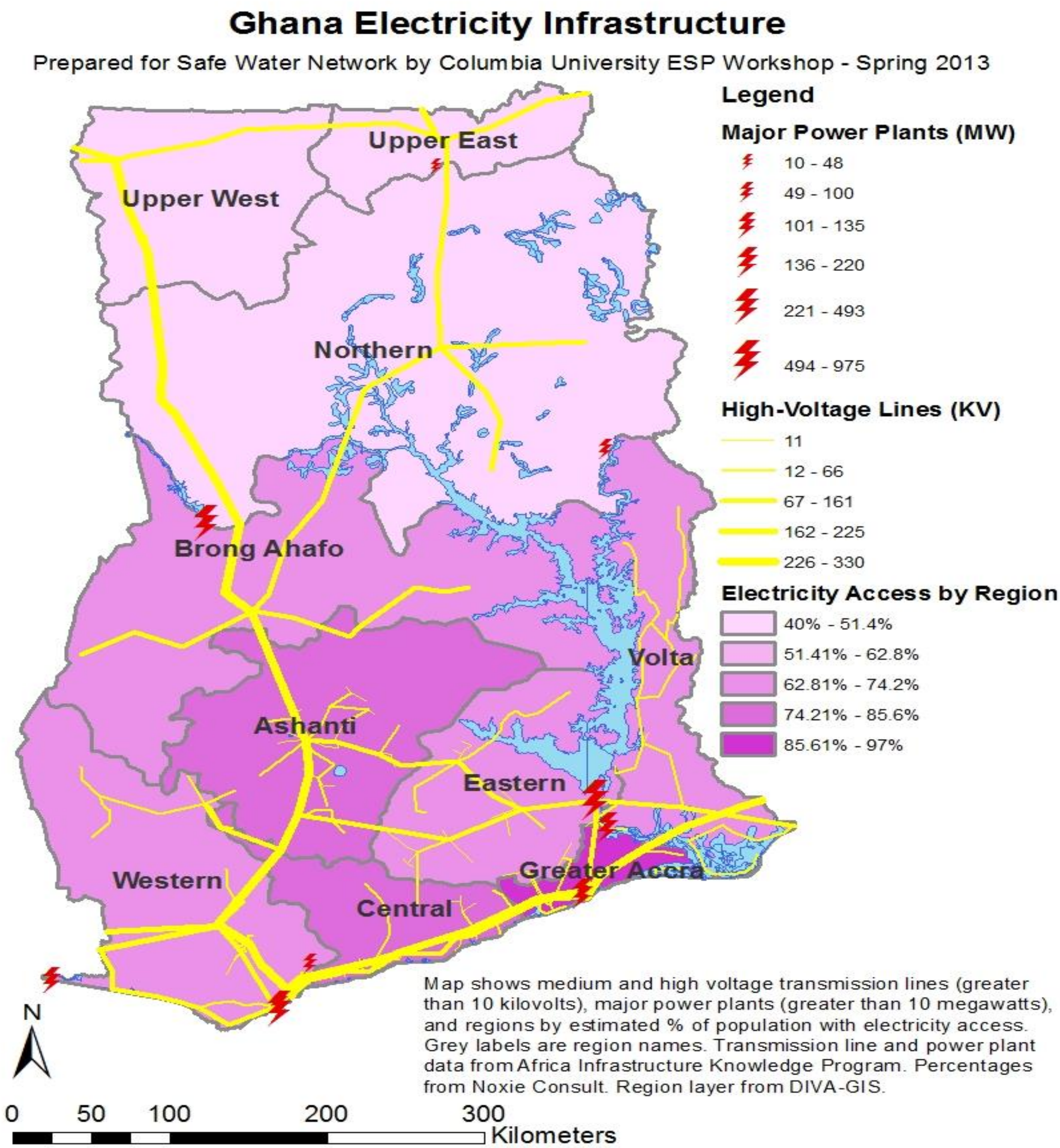
Founded by local students in the eastern Indian state of Orissa (Odisha), Gram Vikas trains communities to construct, manage, and maintain their sanitation facilities (e.g., toilets and water tanks). The organization specifically targets rural areas and works to provide clean drinking water and sanitation facilities in impoverished villages.

The group stresses the importance of sanitation and maintaining sanitation facilities separate from water sources and teaches community members to construct and manage sanitation facilities that use clean water piped from the community water tank. Community members create a core fund to finance these facilities and each household contributes roughly 1,000 Rupees for the sanitation system's maintenance and expansion.

Gram Vikas only operates in villages where all residents have agreed to contribute and participate in every stage of the project. After the entire village agrees to participate, the organization helps the community construct a water storage tank and identical sanitation facilities in each home. The water storage tank uses a gravity flow system to ensure water can reach homes even without electricity. The program has been successful in several communities and the newly adopted good hygiene practices have improved water quality and caused an 80% reduction in the frequency of waterborne diseases. Additionally, direct clean water access has eliminated water gathering as a chore for local women who now have extra time for other tasks or to even start small businesses for supplemental income.

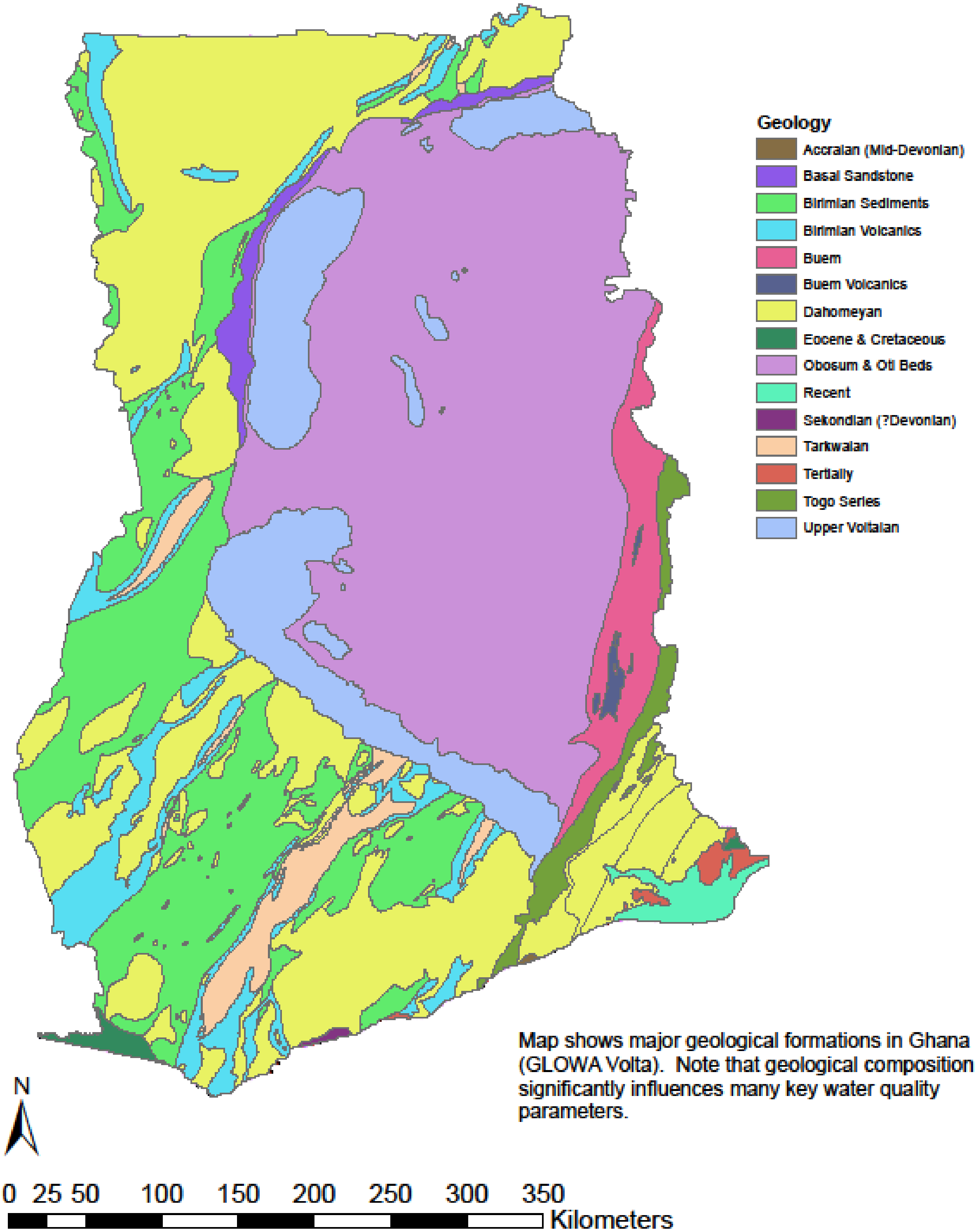
# Appendix B: Example GIS Maps for Ghana

The following series of maps were created as examples of the types of data that can be communicated about Ghana through GIS mapping:

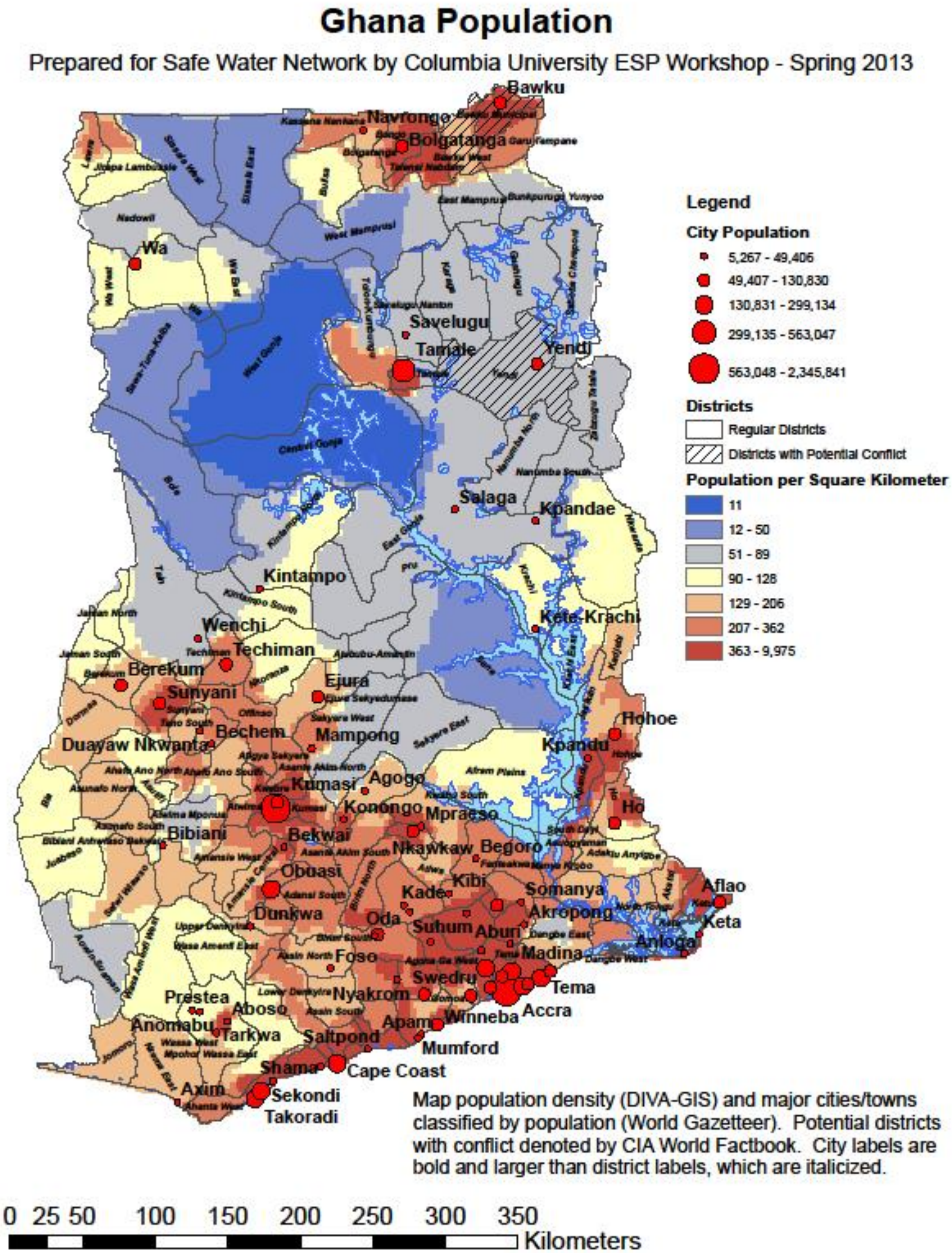


## Ghana Geological Formations

Prepared for Safe Water Network by Columbia University ESP Workshop - Spring 2013

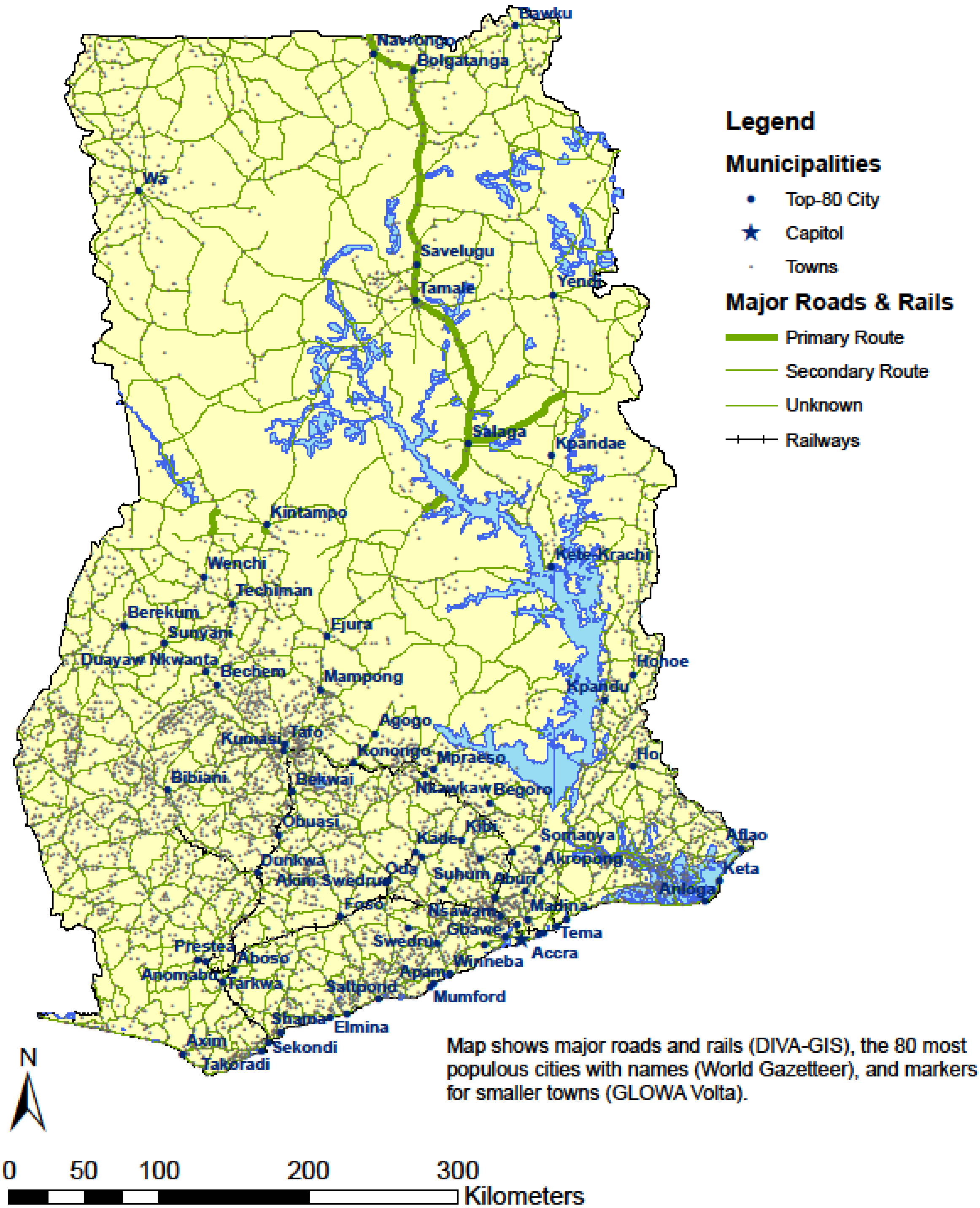



Map shows major geological formations in Ghana (GLOWA Volta). Note that geological composition significantly influences many key water quality parameters.


Ghana Population
Prepared for Safe Water Network by Columbia University ESP Workshop - Spring 2013
Legend
City Population
5,267 - 49,406
49,407 - 130,830
130,831 - 299,134
299,135 - 563,047
563,048 - 2,345,841
Districts
Regular Districts
Districts with Potential Conflict
Population per Square Kilometer
11
12 - 50
51 - 89
90 - 128
129 - 206
207 - 362
363 - 9,975
Bawku
Navrongo
Bolgatanga
Wa
Savelugu
Tamale
Yendi
Salaga
Kpandae
Kintampo
Kete-Krachi
Wenchi
Techiman
Berekum
Sunyani
Ejura
Bechem
Mampong
Duayaw Nkwanta
Hohoe
Kpandu
Kumasi
Agogo
Konongo
Mpraeso
Ho
Bibiani
Bekwai
Nkawkaw
Begoro
Obuasi
Kibi
Kade
Somanya
Aflao
Dunkwa
Oda
Suhum
Aburi
Akropong
Keta
Anloga
Foso
Madina
Swedru
Tema
Prestea
Nyakrom
Accra
Aboso
Winneba
Anomabu
Apam
Tarkwa
Saltpond
Mumford
Shama
Cape Coast
Axim
Sekondi
Takoradi
Map population density (DIVA-GIS) and major cities/towns classified by population (World Gazetteer). Potential districts with conflict denoted by CIA World Factbook. City labels are bold and larger than district labels, which are italicized.
0 25 50 100 150 200 250 300 350
Kilometers

## Ghana Roads, Cities, and Towns

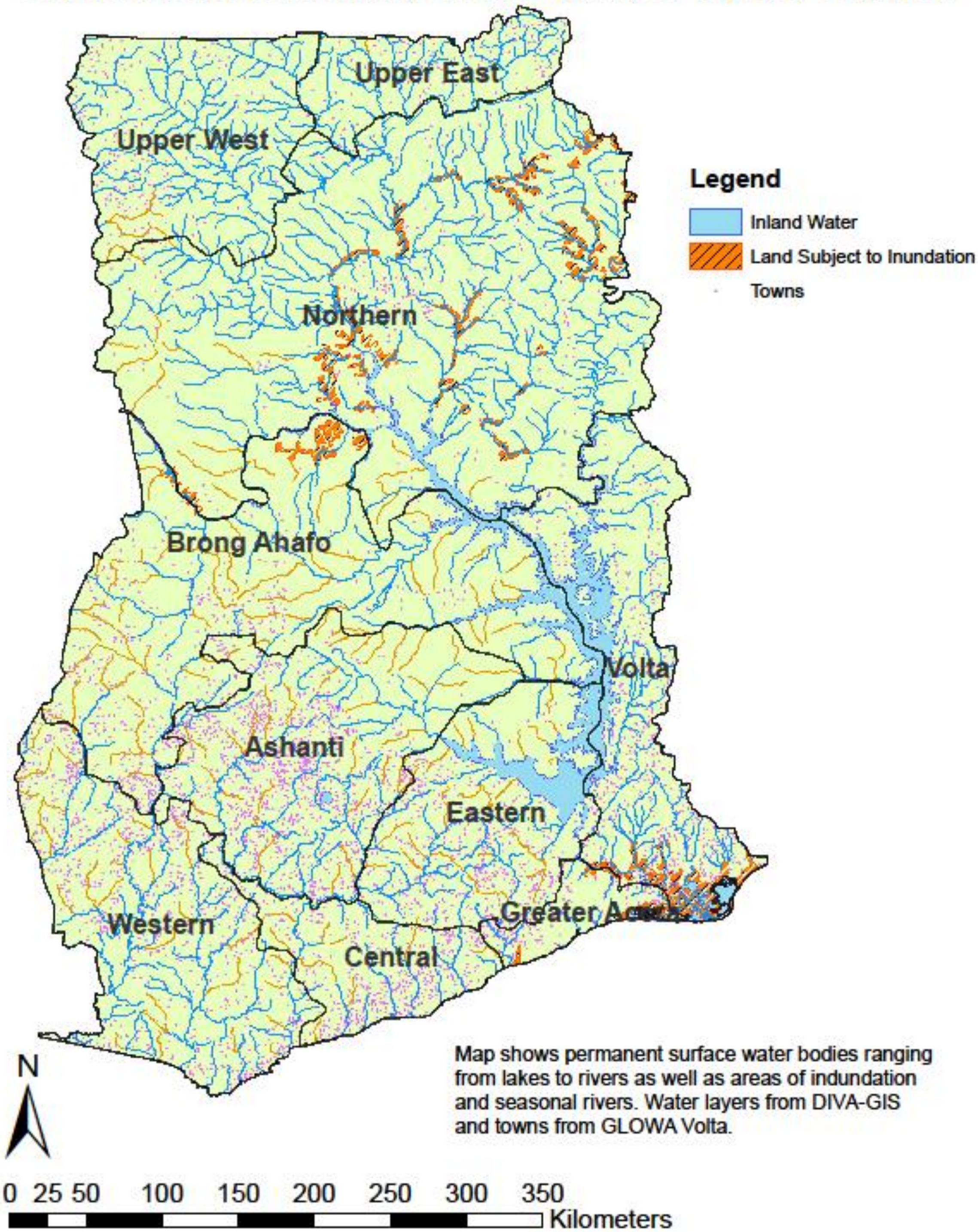
Prepared for Safe Water Network by Columbia University ESP Workshop - Spring 2013




Map shows major roads and rails (DIVA-GIS), the 80 most populous cities with names (World Gazetteer), and markers for smaller towns (GLOWA Volta).

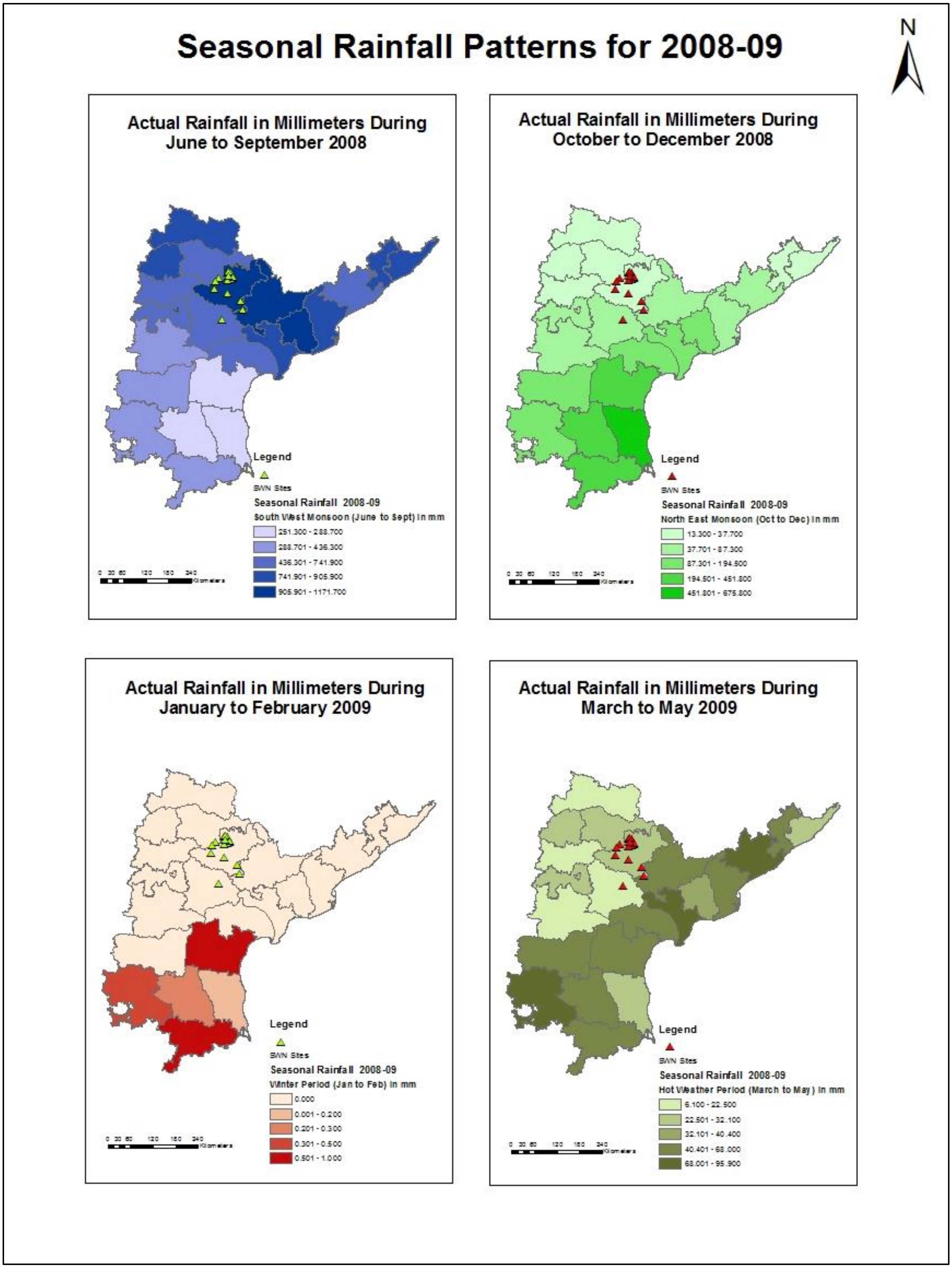
# Ghana Surface Water

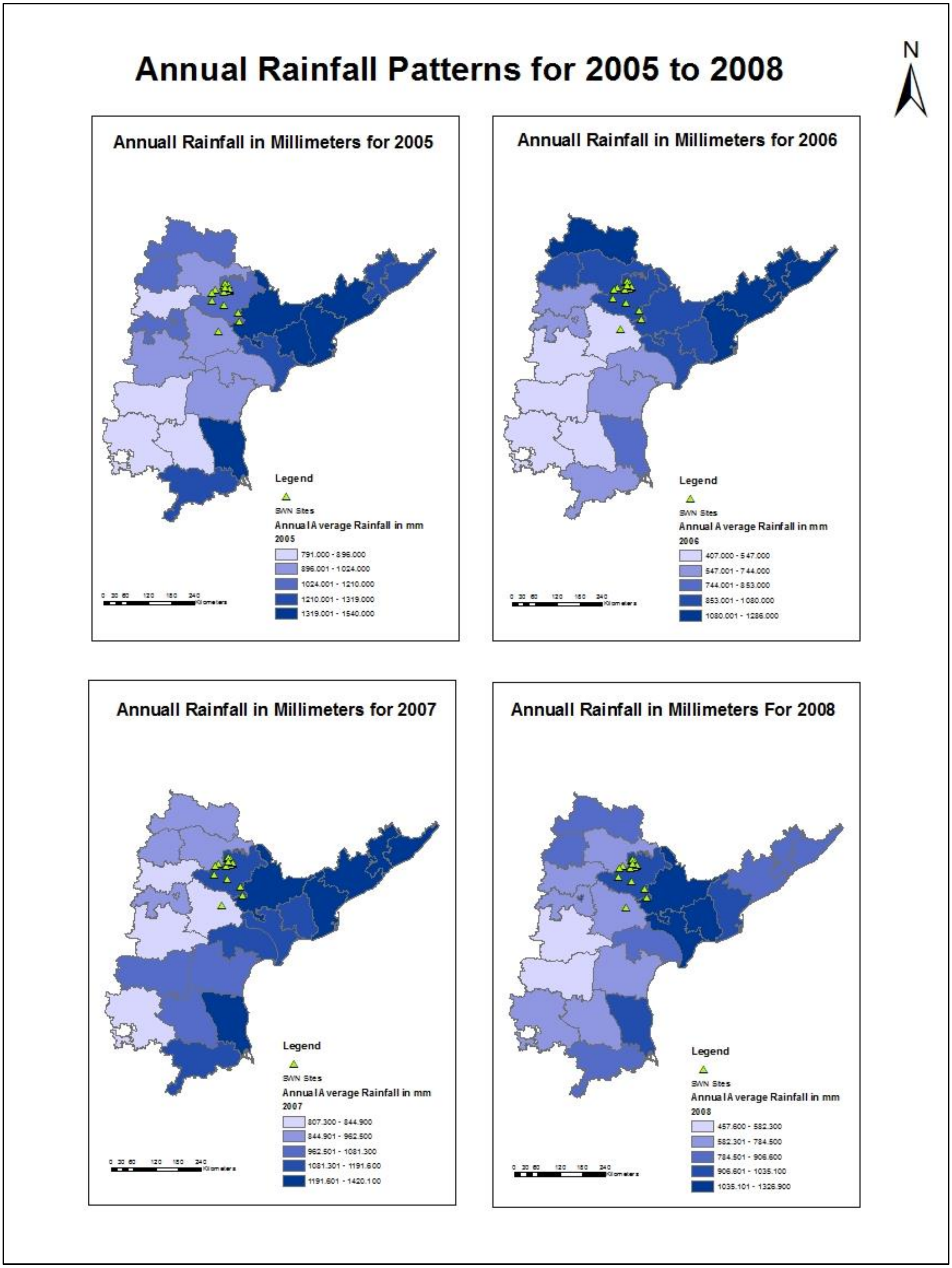
Prepared for Safe Water Network by Columbia University ESP Workshop - Spring 2013



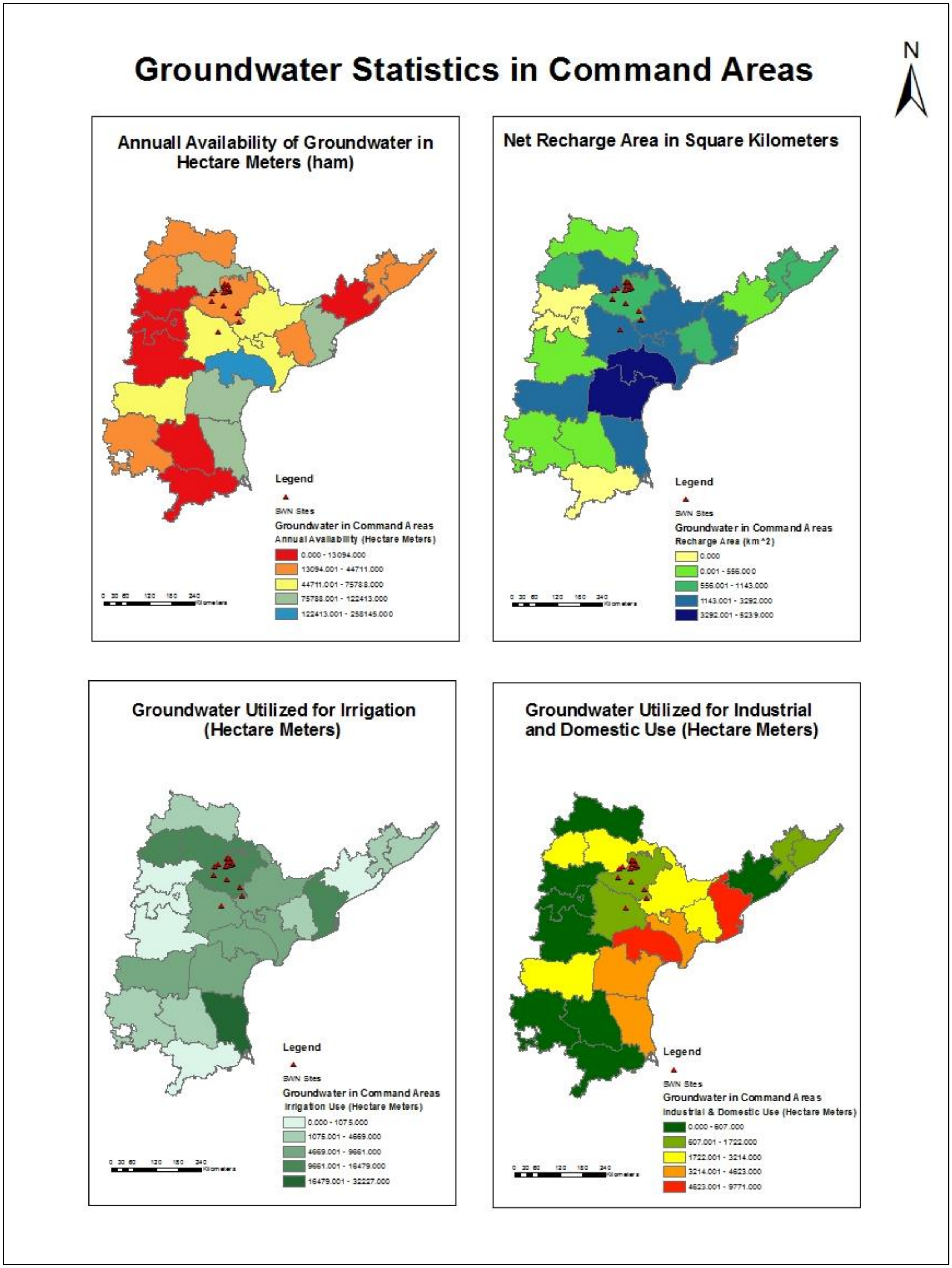
# Appendix C: Additional GIS Maps for Andhra Pradesh, India

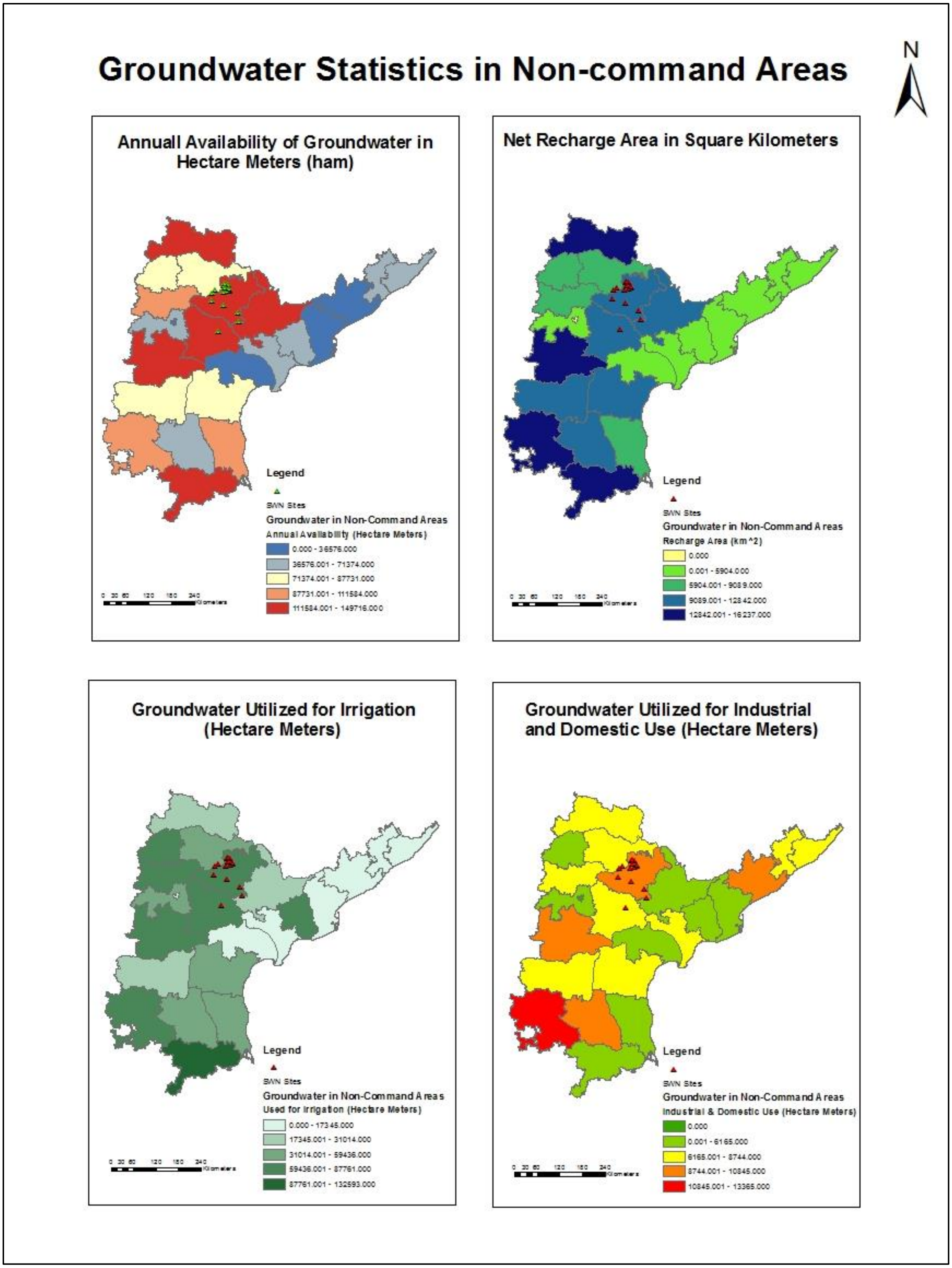
The following series of maps were created as examples of the types of data that can be communicated about India through GIS mapping:

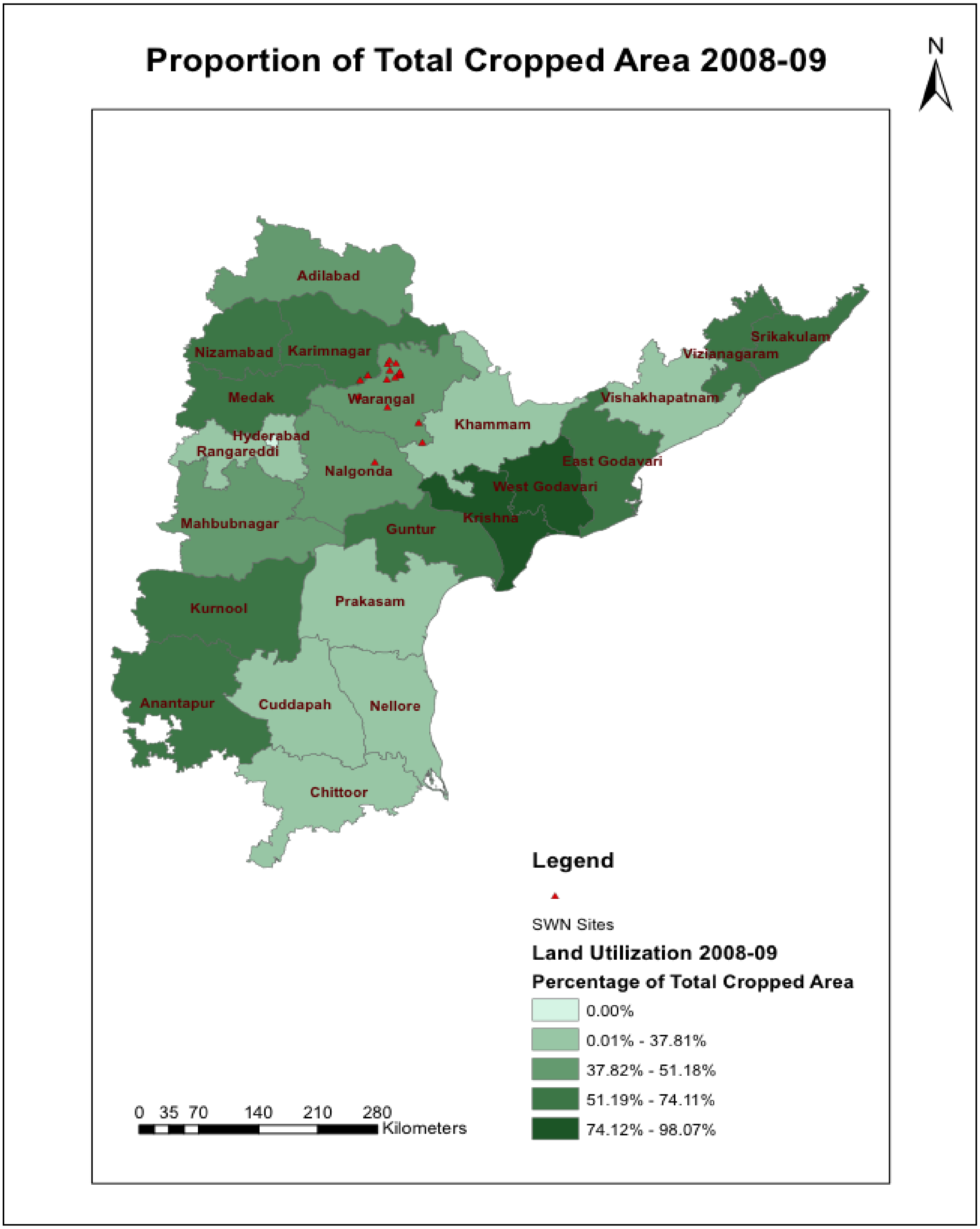

Seasonal Rainfall Patterns for 2008-09
N
Actual Rainfall in Millimeters During June to September 2008
Legend
SWN Sites
Seasonal Rainfall 2008-09
South West Monsoon (June to Sept) in mm
251.300 - 288.700
288.701 - 436.300
436.301 - 741.900
741.901 - 905.900
905.901 - 1171.700
Actual Rainfall in Millimeters During October to December 2008
Legend
SWN Sites
Seasonal Rainfall 2008-09
North East Monsoon (Oct to Dec) in mm
13.300 - 37.700
37.701 - 87.300
87.301 - 194.500
194.501 - 451.800
451.801 - 675.800
Actual Rainfall in Millimeters During January to February 2009
Legend
SWN Sites
Seasonal Rainfall 2008-09
Winter Period (Jan to Feb) in mm
0.000
0.001 - 0.200
0.201 - 0.300
0.301 - 0.500
0.501 - 1.000
Actual Rainfall in Millimeters During March to May 2009
Legend
SWN Sites
Seasonal Rainfall 2008-09
Hot Weather Period (March to May) in mm
6.100 - 22.500
22.501 - 32.100
32.101 - 40.400
40.401 - 68.000
68.001 - 95.900



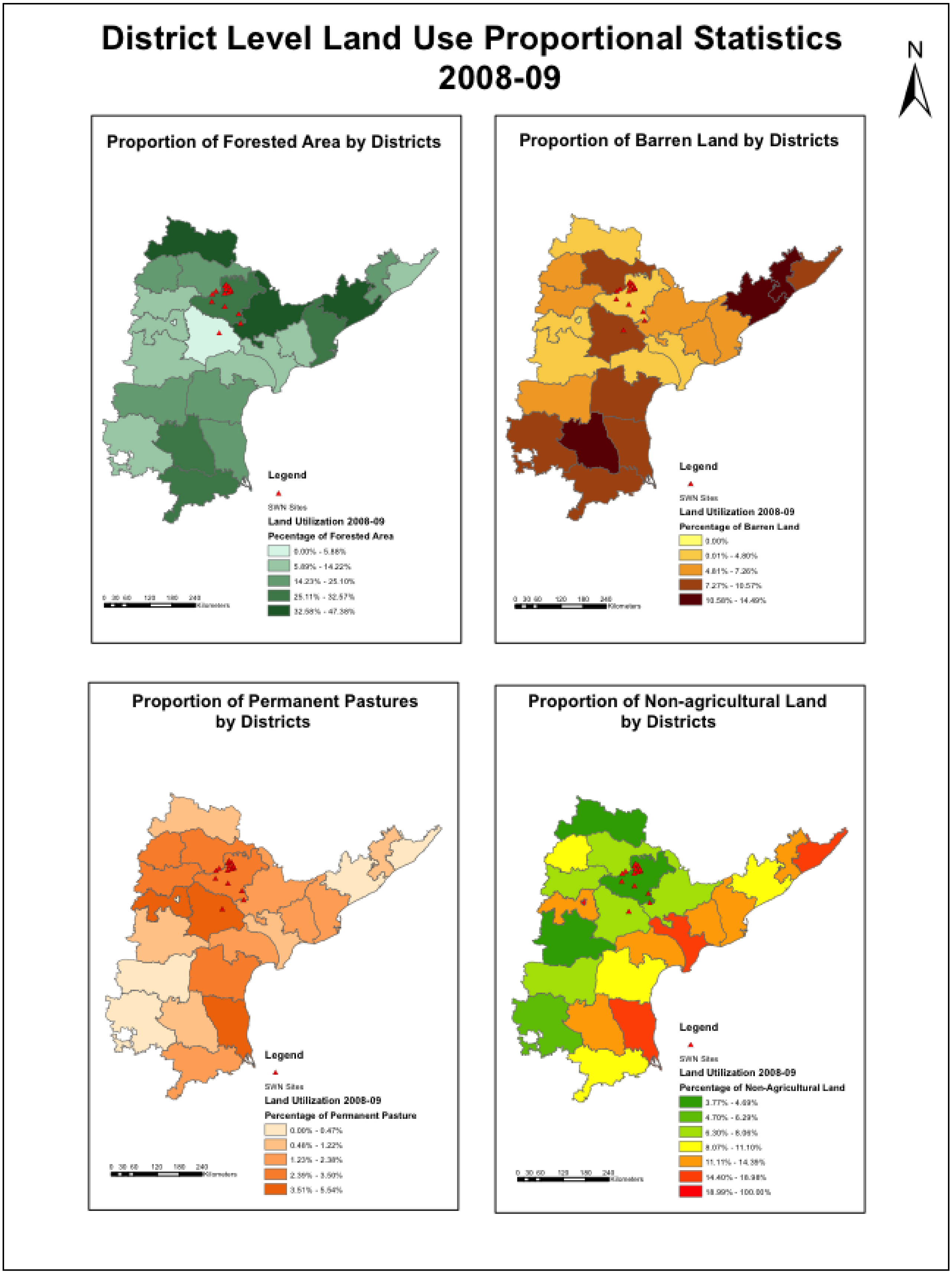
Annual Rainfall Patterns for 2005 to 2008
N
Annuall Rainfall in Millimeters for 2005
Legend
SWN Sites
Annual Average Rainfall in mm
2005
791.000 - 896.000
896.001 - 1024.000
1024.001 - 1210.000
1210.001 - 1319.000
1319.001 - 1540.000
0 30 60 120 180 240
Kilometers
Annuall Rainfall in Millimeters for 2006
Legend
SWN Sites
Annual Average Rainfall in mm
2006
407.000 - 547.000
547.001 - 744.000
744.001 - 853.000
853.001 - 1080.000
1080.001 - 1286.000
0 30 60 120 180 240
Kilometers
Annuall Rainfall in Millimeters for 2007
Legend
SWN Sites
Annual Average Rainfall in mm
2007
807.300 - 844.900
844.901 - 962.500
962.501 - 1081.300
1081.301 - 1191.600
1191.601 - 1420.100
0 30 60 120 180 240
Kilometers
Annuall Rainfall in Millimeters For 2008
Legend
SWN Sites
Annual Average Rainfall in mm
2008
457.600 - 582.300
582.301 - 784.500
784.501 - 906.600
906.601 - 1035.100
1035.101 - 1326.900
0 30 60 120 180 240
Kilometers


Groundwater Statistics in Command Areas
N
Annuall Availability of Groundwater in Hectare Meters (ham)
Legend
SWN Sites
Groundwater in Command Areas
Annual Availability (Hectare Meters)
0.000 - 13094.000
13094.001 - 44711.000
44711.001 - 75788.000
75788.001 - 122413.000
122413.001 - 258145.000
0 30 60 120 180 240
Kilometers
Net Recharge Area in Square Kilometers
Legend
SWN Sites
Groundwater in Command Areas
Recharge Area (km^2)
0.000
0.001 - 556.000
556.001 - 1143.000
1143.001 - 3292.000
3292.001 - 5239.000
0 30 60 120 180 240
Kilometers
Groundwater Utilized for Irrigation (Hectare Meters)
Legend
SWN Sites
Groundwater in Command Areas
Irrigation Use (Hectare Meters)
0.000 - 1075.000
1075.001 - 4669.000
4669.001 - 9661.000
9661.001 - 16479.000
16479.001 - 32227.000
0 30 60 120 180 240
Kilometers
Groundwater Utilized for Industrial and Domestic Use (Hectare Meters)
Legend
SWN Sites
Groundwater in Command Areas
Industrial & Domestic Use (Hectare Meters)
0.000 - 607.000
607.001 - 1722.000
1722.001 - 3214.000
3214.001 - 4623.000
4623.001 - 9771.000
0 30 60 120 180 240
Kilometers


Groundwater Statistics in Non-command Areas
N
Annuall Availability of Groundwater in Hectare Meters (ham)
Legend
BWN Sites
Groundwater in Non-Command Areas
Annual Availability (Hectare Meters)
0.000 - 36576.000
36576.001 - 71374.000
71374.001 - 87731.000
87731.001 - 111584.000
111584.001 - 149716.000
0 30 60 120 180 240
Kilometers
Net Recharge Area in Square Kilometers
Legend
BWN Sites
Groundwater in Non-Command Areas
Recharge Area (km^2)
0.000
0.001 - 5904.000
5904.001 - 9089.000
9089.001 - 12842.000
12842.001 - 16237.000
0 30 60 120 180 240
Kilometers
Groundwater Utilized for Irrigation (Hectare Meters)
Legend
BWN Sites
Groundwater in Non-Command Areas
Used for Irrigation (Hectare Meters)
0.000 - 17345.000
17345.001 - 31014.000
31014.001 - 59436.000
59436.001 - 87761.000
87761.001 - 132593.000
0 30 60 120 180 240
Kilometers
Groundwater Utilized for Industrial and Domestic Use (Hectare Meters)
Legend
BWN Sites
Groundwater in Non-Command Areas
Industrial & Domestic Use (Hectare Meters)
0.000
0.001 - 6165.000
6165.001 - 8744.000
8744.001 - 10845.000
10845.001 - 13365.000
0 30 60 120 180 240
Kilometers



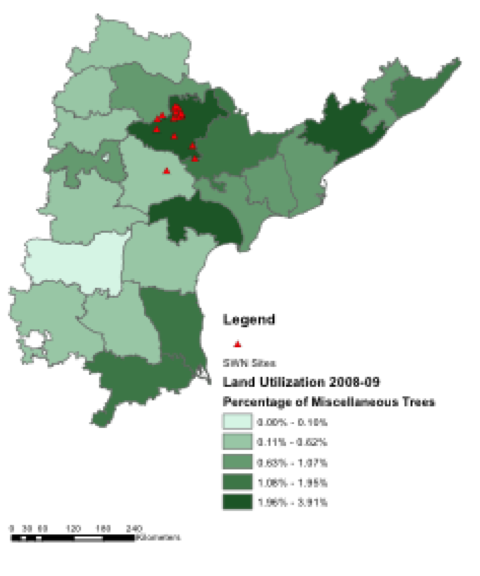
Proportion of Total Cropped Area 2008-09
N
Adilabad
Nizamabad
Karimnagar
Medak
Warangal
Hyderabad
Rangareddi
Nalgonda
Khammam
Mahbubnagar
Guntur
Krishna
West Godavari
East Godavari
Vishakhapatnam
Vizianagaram
Srikakulam
Kurnool
Prakasam
Anantapur
Cuddapah
Nellore
Chittoor
Legend
SWN Sites
Land Utilization 2008-09
Percentage of Total Cropped Area
0.00%
0.01% - 37.81%
37.82% - 51.18%
51.19% - 74.11%
74.12% - 98.07%
0 35 70 140 210 280
Kilometers



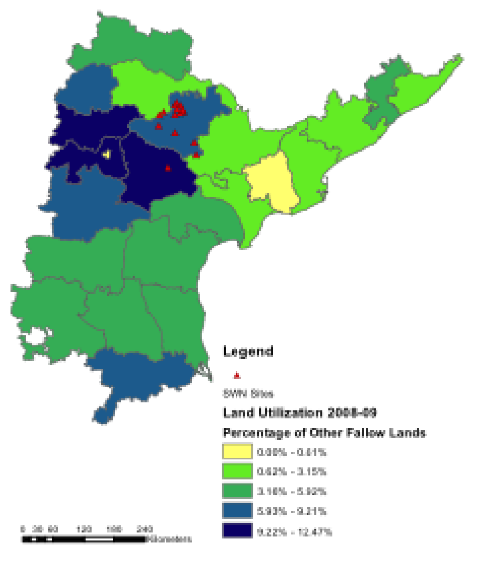
District Level Land Use Proportional Statistics
2008-09
N
Proportion of Forested Area by Districts
Legend
SWN Sites
Land Utilization 2008-09
Pecentage of Forested Area
0.00% - 5.88%
5.89% - 14.22%
14.23% - 25.10%
25.11% - 32.57%
32.58% - 47.38%
0 30 60 120 180 240
Kilometers
Proportion of Barren Land by Districts
Legend
SWN Sites
Land Utilization 2008-09
Percentage of Barren Land
0.00%
0.01% - 4.80%
4.81% - 7.26%
7.27% - 10.57%
10.58% - 14.49%
0 30 60 120 180 240
Kilometers
Proportion of Permanent Pastures by Districts
Legend
SWN Sites
Land Utilization 2008-09
Percentage of Permanent Pasture
0.00% - 0.47%
0.48% - 1.22%
1.23% - 2.38%
2.39% - 3.50%
3.51% - 5.54%
0 30 60 120 180 240
Kilometers
Proportion of Non-agricultural Land by Districts
Legend
SWN Sites
Land Utilization 2008-09
Percentage of Non-Agricultural Land
3.77% - 4.69%
4.70% - 6.29%
6.30% - 8.06%
8.07% - 11.10%
11.11% - 14.39%
14.40% - 18.98%
18.99% - 100.00%
0 30 60 120 180 240
Kilometers

# District Level Crop Land Use Proportional Statistics 2008-09

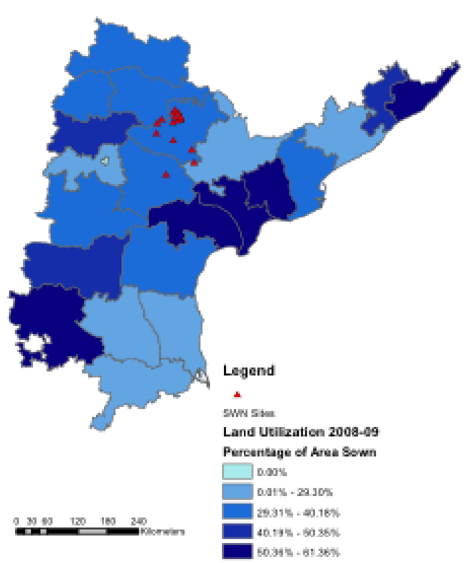
### Proportion of Land Covered by Miscellaneous Trees



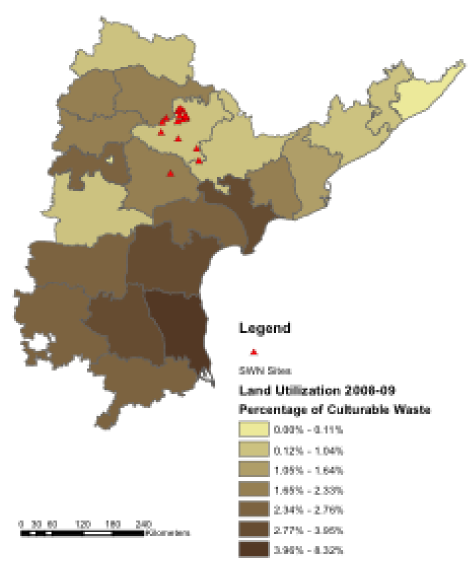

### Proportion of Other Fallow Lands by District

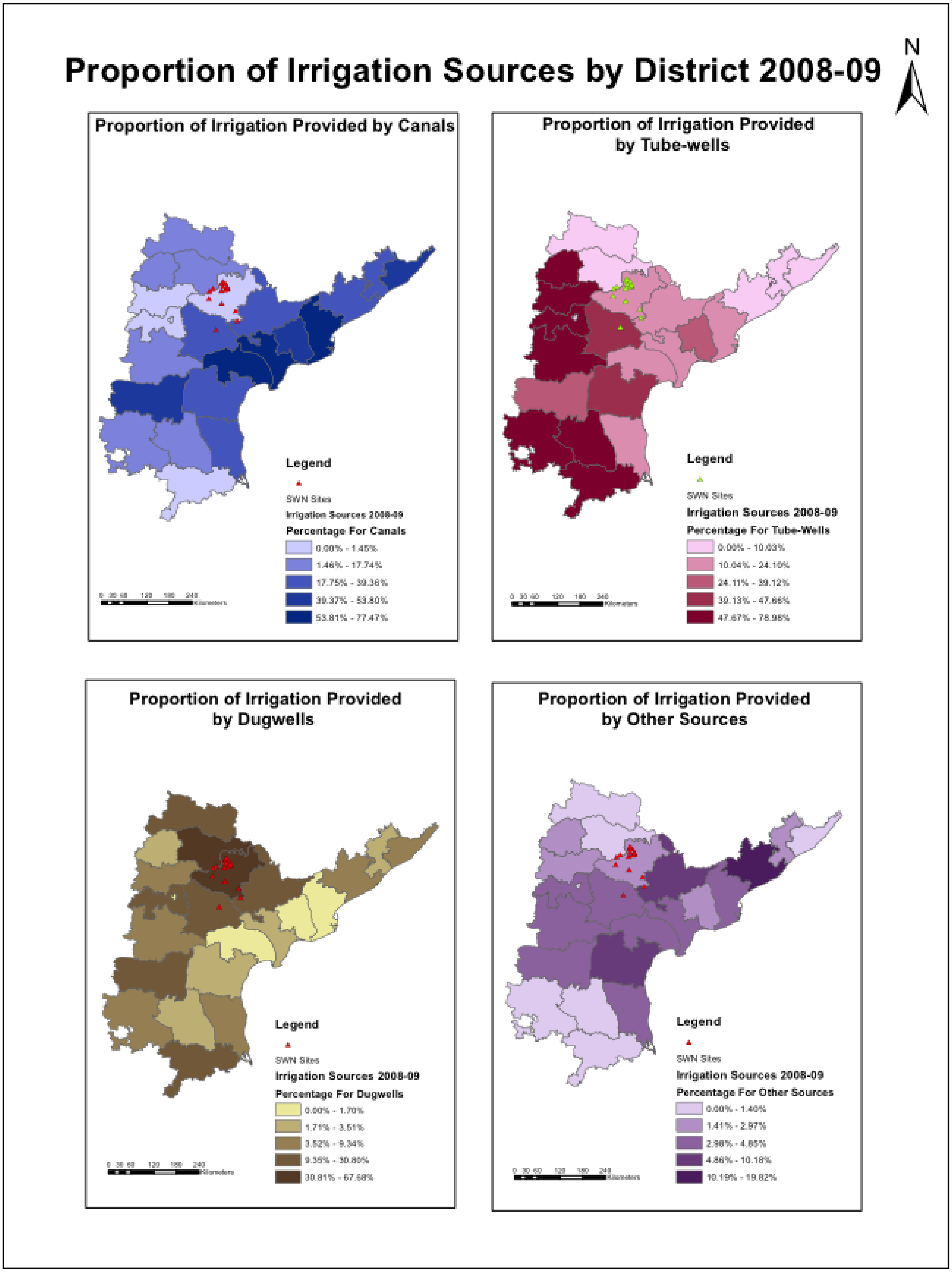


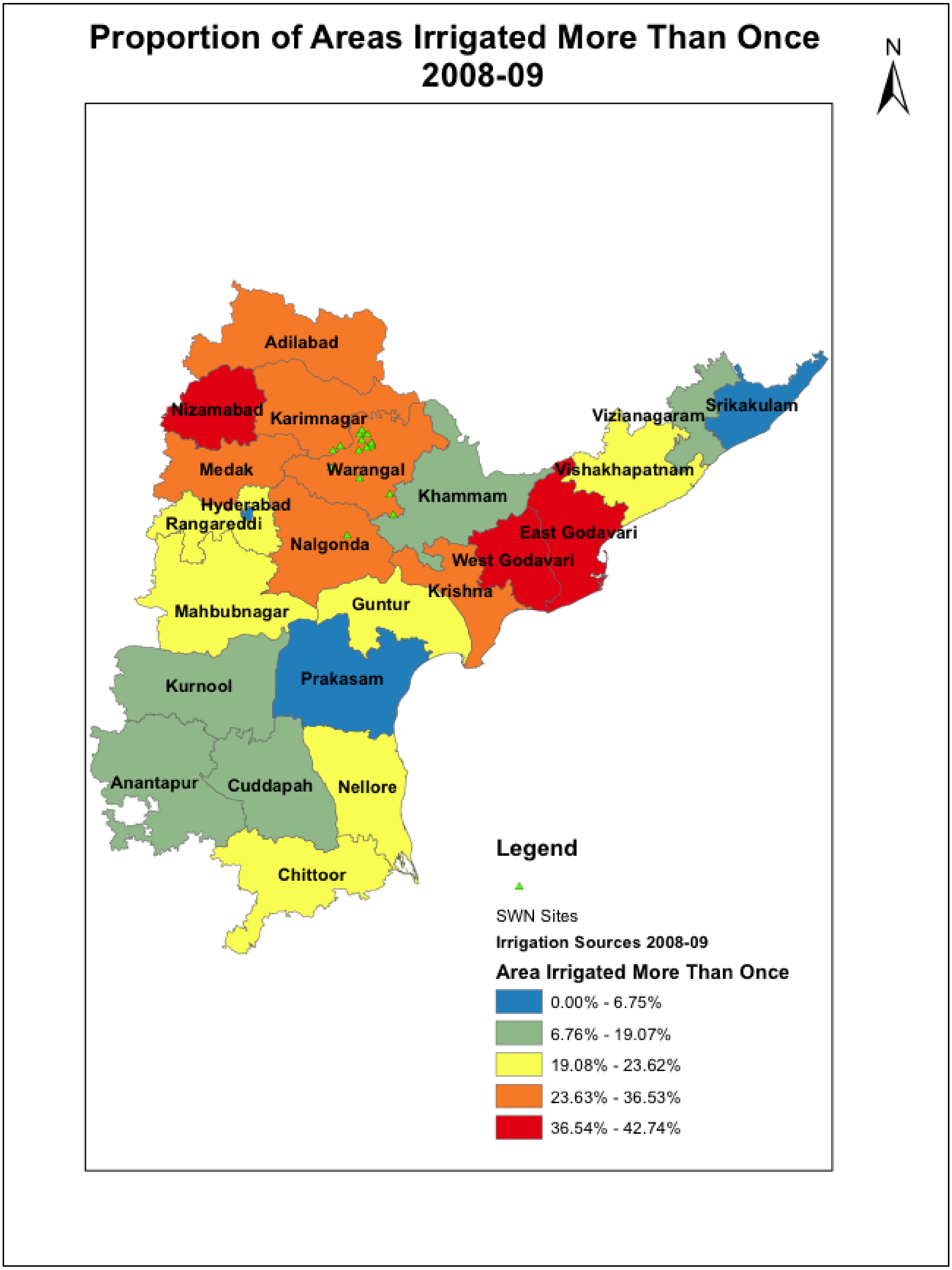

### Proportion of Land Area Sown by Districts




### Proportion of Land Consisting of Culturable Waste




Proportion of Irrigation Sources by District 2008-09
N
Proportion of Irrigation Provided by Canals
Legend
SWN Sites
Irrigation Sources 2008-09
Percentage For Canals
0.00% - 1.45%
1.46% - 17.74%
17.75% - 39.36%
39.37% - 53.80%
53.81% - 77.47%
Proportion of Irrigation Provided by Tube-wells
Legend
SWN Sites
Irrigation Sources 2008-09
Percentage For Tube-Wells
0.00% - 10.03%
10.04% - 24.10%
24.11% - 39.12%
39.13% - 47.66%
47.67% - 78.98%
Proportion of Irrigation Provided by Dugwells
Legend
SWN Sites
Irrigation Sources 2008-09
Percentage For Dugwells
0.00% - 1.70%
1.71% - 3.51%
3.52% - 9.34%
9.35% - 30.80%
30.81% - 67.68%
Proportion of Irrigation Provided by Other Sources
Legend
SWN Sites
Irrigation Sources 2008-09
Percentage For Other Sources
0.00% - 1.40%
1.41% - 2.97%
2.98% - 4.85%
4.86% - 10.18%
10.19% - 19.82%


Proportion of Areas Irrigated More Than Once
2008-09
N
Adilabad
Nizamabad
Karimnagar
Medak
Warangal
Hyderabad
Rangareddi
Nalgonda
Khammam
Vizianagaram
Srikakulam
Vishakhapatnam
East Godavari
West Godavari
Krishna
Guntur
Mahbubnagar
Kurnool
Prakasam
Anantapur
Cuddapah
Nellore
Chittoor
Legend
SWN Sites
Irrigation Sources 2008-09
Area Irrigated More Than Once
0.00% - 6.75%
6.76% - 19.07%
19.08% - 23.62%
23.63% - 36.53%
36.54% - 42.74%