SUSTAINABILITY OF COMMUNITY-BASED DRINKING WATER SYSTEMS IN DEVELOPING COUNTRIES

By

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Dedicated to my parents, grandparents, and teachers

ABSTRACT

A basic framework for sustainable community-based drinking water systems (CBDWS) is studied in this research program; it is based on the performance of existing water supply systems and on the responses to a survey by the various stakeholders. A model for overall sustainability was developed and validated through its application to about 70 CBDWS in rural settings of northern areas of Pakistan (as part of a developing country case study). In addition, analyses and scenario projections of environmental component of sustainability were made along with detailed analyses and syntheses of statistical surveys to gauge stakeholder perspectives and priorities and to incorporate the results in overall sustainability.

The study concluded that sustainable CBDWS can be developed and operated only with active participation of stakeholders (grouped by experience as technical, environmental, economic, social, and institutional). The system must maintain safe and drinkable water resources (environmental considerations) and also maintain the potential for renewability through technically optimized design, high quality execution and regular infrastructure maintenance in an economically beneficial and self-reliant set-up. Social and institutional involvement must also be an integral part of the system. Failure of any of these components can affect the sustainability of the entire system.

A relevant definition for sustainable CBDWS was formulated, along with the development of a new model for CBDWS sustainability. The model showed that properly maintained sources, proper infrastructure, aware society, stable economy, and effective institutions are linked components of a sustainable CBDWS, and failure of any of these components can affect the sustainability of the entire system. Scenarios for population that would be without access to improved drinking water in 2015 were also projected on the basis of the field studies. The field studies concluded that environmental sustainability in terms of capacity, quality, reliability and protection of drinking water sources is critical.

Projection of these findings to a broader level shows that unless urgent measures are undertaken, serious "fallbacks" may occur in the established Millennium Development Goals (MDG) of the United Nations. In the context of the relevant MDG, such fallbacks can reverse the situation to a previously unsustainable condition.

The stakeholder subjectivities and priorities for the various elements of CBDWS were examined and quantitatively incorporated into the system. The environmental and institutional components appeared as higher priorities among the various group stakeholders. The environmental component is a higher priority among stakeholders with natural sciences and engineering backgrounds, whereas institutional component (related to community institutions) is the foremost priority for stakeholders with social sciences backgrounds. Finally, for monitoring and evaluating CBDWS, a cost-effective and user-friendly applied framework capable of accommodating field data with varying levels of quality was developed.

RÉSUMÉ

Un cadre de base pour les systèmes d'eau potable communautaires durables (CBDWS) est étudié dans ce programme de recherche, il est basé sur la performance des systèmes d'approvisionnement en eau existantes et sur les réponses à une enquête menée par les différents intervenants. Un modèle de durabilité globale a été développée et validée par son application à environ 70 CBDWS en milieu rural des régions du nord du Pakistan (dans le cadre d'une étude de cas de pays en développement). En outre, les analyses et les projections du scénario de composante environnementale du développement durable ont été faites ainsi que des analyses et des synthèses détaillées des enquêtes statistiques pour évaluer les perspectives et les priorités parties prenantes et d'intégrer les résultats en matière de durabilité globale.

L'étude conclut que CBDWS durables peuvent être développés et exploités uniquement avec la participation active des parties prenantes (défini dans l'étude: techniques, environnementales, économiques, sociales et institutionnelles). Le système doit conserver des ressources en eau salubre et potable (considérations environnementales) et aussi de maintenir le potentiel de renouvellement grâce à une conception techniquement optimisé, l'exécution de haute qualité et un entretien régulier de l'infrastructure d'une manière économiquement avantageuse et autonomes set-up. L'engagement social et institutionnel doit également faire partie intégrante du système. Défaillance d'un de ces composants peut affecter la durabilité de l'ensemble du système.

Une définition pertinente pour CBDWS durable a été élaboré, avec le développement d'un nouveau modèle de durabilité CBDWS. Le modèle indique que les sources sont bien entretenus, infrastructures adéquates, la société consciente, une économie stable et des institutions efficaces sont des éléments nécessaires et liés d'une CBDWS durables, et l'échec de l'un de ces composants peut affecter la durabilité de l'ensemble du système. Scénarios pour la population qui seraient sans accès à l'eau potable en 2015 ont également été projetées sur la

base d'une étude de terrain. L'étude de terrain a conclu que la durabilité de l'environnement en termes de capacité, la qualité, la fiabilité et la protection des sources d'eau potable est essentielle. Projection des conclusions de l'étude sur le terrain à une plus grande échelle montre que si des mesures urgentes ne sont pas prises, solutions de repli graves peuvent survenir dans les Objectifs du Millénaire pour le développement établis (OMD) des Nations Unies. Dans le contexte des OMD pertinents, ces solutions de repli peuvent inverser la situation d'un état précédemment insoutenable.

Les subjectivités des parties prenantes et des priorités pour les différents éléments de CBDWS ont été examinés et quantifiable incorporés dans le système. Les composantes environnementales et institutionnelles sont apparues comme des priorités plus importantes entre les différentes parties prenantes du groupe. La composante environnementale est une priorité plus élevée chez les intervenants en sciences naturelles et en génie milieux, alors que composante institutionnelle (par rapport aux institutions communautaires) est la priorité pratique pour les parties prenantes avec les sciences sociales milieux. Enfin, pour suivre et évaluer CBDWS, un cadre appliqué rentable et convivial, mais bien définie et systématique capable de recevoir des données de terrain avec différents niveaux de qualité a été développé.

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ABBREVIATIONS / ACRONYMS

A/E	Academia/Education
AHP	Analytical Hierarchy Process
C/F	Consultancies/Field
CBDWS	Community-Based Drinking Water Systems
CBS	Community-Based Systems
CO	Community Organization
JMP	Join Monitoring Program
MCA	Multi Criteria Analysis
MDG	Millennium Development Goals
NU	National Unit
PU	Provincial Unit
DU	District Unit
SADC	Southern African Development Community
SPO	Service Providing Organization
UI	Umbrella Institutions
UN	United Nations
UNICEF	United Nations International Children's Emergency Fund
WCED	World Commission on Environment and Development
WHO	World Health Organization
WMO	World Metrological Organization
WSSD	World Summit on Sustainable Development

LIST OF DEFINITIONS

Aware society	A society aware of all water-related issues, including water use practices in environmental friendly manner, in terms of quality, quantity, and protection of sources
Access to clean drinking water	A minimum of 20 liters per person per day from a source within one kilometre of the person's dwelling
Community-based systems	A system managed by the community of consumers through community institutions such as the various community organizations
Community organization	An organization of consumers involved in the system at various levels of system development, including need identification, development of the required infrastructure, and its operation and management
Stakeholder	An individual or a group who may affect the system or is affected by the system
Maintained sources	Drinking water sources maintained for their quality and quantity around renewable capacity
Effective society	An aware society of consumer practicing better water usage practices and actively involved in the activities to manage a community-based system
Stable economy	An economy which is self-reliant for finances to manage a system and results in positive economic impacts on the society

CHAPTER 1. INTRODUCTION

Development of a basic framework for a sustainable Community-Based Drinking Water System (CBDWS) is a complex task, requiring input from vastly different fields. This study is aimed at developing the required information to enable further developments can assist with integration of the various components necessary for effective design of any infrastructure asset for sustainability.

1.1. INTRODUCTION

A majority (about 84%) of the world population without improved drinking water sources lives in rural areas (2010), and almost all of them are in developing countries. Consequently, this research program focussed on community-based drinking water systems (CBWDS) in rural areas of developing countries. A field study was conducted in a region, situated between latitudes 31.5º and 35º N of northern Pakistan, to examine the performance of CBDWS in a developing country. Another study was conducted to examine stakeholder priorities and subjectivities about sustainable CBDWS. Finally, an applied framework was developed to monitor, evaluate and, enhance the sustainability of CBDWS.

1.2. SIGNIFICANCE OF THE RESEARCH PROGRAM

Clean water is essential for healthy human life, and "human right to water is indispensable for leading a life in human dignity. It is a prerequisite for the realization of other human rights" (CESCR, 2003). Despite acknowledging this fundamental human right, about a billion people throughout the world are still living without sustainable access to safe drinking water, which results in a poor quality of life, pre-mature deaths and several socio-economic and environmental problems. According to the Pacific Institute Research Report (Gleick, 1998), this situation may lead to 135 million deaths due to water-related diseases by 2020. It should be noted that even if the Millennium Development Goals (MDGs) of the United Nations are achieved, as many as 76 million people could still die because of water-related diseases by the year 2020.

Concerns about universal access to safe drinking water have persisted and acknowledged even earlier than declaration of MDGs The UN had declared the 1980s the "International Drinking Water and Sanitation Decade" with the slogan "Water and Sanitation for All", aimed at achieving 100% worldwide coverage in water supply and sanitation by 1990 (Black, 1998). Fulfilling this goal would have required construction of new water distribution infrastructure for 1.2 billion people -- about 23% of the world population (WHO/UNICEF, 2010). These systems exist mostly in rural areas in developing countries; however, despite significant efforts, these goals were not attained. In 2000, the World Health Organization (WHO) estimated that about 1.1 billion people (21% of world population) still lacked access to safe water supply (Gleick, 2002). An MDG set in the UN Declaration of 2000 was to reduce by half the 1990 proportion (23%) of the world population without access to safe drinking water by 2015. This target was re–affirmed by the World Summit on Sustainable Development (WSSD) in 2002 (UN, 2005) with WHO declaring 2005–2015 as "the decade of water" to eventually have water and sanitation for all (Montgomery and Elimelech, 2007) .

Since the early 1990's, worldwide efforts to address water issues have been based broadly on the concept of *participatory approaches*, which involve effective participation of all stakeholders, including the members or representatives of the local community. This concept was promulgated through the 1992 Dublin International Conference on Water and the Environment (ICWE) and the 1992 Rio de Janeiro UN Conference on Environmental Development (UNCED): "Water development and management should be based on participatory approach, involving users, planners and policy makers at all levels" (WMO-UN, 1992). Although the concept was not new, it helped gain wider acceptance for various reasons, including the recognition of limited positive results of centralized management of water resources with various negative effects on resource management. This led to the development of a number of participatory models for all sorts of water resources management. Popularity of such models was especially noticed in areas where people were facing shortage of resources and discriminatory patterns of water allocation (SADC, 2002); however, this was not limited to drinking water only. Community-based drinking water systems (CBDWS) became the most common and popular frameworks to fulfill the goals of participatory approaches, especially in developing countries, where resources were limited and challenges were tougher due to the absence or ineffectiveness of governmental agencies, limitation of existing water sources, and inequality in social and economic conditions of various segments of the societies.

CBDWS were shown to be beneficial in resolving several complex local issues and disputes by reasonable sharing of the costs of execution and by creating awareness and a sense of ownership among the participants (Mujwahuzi, 2002). However, sustainability of CBDWS is being persistently debated around the question: *"Are these CBDWS sustainable?"*

1.3. RESEARCH PROBLEM

An answer to the question "Are such CBDWS sustainable?" is complex. The concept of sustainable development in the Brundtland Report of the World Commission on Environment and Development "Our Common Future"(WCED, 1987) received considerably wider acceptance; however, much work was required to convert the concept into meaningful measureable terms for achievement of sustainability and evaluation of progress towards this goal (WHO/UNICEF, 2012). As a consequence of the vagueness and ambiguity of the concept of sustainability, engineering studies and applications remain short of a coherent, philosophically appropriate, and meaningfully quantifiable definition of sustainability. Such a measureable definition requires criteria that are applicable to interdisciplinary and integrated approaches to simultaneously addressing problems stemming from engineering, environmental, and social sciences.

Lack of an appropriate definition of sustainable CBDWS, and of a framework to develop a suitable evaluation approach to judge the sustainability of any existing CBDWS, are wrought with uncertainties; there are serious concerns in the literature about the sustainability of the existing systems (examples presented in Table 4.1). Commonly reported achievements in the proportion of worldwide population without access to clean drinking water (e.g., UNICEF/WHO, 2012) are made without evaluating the sustainability of new and existing built systems. This impacts any developments negatively, and may lead to severe problems toward providing long-lasting and socially equitable. Consequently, the current practices may result in wastage of natural, financial, and human resources, which may in turn cause fatigue and frustration among the aid-providing organizations and the financial donors.

Also, the complexity of the situation in the field must not be underestimated. Firstly, the various stakeholders have widely varying backgrounds, which can lead to very different priorities towards sustainable systems. Consequently, the pace of achievements and the effectiveness of community institutions become questionable. Secondly, the continuous population growth, changing life styles, and changing climate often lead to local over-exploitation of the water resources. Such situations can cause conflicts and disputes, which are exacerbated by the increasing contamination of the existing water sources. The development of a framework to evaluate sustainability of CBWDS and to increase communications between stakeholders can be helpful.

1.4. Research Objectives

The main objective of this research program is to contribute to the development of a basic framework for sustainable CBDWS based on the performance of existing systems and involvement of the various stakeholders. Any detailed research program covering all aspects of the main objective would require multi-year interdisciplinary research activity. Consequently, specific objectives were set for this research program, as follows:

1. Developing a definition for sustainable CBDWS by reviewing the basic concepts of sustainability and participatory approaches, and to develop the essential components of a sustainable CBDWS;
2. Developing a model for overall sustainability of CBDWS, and validating the model through its application to an existing CBDWS;
3. Examining the environmental status linked with the CBDWS and possible impacts in light of the current situation;
4. Understanding the stakeholder perspectives by examining their priorities and subjectivities towards sustainability of CBDWS;
5. Presenting a proposed applied framework for monitoring, evaluation and, enhancement of sustainability of CBDWS.

1.5. Methodology

To achieve these objectives, two major studies were undertaken as follows:

1.5.1. FIELD WORK

The field study was performed in 70 rural communities in sub-mountainous regions of northern Pakistan, situated between latitudes 31.5 and 35° N; it included visits to the various CBDWS from the source to the consumer end, along with detailed interactions with the various service providing agencies, community organizations, and a detailed review of the available documents and reports. The detailed community surveys focused on five major aspects of sustainability of CBDWS: technical, environmental, economic, social, and institutional. This work was aimed at examining the existing systems, gathering the necessary data to validate the sustainability model, and to review the impact of the environmental components on the results achieved. Detailed methodologies are described in Chapter 3.

1.5.2. SURVEYS

Surveys were conducted to obtain stakeholder judgments about the different components and the relevant sustainability factors related to any CBDWS. The surveys were conducted on line, as well as, in the printed format. The results obtained from pair-wise comparison of the various components and factors were then synthesized by applying Multi Criteria Analysis (MCA), using the Analytical Hierarchy Process (AHP). The relevant details are presented in Chapter 3 and the printed survey questionnaire is reproduced in Appendix A.

1.6. THESIS ORGANIZATION

The first chapter (Introduction) is followed by the basic concepts related to sustainability, participatory approaches, and the Analytical Hierarchy Process (AHP) required for understanding and development of the needed frameworks in Chapter 2.

Chapter 3 presents the methodologies used for this study. It is described in two major sections: the methodology for field work (applicable to Chapter 4 and 5) and the methodology for surveys related to the stakeholders (Chapter 6). The common methodologies that would pertain to each manuscript were pooled together to minimize any redundancies and to avoid any duplication.

Chapter 4 deals with the overall sustainability of CBDWS. A model for sustainable CBDWS is presented and validated using the data gathered during the field study. Overall findings of the fieldwork are presented for technical, environmental, economic, social, and institutional aspects, along with the associated field observations and some additional information. Major improvements in the existing practices are recommended.

Chapter 5 examines the environmental aspects of sustainability of CBDWS, as measured during the field work for the 70 communities visited. It establishes the current situation and presents future scenarios for the possible impact of the lack of environmental sustainability on the long term attainments of the MDG for reduction of the world population without access to safe drinking water.

Chapter 6 examines the stakeholder perspectives and their subjectivities. It quantifies how different groups of stakeholders prioritize the various components of sustainability, where they mutually agree and disagree, and how their judgments can be synthesized in a systematic manner using AHP.

Chapter 7 proposes a preliminary applied framework for monitoring, evaluation and improvement of sustainability of CBDWS.

Chapter 8 presents the general conclusions from this study and the resulting recommendations. This chapter also explains the significance of this research and proposes the needed future research work.

Four appendices are also included at the end of the thesis, as follows:

Appendix A presents the questionnaire used in the fieldwork. In first part, the questionnaire is presented in English along with the summary results, while the second part has the questionnaire in Urdu language, which was used in the filed study.

Appendix B presents the survey questionnaire utilized for obtaining stakeholders subjectivities.

Appendix C summarizes the procedural details for estimation of weights for various elements of sustainability utilizing Analytical Hierarchy Process (AHP).

CHAPTER 2. LITERATURE REVIEW AND BASIC DEFINITIONS

[This chapter reviews and evaluates some of the basic concepts of sustainability, along with an examination of the conflicting interpretations and the current debates. The objective is to develop a definition of overall sustainability of CBDWS (Community-Based Drinking Water Systems) and an approach to evaluate it. Environmental sustainability of CBDWS is reviewed for its possible effects on such systems. The chapter also reviews the concept of participatory management approaches, stakeholders, multi-criteria analysis (MCA) required for synthesizing stakeholder subjectivity for a better understanding of stakeholder priorities. Finally, the framework for monitoring and evaluation of sustainability of CBDWS is discussed and the guiding principles for development of a holistic evaluation framework are described.]

2.1. SUSTAINABILITY AND ITS EVALUATION

2.1.1. SUSTAINABILITY

Sustainability (*noun*) represents the ability of a system to sustain, and the word sustainable (*adjective*) implies the capability of being sustained. Both words are derived from English verb "to sustain". The various English dictionaries trace this verb back to the late 13th century, and link it to a Latin verb "sustinere" (to uphold) as its origin, which came to English language via old French word "sustenir".

Based on the dictionary definitions, "sustainability" can be considered to be *an ability of something [which for our purposes may be considered a system] to continue to exist, maintain, and remain operational for an extended period of time [equal to or more than the design life] into the future without any significant interruptions, breakage or failure, resulting in improvement of the quality of] life by providing strength, energy, and hope [which we may refer to as resilience].*

2.1.2. DEFINING SUSTAINABILITY

It is difficult for engineering purposes to work with the abstract concept of sustainability because it is defined loosely and based on unquantifiable criteria. This problem is further exacerbated in engineering applications which have to deal with integrated and interdisciplinary approaches to resolving issues that are not only problems of engineering, but also of other disciplines (such as social sciences). An attempt is made to define sustainability in a philosophically appropriate, socially relevant, and adequately quantifiable manner for meaningful engineering applications. This exercise would be futile and superfluous without a consensus in engineering conventions on measureable criteria for relating sustainability as a construct in engineering applicable to social sciences. In the absence of such a consensus, it is important to develop a foundation for this construct.

The Brundtland Commission definition is considered by many as the most basic and most frequently quoted definition of sustainability. Despite several questions about these definitions, "it is a durable definition because it is flexible and open to interpretation"(Prugh and Assadourian, 2003). In fact, the Brundtland Commission definition of sustainable development was more of a concept than a definition, owing to abstract ideas of present and future needs, requiring definitions for the various contexts of application.

The concept of sustainability and sustainable development are commonly used as interchangeable terms. However, the former received much wider acceptance after the Brundtland Report "Our Common Future" of the World Commission on Environment and Development (WCED, 1987). The Brundtland Report noted that a development can be made sustainable by ensuring that "it meets the needs of the present without compromising the ability of future generations to meet their own needs". Since then, this concept has been adopted as a key element for sustainability, or sustainable development.

The concept of sustainability was promulgated and well taken during last three decades; however, this promulgation has led to considerable discussion. Some of the recent debates about the basic concept of sustainability and its attributes are reviewed briefly aimed at achieving clarity for developing a quantifiable definition for sustainable CBDWS, as follows.

2.1.3. Sustainability Attributes

Since 1987, several different definitions of sustainability have appeared in the literature along with the attempts to understand the concept for its application to practical life.

Costanza and Patten (1995) noted that misdirection in developing a definition for sustainability was due to the differences in opinion on "prediction of what will last, and of achieving consensus on what we want to last". In addition, the failure to account for "the range of interrelated time and space scales over which the concept must apply", which creates further difficulties in development of a clear definition. They concluded that sustainability cannot be *maintenance forever* as all systems have limited longevity. If system sustainability was supposed to have an infinite life span, nothing would be sustainable. Rather, a system is sustainable if it "attains its full expected life span within the nested hierarchy of systems [a meta-system] within which it is embedded" (Costanza and Patten, (1995). They provided the example of an individual human being considered sustainable in the earth meta-system, if he/she achieves normal life span. Factors causing a reduction in normal life span of a system component reduce sustainability of the system; for the human example, these factors could include various life-threatening diseases. A system can be considered to be sustainable if "it persists in nominal behavioral state" for a time equal to or more than its normal natural expected life, keeping in mind that the life span of a component can be different from that of the system. Therefore, sustainability cannot mean existence, continuation, or maintenance of each and every component of a system, or a sub-system for ever. The ASCE/UNESCO Committee (1998) noted that "the word sustainability implies continuance or maintenance", whereas development implies change. Therefore, sustainable development "can be viewed as maintenance of a positive rate of improvement." Again, "improvement involves change"; therefore, this provides an important base to understand that "continued existence [of something] is not a necessary condition for sustainable development". Periodic modifications of the systems are required to meet changing demands and conditions. Figure 2.1 summarizes this concept.

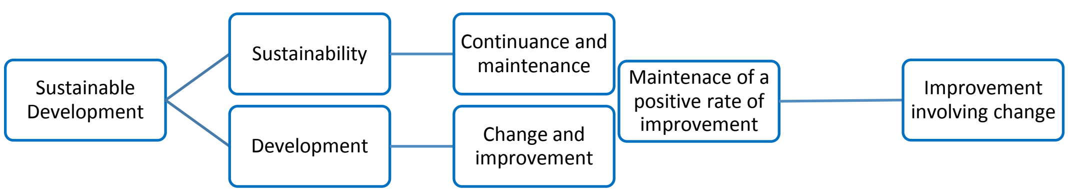


Figure 2.1 : Sustainable development

Any action to fulfill the demands at a given time by making improvements in any component or sub-system of an overall system should be considered a pro-sustainability action as long as it does not impair the environment and the capacity of the coming generations to meet their needs.

2.1.4. SUSTAINABILITY OF DRINKING WATER SYSTEMS

A joint task committee of the Division of Water Resources Planning and Management of the American Society of Civil Engineers (ASCE) and the International Hydrological Program of the United Nations Educational Scientific and Cultural Organization (UNESCO) has made a valuable contribution to define and develop suitable criteria for sustainability of water resources. They explored ways to use the concept of sustainability for evaluation of system performance and alternatives. The committee considered various aspects and delineated some principles before developing a definition for sustainable water resources including the following:

- Guidelines for sustainable water resource systems can be developed with respect to **technical** aspects (design and management of physical infrastructure, planning and technology), **environmental** aspects, **economic** and financial aspects, **social aspects** (including human health and welfare), and **institutional** aspects.
- Such guidelines should be developed by involving all of the stakeholders, using a *bottom-up approach*.
- Sustainable water resource systems must provide water in sufficient quantities and quality at acceptable prices, with acceptable reliability, while protecting the environment.
- In consideration of future risks and uncertainties, the guiding principle for sustainability should be "to maintain the options available to future generations".

The committee defined sustainable water resources systems as "those designed and managed to fully contribute to the objectives of the society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity"(ASCE/UNESCO, 1998). This definition, along with the above principles, provides a way forward to developing a definition for sustainable CBDWS. However, some other aspects and components of sustainability also need to be considered for a holistic definition.

Sahely et al. (2005) linked sustainability with efficient services to maintain public health and welfare in a cost effective manner without negatively impacting the environment. Intergenerational sustainability requires management of water resources to ensure that consumption practices do not make them irreversibly impaired (Jaffe and Al-Jayyousi, 2002). Sustainable development is associated with meeting economic, environmental and social objectives for a better quality of life for individuals and generations. Its further interpretation involves "provision of more effective and efficient services which maintain public health and welfare, whilst reducing harmful resources and environmental impacts" (Foxon et al., 2002). Adequate quantity and quality of water is a necessary condition for sustainable development (Kundzewicz, 1997). Sustainable development in terms of financial viability considers the recovery of **all** costs associated with the development policy (ASCE/UNESCO, 1998). The 1996 Civil Engineering and Research Foundation Symposium (CERF 1996) of the American Society of Civil Engineers (ASCE) defined sustainable development as development to meet "growing human needs for natural resources, industrial products, energy, food, transportation, shelter and effective waste management, while conserving and protecting environmental quality and the natural resource base essential for future generations". In simple words, sustainable development is a process of harmoniously exploiting resources, directing investments, and accomplishing institutional change to enhance both current and future potential to meet the present and future human needs (Mirza, 2006).

2.1.5. Sustainability of CBDWS – A Proposed Definition

The future practices for design, construction and operation of sustainable drinking water supply systems in rural areas of developing countries could possibly involve a system designed to supply water from a source (ground or surface water) to a rural community, with few community-based governance structures. Such a drinking water supply system could involve the following aspects:

- **Technical Aspects,** involving conception, feasibility studies, design, construction, maintenance, operations, rehabilitation (when necessary), and finally, decommissioning and sustainable disposal at the end of its useful service life. Basically, these constitute planning, design and management of the physical infrastructure, and the technologies involved.
- **Environmental Aspects** involving the required environmental assessment, maintenance of the renewable source capacity and protecting it from contamination.
- **Economic Aspects** requiring the lowest optimized life-cycle cost, besides the project being financially self-sufficient with the agreed contributions from community members. Funds would always be available for maintenance, which must never be deferred.
- **Social Aspects** requiring equitable access to safe drinking water in adequate quantity and of good quality, and ensuring protection of human health and social welfare.
- **Institutional Aspects** requiring effective local community organization and management units, who are responsible for all operations and budgets and for collection of the needed funds from community members.

It should be noted that these five aspects constitute the basic **components** of sustainability for a CBDWS. The needed guidelines should be developed by involving all of the stakeholders, using a *bottom-up approach*. (ASCE/UNESCO, 1998).

Based on the discussion and the details presented above, a definition of *sustainable* is proposed as follows:

> *A sustainable CBDWS is a drinking water system capable of delivering safe and sufficient drinking water, based on participation of* ***stakeholders****, while: (i) maintaining (not eroding)* ***environmentally*** *the source renewable capacity and protecting them from contamination), (ii)* ***technically*** *optimizing design with high quality execution and regular maintenance of distribution infrastructure, (iii) developing and running the system in an* ***economically*** *beneficial and financially self-reliant manner, (iv) promoting* ***socially*** *equitable access to clean drinking water through awareness and involvement of communities, and (v) relying* ***institutionally*** *on effective local community organizations and management units.*

This definition can be summarized in a conceptual model shown in Figure 2.2.

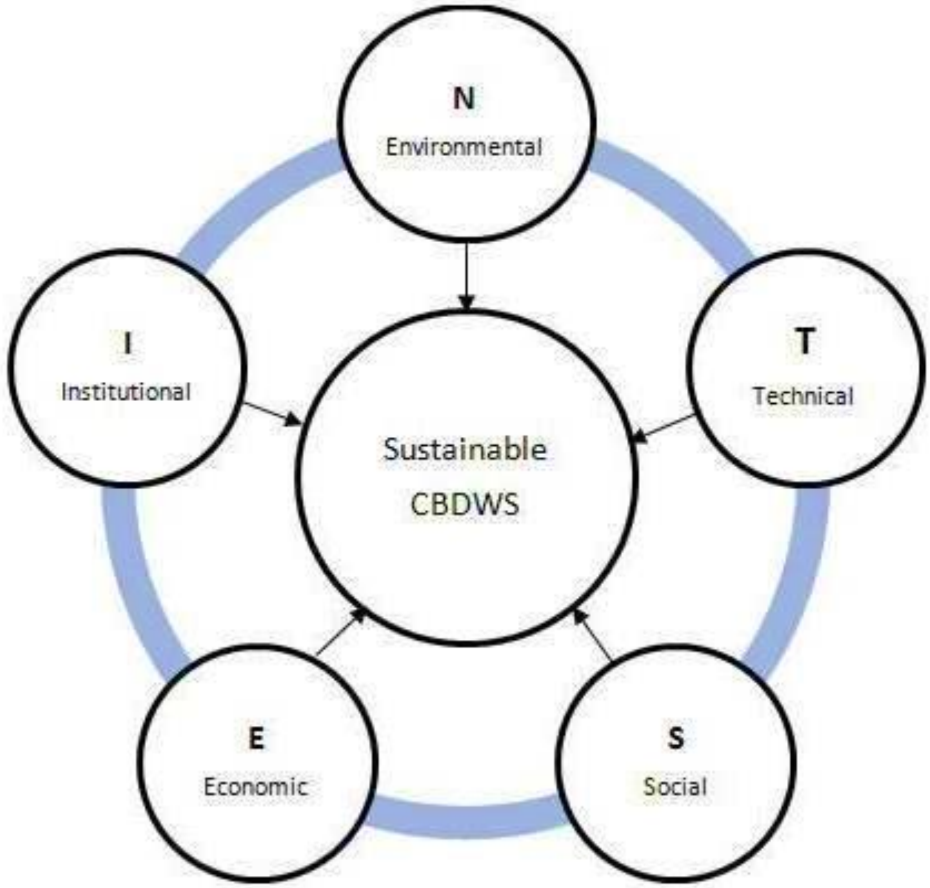


Figure 2.2: Components of a sustainable CBDWS

2.2. ENVIRONMENTAL SUSTAINABILITY

Environmental sustainability of a water source is related first to its exploitation by maintaining "environmental protection through limiting the extraction of water to a capacity below what is actually available" (WHO, 2008). Factors, such as availability, variability and quality of water to meet ecological and human needs are directly linked with environmental sustainability through the hydrological cycle, topographic and groundwater conditions, and the local climate (Furey and Lutyens, 2008). Environmental sustainability is vital to sustain the global life-support systems. It requires that the capacity of water sources of the global ecosystem must not be impaired. These sources are limited and their depletion and/or pollution can affect all life considerably (Goodland, 1995). Beyond the stipulated quantity of water being available, environmental sustainability should also consider the quality of the water from natural sources (Malley et al., 2009). Therefore, one can define environmental sustainability as a component of overall CBDWS sustainability dealing with criteria related to the capacity, reliability, quality, and protection of the drinking water sources.

WHO and UNICEF define reasonable access to drinking water as a minimum of 20 L (5 gal.) per person per day from a source within one kilometre of the person's dwelling (Oldfield, 2006). Meeting this water quantity on a sustainable basis ensures a reliable drinking water source, which is affected by the variability in the quantity of water available. For example, short–term seasonal variations in precipitation would seriously affect rivers and stream flows; long–term trends are evident in the levels of groundwater and large lakes. These may occur due to human activities and changes in precipitation patterns due to the global climate change (National Academy of Sciences, 2008).

An improved drinking water source is defined by WHO and UNICEF as "a drinking water source or delivery point that, by nature of its construction and design, is likely to protect the water source from outside contamination, in particular from faecal matter" (WHO/UNICEF, 2010); chemical and bacteriological contamination should also be included in consideration of source sustainability. Drinking water sources are highly vulnerable, as water is a good solvent for the various external contaminants. A multi–barrier protection approach is strongly recommended to protect drinking water, involving prevention of contaminant ingress at source, proper treatment and distribution systems, water testing, and training of the personnel involved. Indeed, in the aftermath of the 2000 Walkerton tragedy, Justice O'Connor emphasized protection of water sources as the first barrier to prevent any contamination (Conservation Ontario, 2009).

As mentioned earlier, environmental sustainability deals mainly with the capacity, reliability, quality and protection of drinking water sources, which provide the basis for selection of major indicators for environmental sustainability of CBDWS. While environmental sustainability by itself is not sufficient for overall sustainability of CBDWS, it is critical to the overall sustainability of CBDWS. The other components of overall sustainability mainly affect the present generations, but environmental sustainability, along with direct effects on the present generation, can strongly influence the ability of the future generations to meet their needs. In fact, it is the environment, which provides a continuous supply of clean and fresh water to humanity (Malley et al., 2009); this establishes the need to focus on environmental sustainability in two ways:

a) Environmental sustainability as an integrated component of the overall sustainability of CBDWS, and
b) The possible impact of environmental sustainability issues on existing drinking water systems, and achievement of the various targets for sustainable access to safe drinking water, such as those in the U.N. Millennium Development Goals.

Some of the recent studies dealing with different aspects of environmental sustainability include the work of the following nature:

a) Literature review dealing mostly with the conceptual discussion of environmental sustainability (Goodland, 1995),
b) Establishing its links with water availability from natural resources (Malley et al., 2009),
c) Management issues such as allocation of budgets (Kao et al., 2009),

d) Examining aspects of related ecological economic perspectives (Lant, 2010), and
e) Assessment indicators for urban water systems (Lundin and Morrison, 2002).

However, the objectives of these studies were different from those of the current work. None of the available studies evaluated the possible impact of environmental sustainability on global targets for sustainable access to safe drinking water. Environmental sustainability is critical to the overall sustainability of CBDWS to such an extent that this component alone can damage any major efforts to provide sustainable access to safe drinking water. The possibility and intensity of such "fallbacks" based on the fieldwork are examined in Chapter 5.

2.3. ELEMENTS OF A SUSTAINABLE CBDWS

The five components of a sustainable CBDWS (Figure 2.1) are generic in nature, and their measurements are based on the various factors and sub-factors associated with each component. A number of such factors and sub-factors were noted in the available literature; however, none of these were based on a holistic approach involving all important factors and sub-factors for sustainability of CBDWS. A preliminary list of the various elements (components, factors and sub-factors) was prepared and subjected to a process of iterative critical reviews by researchers and the various stakeholders (Table 2.1).

Three guiding principles were established for identification and selection of the required factors and sub-factors:

1. Consistency with the concept and the adopted definition of overall sustainability of CBDWS

2. Measurability with and without sophisticated instruments to accommodate the constraints of the various resources, especially in developing countries – the major regions with drinking water crises
3. Flexibility to accommodate a mixed data type to measure the status of a factor or sub-factor

A list for the various elements (components, factors and sub-factors) based on a survey of the literature was initially developed. The factors and sub-factors were selected using the processes outlined in Chapter 3. This exercise resulted in a final selection of 11 factors and 29 sub-factors for the five components of sustainability of CBDWS.

It should be noted that some factors were not included in the final list due to the complexity of their nature and the current status of the available information such as the effect of climate change on environmental sustainability of CBDWS. Climate change has a direct link to the hydrological cycle and other water–related processes (Malley et al., 2009); it has the potential to change the hydrological cycle due to changes in temperature, melting of glaciers, and precipitation patterns, which can seriously impact sustainability of water sources (Vairavamoorthy et al., 2008). However, mitigation or reduction of this impact at the level of the communities needs further research, firstly at the broader regional level, and then with respect to the types of water resources in the various communities. However, such factors can be included in the proposed framework (Chapter 7), when suitable data become available, without affecting the overall priority arrangement of other components of sustainability of CBDWS.

Table 2.1 - Elements of a sustainable CBDWS

Component	Factors	Sub-Factors
Technical	Design and execution of distribution infrastructure	Design optimization Available pressure at delivery points Protection from external pollution Safety against threats/disasters
	Maintenance	Physical conditions Service interruptions Preventive and remedial maintenance
	Water quality in distribution system	Existence of treatment facilities Efficiency of treatment facilities Water quality at consumer end
Environmental	Source capacity	Present capacity of the source Reliability of the source over time
	Source quality	Water quality at source Water source protection
Economic	Financing	Available for operation and maintenance Depreciation – asset cost decrease over Reliability and continuity of finances
	Economic Impacts	Direct benefits Indirect benefits
Social	Social awareness	Awareness of water-related issues Water usage practices
	Social involvement	Population coverage - Quantitative Equity/inclusion (different sectors)
Institutional	Community organizations	Existence of community organizations Effectiveness of community
	Operation and maintenance (O&M) units	Existence of O&M units Skills and training of committee Transparency in utilization of funds Inventories/records for maintenance

2.4. PARTICIPATORY APPROACHES – COMMUNITY-BASED SYSTEMS

Although the concept of participatory approaches is not new, it has been adopted increasingly over the past two decades (Mujwahuzi, 2002). Participatory approaches involving stakeholders and communities in the overall process of water resource planning, development and management were seen as a viable alternative to centralized management. Here, CBDWS represents the concept of participatory approaches in water resources development and management with special emphasis on the distribution of drinking water to the local population. These systems are operated and maintained by group(s) of people living in a village or a defined area through community organizations, comprising the various sub-units. These communities have common ownership of drinking water sources in the vicinity, and share the socio-economic impacts related to drinking water sources.

A Southern African Development Community (SADC), along with its partners, published a technical report contributing to "practical approaches and operational tools for enhancing sustainable management of water resources"(Mujwahuzi, 2002). A summary of some important benefits of community-based systems (CBS) noted through the case studies of community-based systems in the various regions of the world follows:

- CBS help in addressing complex issues due to the involvement and input of the primary stakeholders, allowing a direct input from the communities benefiting directly or indirectly from the system.
- CBS increase the awareness of the community water resources endowment and promote the understanding of conflict between water availability and demand. Thus, communities adapt more readily to sustainable water use practices.
- CBS provide a forum to manage water use and resource ownership conflicts.

Jonsson et al. (2011) observed that involvement of stakeholders is useful in obtaining essential information and insight into the problem, resolution of possible conflicts and obstacles, critical examination of the proposed measures and search for locally acceptable solutions, and in making efforts on the political front for their implementation. Involvement of the community helps in making not only the various projects possible with limited resources, but it also helps in creating a sense of awareness and ownership within the community. Moreover, community members would have better monitoring capabilities as they live locally, understand the culture, and share a common socio-economic background.

These benefits of CBDWS can help the local communities considerably. However, these stakeholders need to be identified.

2.4.1. STAKEHOLDERS

Freeman and Reed (1983) reviewed the available definitions of the term "stakeholders" since the term was coined in an international memorandum at the Stanford Research Institute (SRI) in 1963. They defined stakeholders as those identifiable groups or individuals who can affect, or can be affected by a system, and/or those on whom the system is dependent for its survival. The ICWE and UNCED identify stakeholders as users, planners and policy makers at all levels, which is in agreement with this definition.

In this study, stakeholders were identified on the basis of above definitions as individuals involved in some way with CBDWS. These individuals have different attributes, such as their professional background and experience (type and duration), especially with drinking water systems, organizational affiliation and their country of origin. Five groups of stakeholders were identified and documented in the survey as follows:

- **Technical:** This group of stakeholders comprises mainly engineers and other professionals associated with the water distribution infrastructure, through its design, execution, maintenance, rehabilitation when needed, and decommissioning and disposal at the end of the asset service life of water distribution infrastructure.

- **Environmental:** This group of stakeholders comprises mainly professionals who are engineers, scientists, and technicians, dealing mainly with planning and monitoring the capacity, reliability, and quality of water resources. They are also concerned with water source protection and environmental impact assessments.
- **Economic:** This group of stakeholders comprises mainly professionals involved with the financing and economic issues related to the water distribution systems. These professions are normally financiers, accounts managers, economists, and donor representatives.
- **Social:** This group of stakeholders comprises mainly social scientists, social organizers, and social workers, who are involved in the social organization of the communities.
- **Institutional:** This group of stakeholders comprises individuals involved with community institutions as members, developers or organizers.

Occasionally in the field, technical, environmental, and economic stakeholders are involved with detailed planning and operation of CBDWS, while social and institutional stakeholders are community users, or are involved in raising awareness in the local population about water-related issues and practices. All stakeholders are normally involved with the policy making process irrespective of their experience (ICWE, 1992). The survey in Chapters 6 and 7 utilized the stakeholders attributes defined here.

It should be emphasized that stakeholder participation is a key feature of CBDWS as it helps in finding better solutions for the various issues related to a CBDWS. Decisions made by the various groups of stakeholders can achieve greater social acceptance, and they can be more favorable economically and friendlier environmentally. A different perspective and attitude towards the problem and its solution, when synthesized in an acceptable manner, can help in achieving sustainable solutions. However, the challenge lies in properly synthesizing the stakeholder views and judgments. Group decisions involving quantification of subjective human opinion are extremely complex (Srdjevic et al., 2007). A Multi-Criteria Analysis (MCA) was used in this research program to meet this challenge.

2.5. MULTI-CRITERIA ANALYSIS (MCA)

There are various tools available to help define the relative priorities (or weights) of the various elements of sustainability by synthesizing the stakeholder inputs and judgments. These priorities or weights help understand the stakeholder subjectivity and develop tools for monitoring and evaluation of CBDWS sustainability. Traditionally, there are different possible approaches for monitoring and evaluation of systems with significant environmental impacts. These approaches include life cycle assessment (LCA), cost benefit analysis (CBA), and multi-criteria analysis (MCA), also known as multi-criteria decision analysis -- MCDA) (Garfì et al., 2011). LCA focuses mostly on the environmental impact assessment associated with a product, while CBA is a process for evaluating a system by comparing its costs to benefits. Both, LCA and CBA are not compatible with the structure of the overall sustainability of CBDWS. However, MCA is more appropriate for ranking "a finite number of options on the basis of a set of evaluation criteria" (Garfì et al., 2011).

MCA was found to be more effective, especially for water management projects, because it adds structure, auditability, transparency and rigor to decision making (Hajkowicz and Higgins, 2008). In the context of the subjectivities involved in the judgments of stakeholders, MCA has a capacity to "enable an integrated assessment of subjective and objective information with stakeholder values in a single framework" (Panthi and Bhattarai, 2008).

2.5.1. SELECTION OF AN APPROPRIATE MCA TECHNIQUE

Huang et al. (2011) reviewed 312 papers published between 2000 and 2009, for detailed evaluation of the various MCA approaches, including Analytical Hierarchy Process (AHP), Multi-Attribute Utilization Theory (MAUT), and others. Some of their major findings, show increasing reliability of AHP, and its selection by researchers in projects similar in nature to the one in this research program follow.

Huang et al (2011) noted that all approaches shared mathematical elements in terms of assigning values for alternatives, multiplying with weights, and obtaining a total end score. They considered AHP to be more appropriate where multiple stakeholders are involved in a decision making process. It is a simple and flexible approach which has the capacity to work even with incomplete and inconsistent data. The main difference lies in how these values are assigned and combined; these evolve as deciding factors for suitability of a method depending on the nature of the information and the available data.

According to Linkov et al. (2005), MAUT relies on the assumptions that decision makers (or stakeholders) are fully rational and aim to maximize the utility/value of their choice. It further assumes perfect knowledge and consistent judgments on part of the participants. AHP uses a quantitative comparative method, rather than utility and weighting functions. It supports the art and capability of relative judgments relying on the supposition that humans are more capable of making relative judgments rather than absolute judgments, and applies a consistency check (Linkov et al., 2005).

The respondents for this research program are stakeholders with varying backgrounds, including members of the local communities. Therefore, the assumptions of complete rationality, ideal knowledge, and consistent judgments may not be applicable; this represents an argument against the use of MAUT. Furthermore, a vast majority of drinking water problems exist in developing countries, and selection of any complex technique would limit its application. By contrast, AHP is a transparent, simple, and practical method. It can be utilized with minimal computer training with software as simple as a regular spreadsheet (Garfì et al., 2011).

In summary, there are many MCA approaches and techniques available, each with its merits and demerits in the context of any specific application. Most of the techniques share common mathematical elements in terms of values, weights and scores. Also, they typically tend to favour the same alternative (Huang et al., 2011), especially for water resources management (Hajkowicz and Higgins, 2008). However, based on the comments by the various researchers and their validation of AHP, it is the most appropriate technique for this research program, especially because of the involvement of multiple stakeholders for group decision making through relative comparison. As mentioned earlier, AHP deals with incomplete and inconsistent responses; it structures the problem, and is transparent in analysis to stakeholders, besides being simple and flexible.

AHP was originally developed by Saaty in the 1970s; it is a suitable methodology for *group decision making*, by synthesizing the opinions of multiple stakeholders in a simple and transparent manner. It is capable of accommodating mixed and less extensive datasets, making it suitable for multidisciplinary project evaluation where human, environmental and engineering concerns need to be assessed together (Garfì et al., 2011), and tested; several *successful applications* are available in the literature (Srdjevic et al., 2007). Therefore, AHP was considered to be more appropriate in the context of the community-based systems, and it was used in this research program, with specific application in Chapter 6 and 7.

2.6. APPLIED FRAMEWORK

Development of an applied framework for monitoring, evaluation, enhancement of sustainability of CBDWS (termed *applied framework*) is one of the main objectives of this research work. The proposed applied framework will not only help to monitor and evaluate the existing systems, but also to improve the sustainability of future systems at the planning and design level.

The development of a framework for monitoring and evaluation of CBDWS sustainability (Chapter 7) was guided by the following attributed guidelines:

1. **Holistic**: The framework must be based on a holistic approach, considering all major components of sustainability in a loop as a "closed system". Sustainability of a single or a few components is not adequate for the overall sustainability of a CBDWS.
2. **Simple and cost-effective**: The framework must be simple and inexpensive to apply.
3. **Data friendly**: Data requirements must be minimal and flexible to accommodate the different data types for a meaningful conclusion. Data can be collected at the various sites with nominal training of the individuals involved. However, the framework must be flexible to accommodate improvements in the quality of information and requirements.

4. **Stakeholder-oriented**: The priorities for the various elements in the framework must be defined by involving the stakeholders.
5. **Adaptable and improvable**: The framework must have the ability to respond to the particular needs of an area under study without changing the integrated set of priorities. However, if the stakeholders of a particular region wish to review these priorities, there must be an easy way of handling such a situation.

   Some efforts have been made to develop frameworks for monitoring and evaluation of sustainability of drinking water systems; however, none of these is a holistic system based on participatory approaches. These frameworks deal with issues, factors, and components, or with pure urban systems. Some examples, with brief descriptions follow:

- *Issue or factor- oriented frameworks*, for example health issues (Kolb Dewilde et al., 2008), or rehabilitation(Hoko and Hertle, 2006), or groundwater sustainability These frameworks were aimed at specific health aspects, and were not designed to cover the overall sustainability of CBDWS.
- *Component- oriented frameworks*, for example environmental (Conrad and Daoust, 2008, Hellström et al., 2000, Spiegel et al., 2001). These frameworks cover sustainability of a particular element only, and not the overall system.
- *The frameworks dealing with urban water systems only* (Kyessi, 2005, Pearson et al., 2010). The specific needs and the overall scenarios for rural water systems and community management are not included.

Beyond these examples, very little work is available in the published literature on frameworks for monitoring and evaluation of sustainability of CBDWS, considering its nature in a holistic manner and stakeholder input.

CHAPTER 3. METHODOLOGY

This chapter focuses on the methodologies for two major studies: (i) the field work, and (ii) the survey. The field work was conducted on 70 existing CBDWS to study the various aspects of overall sustainability of these systems,, with an additional focus on their environmental sustainability. The survey was conducted to obtain stakeholder opinion/judgments and priorities for the elements of sustainability of CBDWS.

The questionnaire used for the fieldwork was aimed at collecting the information/data about existing CBDWS. Another questionnaire was utilized for collecting stakeholder judgments. All work was done in compliance with the McGill Research Ethics Board Codes.

3.1. FIELDWORK: COMMUNITY-BASED DRINKING WATER INFRASTRUCTURES AND COMMUNITY ORGANIZATIONS

3.1.1. PROCEDURES

The fieldwork was conducted in 70 communities practicing CBDWS. Before starting the fieldwork, a pilot study was conducted in the region of fieldwork, situated between latitudes 33.5° and 35°, in the northern part of Pakistan. The pilot study was aimed at refining the framework for the main fieldwork. The region was selected randomly from among the communities practicing CBDWS for about more than two decades.

Development of the refined framework consisted of visiting the communities, examining the existing infrastructure from sources to consumer end and collecting the data through various stakeholders. A standard questionnaire was developed (Section 3.1.2, Appendix A) for responses by community representatives. These respondents were mostly representatives elected by the communities (Section 3.1.3). In addition, several interviews on the subject were conducted with stakeholders, aimed at developing a better understanding of the existing systems. The major findings were formulated on the basis of the questionnaire and other available documents, such as water quality test reports, and the records of the community and the service providing organizations; the interview results were not used for these findings. Water samples from a few sources and consumer places were collected and tested randomly to ascertain the reported trends.

3.1.2. QUESTIONNAIRE DEVELOPMENT

A preliminary questionnaire was developed based on a detailed review of the literature, and refined through an iterative process of critical examination at meetings of a group of researchers, and interactions with the various groups of stakeholders. The draft questionnaire was then translated into Urdu, the most commonly used language in Pakistan. This questionnaire was tested for response by 15 (21.4%) randomly selected communities, along with visits to the water systems in these communities. Several meetings were held with the service providing agencies, donor representatives and water consumers. In addition, numerous documents, such as the needs identification reports, contract documents, social and economic profiles of the communities, and the recorded comments of the participants during stakeholder meetings were studied with the cooperation of these agencies and community institutions. It was ensured that the questionnaire was clear and easy to understand. The final questionnaire consisted of 62 questions.

3.1.3. PARTICIPANTS

The fieldwork participants were divided into two categories: (i) respondents for the questionnaires and (ii) supporting participants. The respondents were basically elected representatives of the communities, responsible for providing the information required in an integrated questionnaire (Appendix A). The supporting participants were individuals and groups, such as members of the communities, groups of research scholars, staff members of water testing laboratories, and members of service providing agencies. They also helped to develop contacts within the communities, and for sharing documents from the data files, participating in interviews and discussions, and testing of randomly selected water samples. Interviews and meetings were organized to develop improved understanding of the common local practices in planning, execution and managing CBDWS. The conclusions of the fieldwork study were drawn based on the data collected through questionnaire, contract documents, laboratory reports, and inspection of the existing infrastructure in the communities.

3.1.4. DATA COLLECTION

Fieldwork was conducted in 70 randomly selected rural communities of the northern region (situated between latitudes 33.5° and 35°) of Pakistan. The objective was to examine the current status of the various elements of sustainability of CBDWS. Figure 3.1(a) shows Pakistan in Asia, while Figure 3.1(b) shows the region of study in Pakistan.

(a)

(b)

Figure 3.1: (a) Map showing Pakistan with green boundaries and the region of field study (red dot) (b) Region of the field studies in northern part of Pakistan.

(Source: Google Maps)

The communities were contacted through their service providing agencies and office bearers, and included the presidents and general secretaries of the various community organizations. The respondents were selected with the help of community organizations; almost all of the respondents were elected representatives of community organizations. All respondents were adequately educated to understand the questions and provide representative answers. This was ensured through the various interviews and random interactions as mentioned earlier. Once the questionnaire was formalized after considerable interaction with the communities, and was translated into Urdu, printed copies of the questionnaire were passed to the selected respondents in consultation with other community members, who were present at these meetings. A relationship of "One community - One questionnaire" was established to provide an equal weight to all communities to ensure better interpretation of the analysis results.

To assess water quality at source and at consumer end, data were collected from three sources: (i) reports of the studies conducted in similar areas from the same region, along with (ii) the test results from some samples collected directly, and (iii) the test reports available in the community records (Table 5.1).

3.1.5. Data Analysis

As mentioned earlier, fieldwork was conducted to implement two major studies (Chapters 4 and 5). The analysis in Chapter 4 is based on both descriptive and inferential statistics. Descriptive statistics mostly describe the present status of the various components in the communities; the observations from the field study are also provided. Inferential statistical analysis is used to test hypotheses of the proposed model for a sustainable CBDWS. The significance test was initiated with an examination of a null hypothesis ($\boldsymbol{H_0}$) for each sub-hypothesis ($\boldsymbol{H_1}$). Two way contingency tables were developed, and tested performing the chi-square test. Significance of the relationship in two way contingency tables was tested using the Pearson chi-square (X^2_p), and the Wilks' likelihood ratio (X^2_w) tests (Legendre and Legendre, 1998). As all test results agreed with each other at a significance level of 0.05, only X^2_p test results were reported. Computations were performed using the XLSTAT software version 2013.4 by Addinsoft SARL.

3.2. SURVEY -- STAKEHOLDER PRIORITIES AND SUBJECTIVITIES

3.2.1. PROCEDURES

The survey was aimed at determining stakeholder priorities and subjectivities about sustainability of CBDWS. It was designed to collect the opinions/judgments of the various stakeholders in the form of relative comparison between the various pairs of components and factors. The priorities of stakeholders were expressed as weights assigned by an individual to sustainability components and factors presented in Table 2.1. These weights were calculated using the specific AHP algorithms (Aczél and Saaty, 1983, Saaty, 1990, Saaty, 2008) (Chapter 2). Stakeholders were contacted through e-mail, seminars, institutions, and social contacts. To facilitate the responses, both electronic and printed versions of the survey were made available to the participants. The responses obtained through printed versions were converted to the electronic format for uniformity of the data set.

Four attributes of the survey respondents (stakeholders) were used to analyze the prioritization process of different groups. The attributes were the organizational employment affiliations (educational institutions, consultants in different fields of engineering, service providing agencies, and communities of consumers), the country of origin (Pakistan or others), the type (technical, environmental, economic, social, and institutional) and length of experience with drinking water distribution systems.

3.2.2. DEVELOPMENT OF THE SURVEY

The survey was presented in research meetings for reviews. The initial draft was developed for all five components, 11 factors, and 29 sub-factors. To apply AHP, judgments were required in the form of pair-wise comparisons on a scale of 1 to 9 (Saaty, 1990, Saaty, 2008) as shown in Table 3.1. The draft survey was then tested by involving more than 50 respondents from different backgrounds and affiliations.

Table 3.1 - Relative importance utilized for pair-wise comparison

Relative importance of elements in any pair	**Value on the scale** (higher value shows relatively greater importance)
Equally important	1
Slightly more important	2 or 3
Clearly more important	4 or 5
Significantly more important	6 or 7
Dominantly / extremely important	8 or 9

The following findings of the pilot study were considered to improve the draft of the survey:

1. The survey should be conducted on-line and in printed formats to involve as many stakeholders as possible.
2. The survey should be manageable for all respondents in terms of its length and required time to focus on the comparisons. As [n(n-1)/2] comparisons were required for 5 components, 11 factors, and 29 sub-factors, the following number of comparisons needed to be performed:

10 for components

55 for factors

406 for sub-factors

A total of 471 comparisons would have been a relatively time-consuming task and contrary to the guidelines. The guideline (Saaty, 1990), suggested comparing a total of 7±2 elements at a time.

As an alternative, considering five components for the entire system, and limiting the factors to only parental factors, and sub-factors to only their parental factors needed the following comparisons:

10 for components

7 for factors

27 for sub-factors

This resulted in a total of 44 comparisons. The estimated time to respond to this survey was a little over 2 hours, including the time to read and comprehend the guidelines, which was acceptable under the circumstances.

Based on the findings of the pilot study, it was decided to include all components and all of the factors for each component in both the online and printed surveys. Sub-factors would be made available as an option to the electronic respondents only. The goal of this exercise was to examine a possible trend in comparison with the assumption that sub-factors share equal weights within their parental factor. A future replication of this study would help further refinement of the trends. It should be noted that once the components are synthesized independently in the AHP format, the margins of errors and variations in the expected results do not affect the component priorities of the overall system. Such variations remain limited within a parental component range only, without affecting the other components. In summary, using this option was not expected to influence the priorities for components at all; however, it was significant in terms of the time and the focus required for completing the survey.

3.2.3. DATA COLLECTION

Over 450 stakeholders were contacted randomly. Online survey was facilitated with a web-based interface, which included a tutorial, and guidance pop-up menus. Additional information was requested before submission. Printed surveys facilitated details of the various elements and procedural guidelines to record the judgments. The questionnaire is reproduced in Appendix B (and the electronic version of this thesis has a copy of the electronic interfaces).

3.2.4. DATA ANALYSIS

MCA was used to estimate the weights of sustainability components and factors, applying AHP (Saaty, 2008). This was done twice to address two different objectives: (i) understanding the priorities and subjectivities of various stakeholders (Chapter 6), and (ii) estimation of the weights for applied framework for monitoring and evaluation of sustainability (Chapter 7). Judgment of each respondent was considered individually for estimation of weights and analysis (Saaty, 2008).

3.2.4.1. PRIORITIES AND SUBJECTIVITIES OF STAKEHOLDERS

The weights of components and factors within components determined by each individual respondent were analyzed on the basis of the four attributes of stakeholders. Note that experience type, employment affiliation and country of origin were categorical variables, while the experience length in years was considered continuous. Statistical testing of the average differences along attribute values for the individual weight values were tested using multivariate analysis of variance (MANOVA) for components and for the factors of the five component because the weight profiles contained more than two values (i.e., more than 1 degree of freedom), and the weights for the factors under the other sustainability components were tested using univariate analysis ANOVA because they contained only two factors (Sokal and Rohlf, 1995). The tests assumed the weights to be normally distributed. Although the distributions were slightly skewed to the right (higher values), performing the same test with log-transformed weights provided the same results. The MANOVA and ANOVA tests were performed using the GLM procedure of SAS/STAT statistical software v. 9.2 (SAS Institute, Cary, NC). Once the overall null-hypothesis of no difference between groups was rejected ($p<0.05$), the similarity between groups was tested using contrasts or using the Duncan multiple pair-wise comparison (Sokal and Rohlf, 1995).

3.2.4.2. Group Decision Making for Applied Framework

A slightly different computational approach from Section 3.2.4.1 was adopted to perform MCA required for applied framework in Chapter 7. Here, the objective was to synthesize the judgments to estimate weights considering groups of stakeholders, and not every individual within the group. Therefore, a synergistic approach was used by combining the judgments of individuals within the groups. As the respondents in each category used a ratio scale to make judgments involving a geometric progression and the property of reciprocity, their judgments were aggregated using the geometric means, (Aczél and Saaty, 1983, Ramanathan and Ganesh, 1994, Saaty, 2008). However, for outcomes (priorities or weights), both geometric and arithmetic means can work (Forman and Peniwati, 1998). For applied frameworks, the arithmetic mean of weights (averaged among groups for each element) was preferred to obtain the sum of weights equal to 100% for a complete and closed system. The consistency of responses for combined judgments of each group was examined for all combinations of elements against the recommended acceptable value of equal to or less than 10% (Saaty, 1990). The details of the mathematical procedure and the required explanation are presented with the results in Chapter 7 and Appendix C.

CHAPTER 4. OVERALL SUSTAINABILITY OF CBDWS

This chapter focusses principally on: (a) the existing status of CBDWS in the communities in Northern Pakistan, and (b) development and validation of the model for sustainable CBDWS. The results are based on fieldwork, which was conducted for the two major studies: (i) overall sustainability of CBDWS (Chapter 4), and (ii) the impact of environmental sustainability on the achievement towards the U.N. Millennium Development Goals for providing sustainable access to safe drinking water (Chapter 5).

4.1. BACKGROUND

As mentioned in Chapter 1, considerable efforts have been made to meet the challenge of sustainable access to safe drinking water, including the efforts made to achieve the targets set in MDG. The progress can be observed from a recent report of the Joint Monitoring Program (JMP) of the World Health Organization (WHO) and the United Nations Children Fund (UNICEF), which noted that, since 1990, over 2 billion people have attained access to improved drinking water sources (UNICEF/WHO, 2012).

However, despite these achievements in terms of the overall proportion of population coverage, the (UNICEF/WHO, 2012) noted the following:

a) Huge disparities exist in developing and least developed countries, between the rich and the poor nations, and between rural and urban populations.

b) Safety of drinking water in terms of water quality is not addressed and a proxy indicator "improved drinking water sources" is used to replace the term “safe drinking water”. It should be noted that definition of “improved drinking water sources” is not based on the quality of water at a particular source, and any source is declared as “improved drinking water source”, which, by the nature of its construction and existence, is likely to be protected from outside contamination, particularly fecal matter. Consequently, an improved drinking water source "may not actually provide 'safe' drinking water".

c) The quantity of water for domestic use and the number of service hours available were not considered.

The observations show that these achievements are mostly in terms of *one time coverage* only, and may not reflect sustainable access to safe drinking water, which is one of the UN Millennium Development Goals. This concern is based on questions of the following nature:

1. Will there be sufficient resources (quantity) of suitable (quality) drinking water in the vicinity of the existing population centres if they are continually utilized at the present rates?
2. The world population will increase considerably in the near future and it would have to live with considerably smaller resources of drinking water in the vicinity of the population centres. Climate change in the future could possibly worsen the situation further in some regions of the world. The question arises: Would the future generations have adequate access to suitable drinking water?
3. Has the distribution infrastructure been designed and maintained to meet the challenges in Questions 1 and 2?
4. How do socio-economic factors affect the sustainability of drinking water systems?
5. What is the capacity of the responsible institutions to deal with the challenges of sustainable systems?

These questions are generic and complex in nature and they are important for consideration of sustainability of any drinking water system. This gap in policy and practice raises questions about the overall sustainability of the existing drinking water systems. It would be useful to recall that overall sustainability of a CBDWS requires well maintained drinking water sources (in quantity and quality), a proper infrastructure (in terms of design and maintenance), an aware society (to adapt supporting water use practices for consumers and the environment), a beneficial economy (direct and indirect economic impacts), and effective community institutions (continuing their existence and effectiveness).

The overall sustainability of CBDWS can be compromised if any of the above components fails to attain the required levels. Several studies show significant deficiencies in performance of these components, especially in developing countries (Haysom, 2006, Lee and Schwab, 2005, Montgomery et al., 2009). Table 4.1 summarizes some of the problems affecting sustainability of drinking water systems in Pakistan. These portray a very different picture when compared with the reports showing absolute coverage of the target proportions. This raises a specific question: *Are these systems sustainable*?

Table 4.1 - Some of the problems affecting sustainability of drinking water systems in Pakistan

Components	Reported problems
Technical	Distribution infrastructure suffers from lack of maintenance and is generally neglected. It faces serious deterioration. About 30 to 40 percent of the water is lost because of leakage from perforated pipes and accessories (Khan and Javed, 2007). About 35% of the present water supply schemes are non-functional (PCRWR, 2002)
Environmental	Water availability has decreased from 5300 cubic meters per capita per annum in 1953 to less than 1000 cubic meters per capita per year presently, and it is projected to decrease further to 659 cubic meters per person per year in 2025 (WWF, 2007). According to population division of United Nations (2013), population of Pakistan was 37.542 million in 1950, which is expected to be 218.124 million in 2025. Water extraction far exceeds its recharge. All surface water bodies have high bacteriological contamination along with other contaminating agents (PCRWR, 2002).
Economic	Health costs due to water-related diseases (mainly diarrhea and typhoid) is estimated to be 114 billion Pakistani rupees (C$ 1.8 billion) in 2006, approximately 1.81% of Pakistan's GDP (WWF, 2007).
Social	About 80% of diseases and 33% of deaths are related to contaminated water (Tahir et al., 1994). Over 250,000 child deaths and loss of 1.6 million healthy life years (Disability Adjusted Life Years - DALYs) are a serious economic loss each year (WWF, 2007).
Institutional	Thousands of water supply schemes throughout Pakistan are examples of complete failure, mostly executed by different agencies and transferred to the communities, who are unable to operate and maintain these schemes (CIDA, 2006)

4.2. PROPOSED MODEL AND RESEARCH METHODOLOGY

4.2.1. DEVELOPING THE MODEL

To answer the above questions about sustainability of CBDWS, development and validation of a model describing how the different aspects of sustainability interact, were required. A conceptual model based on the proposed definition of sustainable CBDWS was presented in Chapter 2 (Figure 2.1). Figure 4.1 shows the extension of that conceptual model to a specific and testable model for a sustainable CBDWS. The following research hypothesis, developed on the basis of definition of a sustainable CBDWS (Chapter 2) and the nature of the reported problems (Table 4.1), provides the foundation for proposed model (Figure 4.1):

Properly maintained sources, proper infrastructure, aware society, stable economy, and effective institutions are necessary and linked components of sustainable CBDWS, and failure of any of these component can affect sustainability of the entire system.

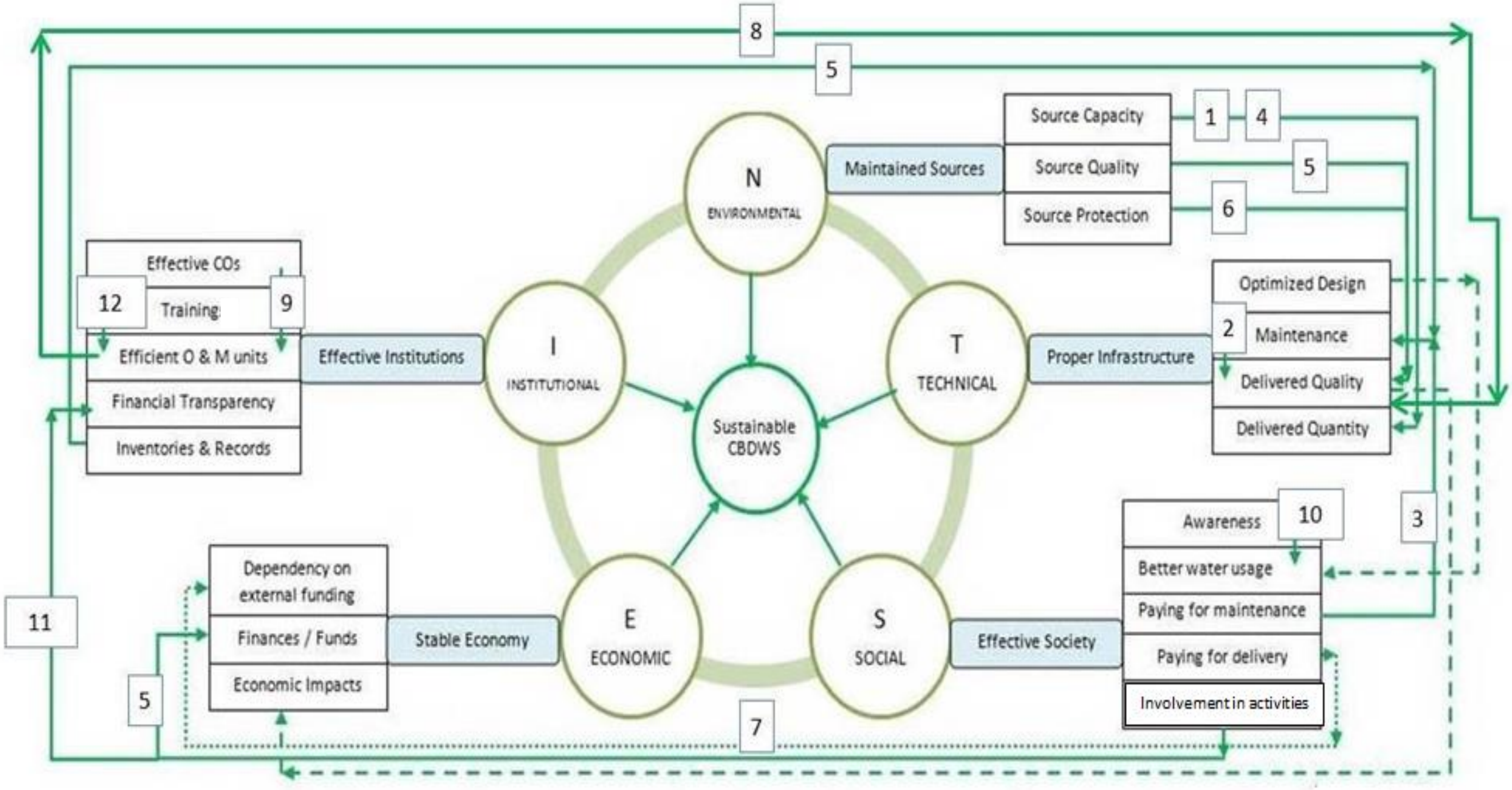


Figure 4.1 : Sustainable CBDWS – A model for overall sustainability of CBDWS

The proposed CBDWS model is shown in Figure 4.1. The numbers on the solid line links indicate the number of correlations/hypotheses. The solid lines with numbers show confirmation of association, while in the case of the dotted line (number 7), no association could be established. The two broken lines, with no numbers, are proposed for future testing, as the required data were not available for these links. The requirements for a sustainable CBDWS model follow:

- The water **sources** should be **maintained** around their renewable capacities without over-exploitation or depletion, and the quality of sources should be maintained by protecting them from contamination, especially biological contamination, at all times
- The **infrastructure** should be **designed** for optimized demand and supply, **and regularly maintained** to ensure fulfillment of continuous consumer demand without interruptions, except for those scheduled for planned improvement of the system.
- An **aware society of consumers s**hould under**stand th**e capacity of the sources in their **vicinity, their role tow**ards optimized water use practices, and their impact on the existing water sources and the overall environment.
- A **stable economy** to provide the required finances and other resources for operational and maintenance needs without relying on external funding resources. This can be ensured by linking CBDWS with direct or indirect economic benefits to the society.
- **Community institutions** should play an active role for keeping the community alive in its participatory role by ensuring the arrangements for recommended operations and maintenance through adequately trained personnel. These institutions should also have significant overall financial role for the entire system.

4.2.2. TESTING THE MODEL

This model was developed on the basis of the above hypothesis, and tested utilizing the data collected during the field study conducted in 70 communities (Chapter 3, Tables 4.2A to 4.2E, and Appendix A). Testing of correlations (sub-hypotheses) was performed by predicting and verifying a certain number of correlations (Table 4.3). . For testing purposes, a null hypothesis (H_0) postulated independence of two descriptors connected by arrows in Figure 4.1. Two-way contingency tables were developed for descriptors based on survey questions, and the relations between descriptors were tested by performing chi-square test (Section 3.1.5). A significance level of $p=0.05$ was adopted.

4.3. RESULTS

The results for overall sustainability of CBDWS are presented in two parts as follows:

1. The existing status of the various technical, environmental, economic, social, and institutional aspects in the context of CBDWS are presented in Tables 4.2A to 4.2E with comments and brief discussion to describe the component-based findings in a descriptive format.
2. Predicted correlations (sub-hypotheses developed for validation of the main hypothesis presented in Section 4.2.1), and the results of the statistical tests for the various correlations are presented in Table 4.3.

Table 4.2 - Status of various sustainability components of CBDWS

Description	Results	Comments and brief discussion
A - Existing Water Sources – Capacity and Quality		
1) Nature of sources	A majority (77%) of water sources in the region of study were surface water sources, including 67% springs, 10% streams/canals and rivers. Open and tube-wells were used in 4% of the communities whereas in 13% of the cases, the types of sources were not reported.	It was reported during the interaction with the community members that deliberate efforts were made to find a source at higher altitudes to ensure gravity flow towards the community area. This selection of sources at higher altitudes is the main reason to have springs for more than two-thirds of the sources.
2) Capacity of existing sources	About 50% of the water sources had the capacity to fulfill the daily consumer needs (mostly up to 20 liters/person/day), while 29% of sources had a lower capacity, and the remaining 21% face seasonal variations.	WHO and UNICEF criteria suggest a minimum need of potable water as 20 litres per person per day. About 58% of the communities reported their daily need of potable water to be equal to 20 litres per person. Therefore, fulfillment of the needs was based on 20 litres per person per day
3) Depletion of sources	About 79% of water sources faced variations, including 21% of sources which could suffer permanent depletion. Only 19% of the sources were stable.	A majority of the communities in the region relied on springs, which suffered from seasonal variations. Precipitation was the major source to feed these springs. Permanent depletion resulted from higher pumping rates as compared with the recharge rates, along with an increase in the needs during hot weather. The community representatives reported

		that several streams had become dry over the past two decades. Open and shallow wells became non-functional and have decreased in number. They have been replaced by deep borings to access water. Seasonal variations had become increasingly severe, and people queue for hours to fetch water.
4) Protection of sources	About 42% of the sources were unprotected	Protection was needed to prevent mixing of external contaminants, which were mainly of "bacteriological" nature through sewage and surface runoffs. Actual number of sources may be higher, as many of the sources had some type of protection. Many sources were poorly protected with deteriorated metallic covers over the storage structures at source.
5) Vulnerability of sources	Over 58% of the sources were reported as being vulnerable and likely to get contaminated or be subjected to a probable increase in the existing contamination level. In addition, a little over 17% of the sources had the possibility of further contamination. Less than 23% sources are reported to face potential contamination/further contamination.	A majority (58%to 75%) of the sources are vulnerable because of improper or no protection at all.

B - ***Distribution Infrastructure***			
1)	Mechanism of delivery	About 58% of the systems were delivering water utilizing gravity flow, while another 14% were partially gravitational. The rest of the systems rely on pumping, requiring electrical power, which is intermittent.	Gravitational flow has numerous advantages, including lower or no energy requirements. However, finding sufficient sources at higher altitudes is a major constraint in these plains.
2)	Optimized design	Manuals of design for these systems showed that the design approaches were often considerably simplified, and the resulting designs were not optimal.	This question was not included in the questionnaire because of its purely technical nature; however, interaction with technical staff of service providing agencies and review of actual designs showed that optimization is still not an integral part of the local practices. Design optimization can help to secure the sources, besides serving consumers at many places.
3)	Operational responsibilities	Nobody is responsible for routine operations in about 50% of the communities.	One of the reasons to leave 50% systems unattended is uncontrolled gravity flow. During informal interactions with community representatives, some consumers were of the view that operational responsibilities are needed for cases involving pumping only.
4)	Maintenance	About 77% of the systems were not maintained regularly. Maintenance was performed only when the system demonstrated serious distress, or it failed, and	Serious maintenance negligence was observed during the field visits. Not only did this negligence result in wastage of water, but it also posed a risk to the quality of water flowing through the pipes.

	regular and timely maintenance rate was reported to be a little over 6% of the systems.	
5) Service interruptions	Over 58% of the systems faced service interruption every month, including 26% of them facing such interruption every week.	Service interruptions were linked with the proper operation and maintenance (O&M) activities. As can be seen from the data, O&M was consistently ignored resulting in frequent service interruptions.
6) Vulnerability of distribution infrastructure (threats and protection)	Around 64% of the systems were threatened by landslides and about 28% of the systems could suffer varying degrees of damage due to earthquakes.	Infrastructure was vulnerable to the local topography, as minor landslides could damage the pipe lines which were not buried underground in many places. Common occurrence of landslides due to earthquakes and seasonal rains was also reported. Earthquakes affect the underground waterways and relocate the sources, especially the springs. Landslides damage not only the distribution infrastructure but also the natural streams and rivers because of the resulting debris. The October 2005 earthquake (7.6 on the Richter scale) demonstrated the most severe impact of such incidents at the highest level.
7) Water quality and tests	Reports from the records of communities and water testing laboratories in the region, and testing of a few directly collected samples showed that about 86% of the sources were	There was not a single treatment unit in any of the 70 communities in the region. Untreated raw domestic sewage was disposed directly into the water bodies. Over 31% of the survey responses confirmed raw sewage as a common

	bacteriologically contaminated(Aslam et al., 2012). About two-thirds of the sources were never tested for water quality before their selection, and over 50% were not examined even after the water supply was initiated to the consumers, until the day of the survey.	pollution source of drinking water. Surface runoffs transfer human (in case of defecation in open fields) and animal excreta into the surface bodies.
C - ***<u>Social Aspects</u>***		
1) Overall awareness	A survey question about the “availability of water resources” was aimed at ascertaining the awareness of local communities. About 44% of the respondents stated that the available water sources are “unlimited and not going to decrease”, compared with 40% of the respondents who were of the opinion that such sources are “limited and would decrease, if wasted”. The concept of “optimized use” was mentioned by a little less than 13% of the survey participants. About 57% of the respondents felt that sewage was not polluting drinking water; although there was no treatment system in any	During random interactions and interviews with survey participants, it was noticed that awareness of the water resources and their optimized usage was minimal or non-existent, even with the personnel of the various service providing agencies. Educational systems and cultural traditions were not helpful in increasing the level of awareness in these regions. In some communities, consumers thought that water was a natural resource and that it would exist indefinitely as humans have no role to play. A commonly held opinion suggested that “flowing water is clean”, irrespective of any quality concerns.

	of the communities studied, and untreated sewage was generally disposed into water bodies.	
2) Financial contributions to operate the system	Over 55% of the communities did not make any financial contributions as tariffs. Only 13% made payments on a regular monthly basis, especially where pumping was involved as electricity charges were to be shared by the consumers. About 32% of the users paid only when emergencies occurred or when payment was demanded. Payments for operation and maintenance (O & M) were regular in less than 21% of the communities. A majority (over 56%) of the communities made such payments only on a casual basis. Payments specifically for maintenance were made in more than 70% of the communities "only when needed", and any such payments on a regular basis were noted only in 13% of the communities.	Such emergencies were mostly linked to failures caused by breakages, and removal of sediments and debris, resulting from landslides. The local communities paid for any resulting rehabilitation and reconstruction. During the random interactions, some people remarked that economic conditions in such (rural) areas of a developing country (as Pakistan) were not stable, which could be a reason for the apparent low financial contributions; however, it was also linked to the lack of awareness of the impact of such practices.
3) Involvement in various activities	About 84% of the communities have regular consumer	People were generally involved in local activities and participated in the meetings.

	memberships. Only 10% of the communities did not have such regular memberships .	However, it was reported that the frequency of such meetings decreased with an increase in the age of the system and it was hoped that external funding would be available.

D - ***Economic Aspects***

1) Economic impacts	About 33% of the communities reported that they suffered from water-related diseases, and about 20% of the respondents reported deaths. In about 40% of the communities, school attendance was affected by the water- borne diseases, and also because children had to fetch water which was in short supply.	Evaluation of the economic impact was not part of the field study. Reliance was placed on previous studies of the economic impact of drinking water, such as that quoted in Table 4.1. Some direct and indirect economic impacts of drinking water, such as health expenditures, time lost in fetching water and its impact on women and children, and the loss of healthy life-years due to water-borne diseases were reported randomly by the community members.
2) Finances	The communities were involved in direct and indirect arrangements of finances, commencing with the implementation of the CBDWS project. During the implementation stage, communities were committed to contributing 15% to 20% of the	Contracts between the service providing agencies and the community of consumers showed that consumers would arrange a specific share annually (2% to 3% of the project cost) for maintenance purposes. However, these contracts do not show what actions would be taken by the community if this clause was not respected. There is no legal way to deal

	cost of the project through labour and supply of local materials. About 2 to 3% of the contract costs were collected and deposited annually in a separate bank account for maintenance expenses; however, only 13% of the communities were regular in such payments.	with these clauses and normally, these are not respected.
3) Dependence on external funding	About one-third of the communities relied on external funding sources for routine operations and maintenance; however, less than 25% of external sources were reported to be "reliable".	External sources include all sources excepting the finances generated by the community itself in regular savings for maintenance on an as needed basis
E – *Institutional Aspects*		
1) Community organizations (COs)	In general, COs were considered to function properly; 51% of the communities were reported to be functioning in an "excellent" manner. In 87% of cases, male organizations were rated to be relatively stronger than the female organizations.	The communities themselves reported the level of satisfaction and confidence in community-based systems
2) Operational units	About 59% of maintenance units were reported to work "efficiently". About 29% of the committees were reported to be "inefficient" and 10% of the	These units are mostly in the form of committees working on a voluntary basis, such as a maintenance committee. Operational units are part of community organizations

	communities had no maintenance units.	
3) Training	In 25% of the communities, no personnel had been trained to operate or maintain the system. The satisfaction level of the trained persons/groups was around 40%.	Service Providing Organizations have been the main sources for training selected person(s) for specific jobs. These are short training programs and normally deal with very basic issues of operation and maintenance of CBDWS.
4) Transparency in utilization of finances/funds	Available maintenance funds were used transparently in 67% of the communities. Another 15% of the communities reported some ambiguities; 2% of the communities reported dishonest use of the funds. About 78% of the communities involved community members and community audit committees to monitor the utilization of funds for maintenance.	Transparent use of finances was reported as the common practice in the communities; the reason was the active involvement of people in day-to-day affairs.
5) Inventories and records	In 40% of the communities, there were no inventories or records for regular maintenance, while another 26% had partial records. Only 26% of the sources were reported to have proper inventories/records.	Most of the maintenance activities are performed on an ad hoc basis. About two-third of the communities have few or no records for maintenance activities. Normally, maintenance is implemented only after failure, resulting in wastage of time and resources along with the negative impact on the overall services life of the distribution infrastructure.

F - *Miscellaneous*		
1) Old and new systems	The older systems (executed between 1970 and 2000) were 11% more depleted and 14% more insufficient than the new systems (executed between 2001 and 2010). However, older systems involved more responsible operations (52%, compared with 43% for new systems) and fewer service interruptions (46% compared with 62% in new systems). The proportion of the old and new systems was approximately 40% and 60%, respectively, in the study.	This indicates an increasing trend for depletion with the passage of time. However, responsible operational activities help in providing better services and delivery

* Minor percentages not shown in the table are mostly cases where no data was received or where the respondents were unsure or where they did not wish to respond

Table 4.3 shows the sub-hypotheses and summary of the related statistical test results. The results presented in Table 4.3 validate the model. The only exception is acceptance of null-hypothesis 7. As mentioned earlier, the data for optimization of design and economic impacts of the CBDWS was not available, which is shown by the dashed line in Figure 4.1.

Table 4.3 – Hypotheses and Test Results

Hypotheses		Survey Questions†	Chi-Square	Result *P*-value = 0.05
Number*	Description			
1	Sufficiency at consumer end depends on the sufficiency at source	Q-9 and Q-18	0.001	Accepted
2	Consistency in delivery services is associated with maintenance of distribution infrastructure	Q-20 and Q-21	0.004	Accepted
3	Maintenance of distribution systems depends on availability of funds	Q-21 and Q-36	0.001	Accepted
4	Water shortage is associated with depletion of sources	Q-5 and Q-9	0.001	Accepted
5	Frequency of maintenance correlates with good archives of inventories and records	Q-21 and Q-24	0.000	Accepted
6	Source contamination is negatively associated with source protection	Q-10 and Q-26	0.042	Accepted
7	Dependency on external funding is linked with payments made by communities for water delivery services.	Q-35 and Q-40	*0.917*	*Rejected*
8	Quality of drinking water services are associated with responsible operation of the systems	Q-19 and Q-20	0.022	Accepted
9	Effective maintenance units are associated with effective community organizations	Q-59 and Q-60	< 0.0001	Accepted
10	Water use practices are linked with the level of awareness in the consumers	Q-46 and Q-47	0.005	Accepted
11	Transparent utilization of funds is associated with the involvement of communities in the system	Q-38 and Q-39	< 0.0001	Accepted
12	Response of community institutions is linked with the training of personnel	Q-59 and Q-63	< 0.0001	Accepted

*Hypotheses numbers correspond to arrow numbers in Figure 4.1.
†Survey questions used as descriptors for each hypotheses (Appendix A).

4.4. DISCUSSION

Eleven out of out of 12 hypotheses were accepted showing a statistical significance at a confidence level of p = 0.05 (Table 4.3). The only correlation (hypothesis 7) between *making payments for delivery services* and *dependency on external sources of funding to run and maintain the sytem* was found to be not significant. The existing financial management practices in the region of study show a similar tendency. The payments for delivery services address mainly the direct cost of power consumption for running pumps. These costs do not include the financial requirements for maintenace of the system (Table 4.2-C, Point 2). The third hypothesis shows that maintenance of the distribution infrastructure is not independent of the availibility of funds for maintenance. The combined reading for both (H-7 and H-3) shows that a separate funding for maintenance of sytems is necessary and payments for administering the expenditures, such as electricity tarrifs should not be confused with each other. Table 4.2 summarizes the status of the various components in the region of study. The various qualitative or descriptive results of the existing status of sustainability components are presented and discussed briefly (Table 4.2-A to 4.2-E).

It should be noted that the two sub-hypotheses shown in Figure 4.1 could not be tested due to the lack of field data; consequently, these two were not included in Table 4.3. The main hypothesis was still found to be valid. The available documents in the community project files showed a generalized approach towards design, irrespective of any optmization practices, and depended on the existing situation of sources and demands. Similarly, the results of studies for economic impact of CBDWS in the regions were not available.

4.4.1. Existing Water Sources

Existing water sources are highly vulnerable, threatening sustainable access to safe drinking water at the very basic level. Only half of the sources have adequate capacity to fulfill the needs of the communities, commonly agreed at 20 litres per person per day (Table 4.2). Continuing depletion and increasing seasonal variations have made the situation more challenging. Protection of the sources is not ensured for both their quality and quantity. A majority of sources face a potentially increasing contamination. These findings show that the status of the sources alone can make the entire system unsustainable. Aging of the infrastructure and the continuing use of water from these sources at rates exceeding their recharge rates is resulting in their depletion. Groundwater sources are becoming less accessible and increasingly polluted with time, needing more effort and energy to overcome the negative impact of untreated sewage. WWF (2007) noted that "Forty million residents depend on irrigation water for domestic use, especially in areas where the ground water is brackish." Similar trends have been reported in other parts of Pakistan. WWF (2007) evaluated depletion of water in provinces, such as Sindh, Balochistan, Punjab and Islamabad. The results are summarized in Table 4.4.

Table 4.4 - Depletion of groundwater sources in different areas of Pakistan

Area	Status of depletion
Islamabad (Capital of Pakistan)	Lowering of the water table by 15.24 meters between 1986 and 2001 (Average water table lowering rate is about 1 m/year)
Lahore (Punjab)	Lowering of the water table by 6.1 meters between 1993 and 2001 (Average water table lowering rate is 0.8 m/year)
Kirther (Sindh)	Average lowering of the water table is 3 meters per annum
Quetta (Balochistan)	Without an artificial recharge, groundwater in the sub-basin of Quetta may be exhausted by 2016

There are other studies indicating that the level of contamination is changing with the change in the depth of the water table from the ground level. WWF (Feb 2007) noted a conclusion of a PCRWR study (1991) that contamination due to agricultural contaminants, such as pesticides, is high in shallow aquifers and is also gradually contaminating the lower aquifers. A water pollution fact sheet (wwfpak.org) describes the contamination of lower aquifers in Lahore. The fact sheet states that ground water pollution in 1989 was observed up to a depth of 91 meters and that it reached a depth of 152 meters in 1992, and presently, it has lowered below 213 meters (Fig 4.2). An article in the Daily Dawn (October 2004) presents the same figures, which implies that the estimates showing the contamination level below 213 meters depth date back to 2004 or earlier. The World Health Organization (WHO) declared it to be a serious contamination and advised that this water should not be used for human consumption.

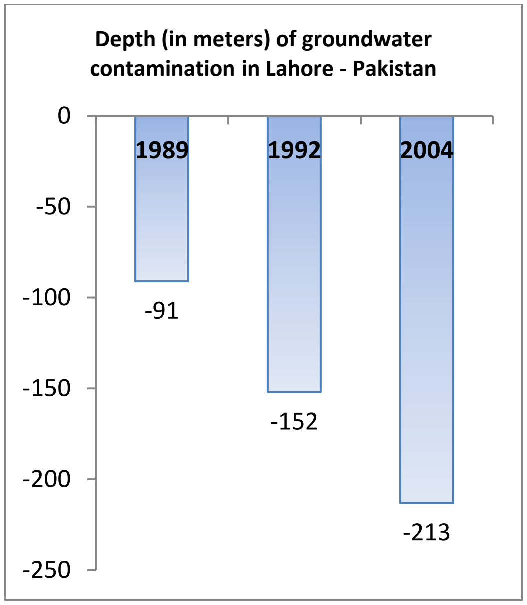


Figure 4.2: Increasing depth (meters) of contamination in groundwater in Lahore, Pakistan

According to Pakistan Water Situational Analysis (waterinfo.net.pk), “In NWFP [presently Khyber Pakhtunkhwa Province] abstraction in excess of recharge in certain areas, such as Karak, Kohat, Bannu and D.I. Khan has lowered the water table and has resulted in contamination from the underlying saline water. In Balochistan, the Makran coastal zone and several other basins contain highly brackish groundwater. As there is no alternative, local communities use groundwater for drinking purposes. In Mastung Valley, the groundwater has been found to have high fluoride content. The Makran coast and Kharan also have high fluoride groundwater.”

A study of the wells dug in four villages near Peshawar showed that 13% of well water at source had been found to be safe, 40% to be satisfactory while the remaining 47% was highly polluted (Zahoorullah et al., 2003). Nine percent of the initially clean water samples at source were found to be grossly contaminated after storage. Consequently, the inhabitants of these communities frequently suffer from incidence of a number of waterborne diseases. Such incidents are prevalent in smaller towns and rural areas of Pakistan, where proper diagnosis and treatment is almost impossible. Poverty and inadequate transportation infrastructure prevent them from visiting a doctor in the cities, or even a local clinic or regional public hospital. Most of them cannot afford to pay for the needed medical services.

In summary, the existing water sources are highly vulnerable, fragile and insufficient. The above examples confirm the trends observed in the field study. Therefore, it must be emphasized that the parameter of percentage coverage of the population for water is absolutely misleading and it cannot ensure sustainable access to safe drinking water.

4.4.2. WATER QUALITY

Although the study area is commonly considered to be naturally clean and environmentally friendly with no industry, or any significant use of agricultural contaminants, such as insecticides and pesticides, its water sources are getting contaminated rapidly. The major sources of contamination are untreated raw sewage and contaminated surface run-offs to drinking water sources. Water testing has not been part of the common practices for CBDWS. Poor quality water results in diseases, premature deaths, and serious socio-economic losses. Poor quality water at source, when delivered without any treatment to consumers, causes serious concerns, which get aggravated when coupled with deteriorated infrastructure that can "suck" aggressive elements from the surroundings. Most of the water supply infrastructure is severely deteriorated, and mixing of sewage with potable water is common, resulting in an unpleasant odor and serious health problems.

Figure 4.3 shows two 2008 photographs from Rawalpindi (a twin city with the capital of Pakistan, Islamabad), showing the high probability of mixing of drinking water with sewage from domestic sewers and open drains. Most of the water pipes leak severely owing to perforations and other forms of deterioration and distress, especially at the joints due to inferior quality of materials and very poor workmanship.

Figure 4.3: Water and sanitation infrastructure in urban areas of Rawalpindi

Figure 4.4 shows another photograph from Mansehra, a town near the field study area. A water main is completely exposed and has extensive leakage. The growth around the pipe shows that the pipe must have been exposed for a considerable time. Such a situation not only wastes water due to heavy leakage but it also serves as a cause of suction of aggressive elements when the pipe does not flow under pressure, and “sucks” the polluted water or other aggressive elements from the surroundings, especially from the deteriorated sewers. All communities in Pakistan, ranging from relatively small towns like Mansehra to mega-cities like Karachi are suffering from similar problems.

Figure 4.4: Condition of water pipe which is completely exposed in Mansehra

Septic tanks are the most commonly used sanitation systems in the region, which are usually built near or inside the compounds surrounding the houses due to space limitations. They are mostly in the close vicinity of the drinking water sources normally an open shallow well (Figure 4.5) or a hand pump. Owing to the absence of regular maintenance and repair practices, part of sewage seeps into the ground and the rest overflows to the immediate vicinity, either directly or indirectly to the nearby water bodies without any treatment when the septic tank becomes full and overflows.

Figure 4.5: A typical septic tank and a dug well within the compound of a house in a town

Such wells are shallow in depth, and receive water from the existing water table; they are located near the septic tanks mostly on the street side. A similar practice is usually repeated with the houses on the other side of the street, causing an overlap with the septic tanks in the recharge areas. The over-flow of the septic tanks follows the drains (covered or uncovered) through the streets, and gradually seeps into the ground because of a minimum use of water and inadequate drain slopes. These and other similar factors significantly increase contamination of water around the wells and hand pumps, which is drawn for household use without any quality checks and treatments to improve its quality. Even at the time of emptying these septic tanks, no inspections or checks are normally made for their physical and "sanitary" condition. No detailed study to estimate the impact of septic tank failures on the surrounding water bodies was available for the study area. However, a study conducted in Indiana in the United States (Lee et al., 2003) can help to understand the basic issue. There were approximately 800,000 septic tanks in Indiana, out of which about 200,000 (25%) were inadequate and had failed. The causes of failure were determined to be soil wetness due to seasonal rise in the water table, undersized systems, their age, and limited soil absorption capacity. After adoption of a regulation in 1990, which established guidelines for septic tank systems and their construction and repair, the failure rate decreased. It was shown that every failing septic tank can discharge over 76,650 gallon (290,150 liters) of untreated waste water every year. Under the prevailing circumstances, the projected failure rate in developing countries could be much higher because of poor quality construction and maintenance practices coupled with the absence of any controlling regulations. Another alternative to the septic tank, commonly used in some areas of Pakistan, is a simple open well (locally termed *gharqī* in Punjab) connected to a house for direct disposal of untreated sewage. Such wells usually have a depth close to that of the water table which causes mixing of the untreated sewage directly with the groundwater. There are no options available for overflow in such disposal wells or *gharqīs,* as the idea behind connecting them to the groundwater is 'mixing of liquid or diluted sewage into the groundwater and allow it to act as a part of groundwater flow. These are the direct causes of biological contamination and deterioration of the groundwater quality in the surroundings. Unfortunately, owing to the absence of tap water connections from a reliable source, this highly deteriorated water is recovered through open wells and hand-pumps, and is used for human consumption without any testing or treatment.

The most common sources of external contaminations are bacteriological in nature. However, in industrial areas, it is combined with untreated industrial effluents, directly disposed into the water bodies. Figure 4.6

shows the combination of bacteriological and industrial contamination discharged directly into the surface water sources.

Figure 4.6: Combination of bacteriological and industrial contamination (Kasoor, Punjab)

Groundwater sources are getting contaminated from seepage through the septic tanks, poor sewage disposal, stagnant ponds and poor drainage, unlined contaminated channels, pesticides/insecticides in agricultural area, and other similar agents. A common practice in these areas is to obtain water from the water table because it requires less energy and effort to draw it to the surface. In cities and towns, almost 90% of such sources are seriously contaminated and affect the consumers. In some communities, the water quality is so poor that the taste and smell can immediately indicate its bad quality without even undertaking any detailed laboratory tests.

In summary, the various examples shown from similar and connected areas, and the available reports show clearly that the water quality in the region is not fit for drinking purposes and that, with passage of time, the extent of contamination will continue to worsen. Without serious consideration of water quality, sustainable access to safe drinking water would be highly compromised.

4.4.3. Distribution Infrastructure

Design documents for distribution infrastructure in every community were not available for review However, the manuals for design and construction of these systems show that the design approaches are often grossly over-simplified. Sustainable access to safe drinking water in an efficient and economic manner requires optimal design to develop in-built controls to deliver water to these communities through careful considerations of the source capacity and the basic needs. This requires data through source monitoring in the field, and population growth trends for the specific communities.

Physical condition of the distribution infrastructure depends highly on proper operations and regular maintenance. Ignoring these aspects has resulted not only in wastage of valuable natural resources, but also in negatively affecting the useful life of the distribution infrastructure. Deferred maintenance costs considerably more to restore the distribution infrastructure to proper working conditions as deferred maintenance leads to increased deterioration at a considerably escalated rate requiring more expensive repair and rehabilitation, which, in turn, results in large compounded deficits over time. This field study showed that half of the communities have no organizational body responsible for operational activities and maintenance, which is undertaken only when some form of distress or failure occurs.

At many critical locations in several communities, distribution infrastructure is not buried for protection, and it remains open on or above ground. In hilly areas, there were many places where distribution infrastructure faces a serious threat from landslides, and damage due to movement of animals. Leakages are common in most of the new and old systems studied. In new systems, it was mostly due to poor design and very faulty workmanship, such as improper joints. Figure 4.7 shows the nature of such deficiencies where deteriorated and improperly or unmaintained infrastructure is the principal reason for water wastage and possible contamination.

Figure 4.7: Wastage of water due to leakage and breakage, resulting from deferred maintenance

4.4.4. AVAILABILITY AND UTILIZATION OF FUNDS

Although some savings were noted in these communities during the interaction with the community organizations in the field, separate estimates and allocation of funds for maintenance were not documented anywhere in the community records. In a few agreements between the communities and the system providers (mostly NGOs), a small percentage (about 2% - 3%) of the project cost was assigned for maintenance purposes every year. However, this agreed proportion of cost was never saved on a regular basis in the communities studied. They arranged the finances on an “as needed” basis to maintain and restore the infrastructure.

There were no serious complaints of financial corruption or misuse of the funds, which are rampant in some developing countries at various government levels. However, community-based systems were found to be at a minimum risk of corruption. The major reason for such transparent use of funds was the involvement of local people at all stages. The role of the NGOs involved was noteworthy in preventing corruption.

Most of the communities did not depend on external sources of funds for maintenance. Community organizations mostly used collection on “as needed” basis from the consumers. The concept of payment for infrastructure depreciation was totally absent. There were examples of systems that were non-functional due to non-payments of electricity bills (for pumping the water to overhead tanks) in both governmental and non-governmental schemes.

Although, regular maintenance is very important for continuous functioning of CBDWS, it is emphasized that properly maintained systems perform above the minimum required performance level for relatively longer time periods (Line 1, Figure 4.8). Occasional and irregular maintenance (Line 2, Figure 4.8) can help to maintain a minimum performance level up to a certain point. However, a system can fail or face premature deterioration with a very low possibility of salvage (Line 3, Figure 4.8) if no maintenance is performed (Mirza, 2005).

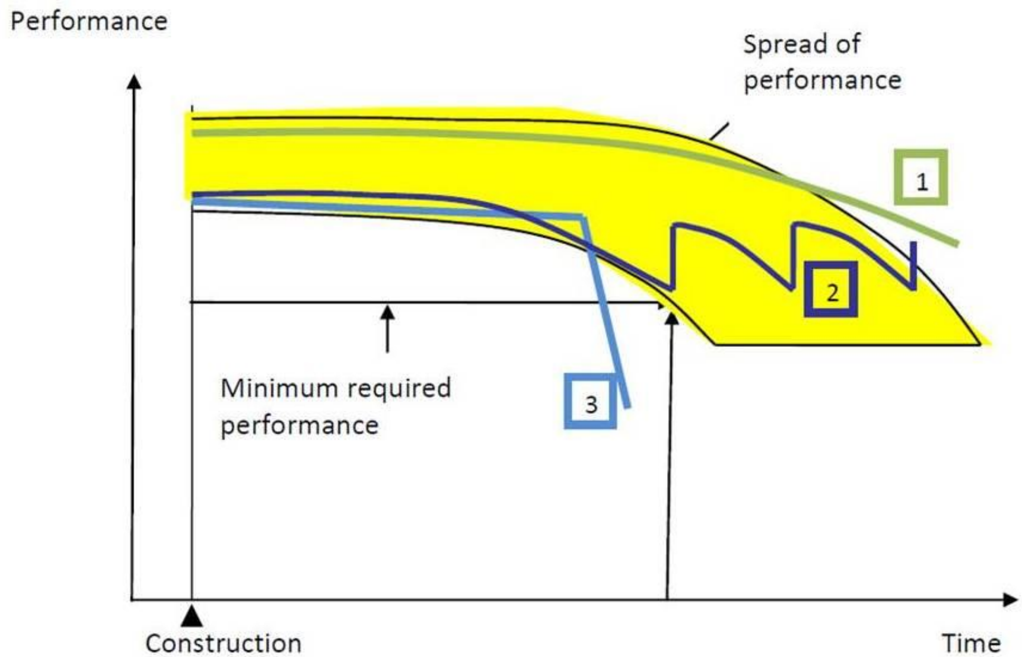


Figure 4.8: Condition of water pipe which is completely exposed (adopted from Sipos, 2011)

The performance curves in Figure 4.8 show that any neglected or deferred maintenance would lead to costly repairs, major rehabilitation or even replacement of some components or the entire structure at an exorbitant cost well before the end of the expected system service life. An approximate relationship between these costs has been proposed by De Sitter's (CEB, 1992), whose Law of Fives suggests that $ 1 spent for correct design and construction (Phase A, Fig. 4.9) is as effective as $ 5 in maintenance during the pre-deterioration stage (Phase B), $ 25 in the deterioration stage (Phase C) and $ 125 in the stage of extensive and major repairs during Phase D (Figure 4.9). This law is not absolute for all type of systems; however, it clearly suggests the intensity and extent of financial impact due to neglected and deferred maintenance on the overall life cycle costs.

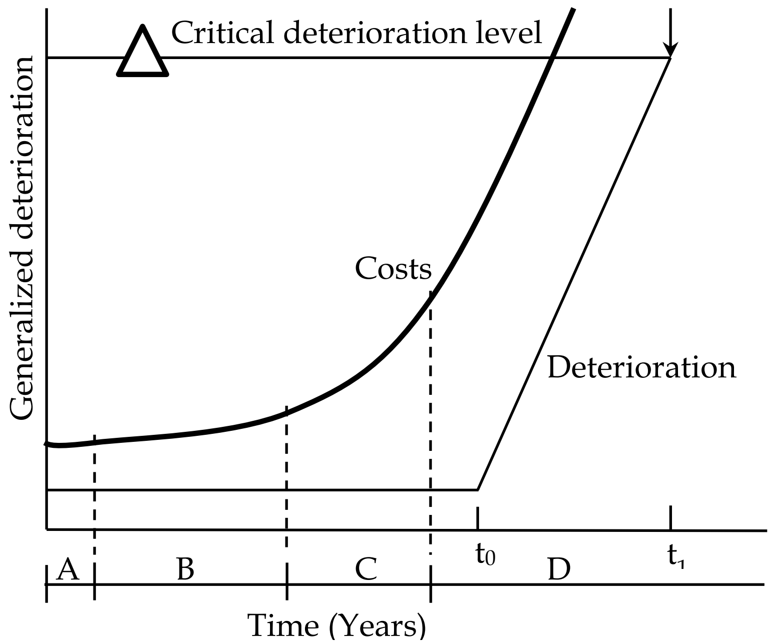


Figure 4.9: The Law of Fives showing the onset of generalized deterioration due to neglect and deferral of maintenance; t1 makes the end of the service life when the system needs to be replaced

No arrangements for such financing requirements are built into the existing system models. Present donors, whether domestic or international, would not be in a position to re-invest in already existing systems for two major reasons:

1. The MDG target was to halve the world population proportion without access to safe drinking water by 2015. The remaining half was to be addressed after 2015, which would have a larger population to serve, as the world population is continuously increasing. This half to be served in the future will represent a difficult challenge, making it harder to cater to the needs of the population already covered. Also, the world would have relatively

less water resources for a larger future population making it considerably harder to handle the predicament.

2. The developing countries will face increasing donor fatigue due to global economic conditions. Difference between international pledges made after the earthquakes in Pakistan (2005) and Haiti (2010), and floods in Pakistan (2010) show that the amounts actually delivered were always less than the originally pledged amounts. Uncertainties such as unforeseen natural disasters (for example, hurricanes or earthquakes) in major donor countries can also create further complexities.

In summary, it will be harder in the future to have the same expectation of donations from developed countries for the remaining half of uncovered population after 2015. Donor agencies and SPOs will be relatively less capable of helping as their resources would have serious limitations. This aspect calls for developing mechanisms for continuity of CBDWS on the basis of community self-reliance; otherwise, “fallbacks” in the coverage of population without clean drinking water will continue to increase.

4.4.5. Socio-Economic Issues

Probability of achieving successful CBDWS is linked to the awareness level and to effective utilization of available resources. Unfortunately, the findings show that communities are not fully aware of the basic issues. About half of the communities assume that existing water sources are unlimited and therefore these do not face any capacity issues. Better usage practices are not enforced. In-built controls such as paying for water consumption beyond the basic needs do not exist. A majority of communities are not aware of the effects of untreated raw sewage disposed into or near water bodies. Interactions with school teachers show that the existing courses and practices in teaching play no role at all towards increasing the awareness about these issues. The entire reliance is on social organizers from the various NGOs to educate the communities. Meeting with service providing NGOs showed that they have serious time, training, and resource limitations. Most of them had targets to form community organizations capable of running a system to execute one project only.

Poor quality water had negative economic impact on the community: Water-related diseases limit their earning capacity, increases costs for travelling and medical expenses, and results in pre-mature deaths. Continuity of the current situation may lead to a chronic situation, affecting all bases of a productive and effective society.

4.4.6. INSTITUTIONAL CAPACITY

Institutions, in general, are the expression of collective human experience and a reflection of the interaction of people with one another and their environment. They play a role in solution of the various social problems. Institutions are required to ensure sustainable systems that are holistic and adaptive in nature (Cortner et al., 1998).

As mentioned earlier, thousands of such systems throughout Pakistan failed owing to administrative and technical incompetence, or due to the lack of overall capacity on part of the responsible community institutions (CIDA 2006). It should be noted that community institutions are not organized on the basis of trained professionals and formal constitutional disciplines; they are only community organizations (COs) based on memberships and hierarchy of office bearers, either elected or agreed upon by the community members. Obviously, availability and willingness are the basic conditions for a member to work as a responsible office bearer. However, any selection on the basis of merit related to skills or technical and administrative capacity is very hard to achieve on a purely voluntary basis. Additionally, the agencies responsible for initial execution of such systems leave the region soon after its completion, and the entire burden is then transferred to the COs. Some of the important issues and practices that need review are:

1. Community institutions are considerably motivated during the needs identification period, following approval of a CBDWS for their community, and during its execution and early days of operation. With formal completion of the project, most of the service providing agencies (NGOs) normally lose their focus and leave the area because their stay in the area is only project-based with no permanence. These service providing agencies have authority only during the execution period, and play the role of pay masters in all operations for design and execution of CBDWS. However, when they leave, communities get relaxed and revert to the "normal" routine activities. The concept of communal ownership, such as owning a community-based project, is not exactly felt in the same way as the personal ownerships. No alternate or umbrella institutions exist to play the role for continuing support, monitoring, and evaluation of the systems over a period of time. Consequently, deterioration in the system commences at the institutional levels and continues to increase with the passage of time.

2. Contracts between the communities and service providing agencies are mostly effective during the execution stages only, because of financial control by the service providing agencies. Almost all of the agreements reviewed did not have any provisions for questions as:

"What are the consequences if a community organization does not follow the guidelines or instructions during the operation and maintenance period, considering the proposed project life?" There are similar questions on the status of these organizations, memberships and their legal position.

3. All positions and responsibilities are entirely voluntary, and any member or activist can retire without any prior notice, causing difficulties for the community.

4. CBDWS are community-managed drinking water systems in a vast majority of cases. These institutions lack independent and capable, trained personnel for proper operation and maintenance on the technical side, who could safeguard the society and the local environment from environmental hazards. There are considerable difficulties on the socio-economic side in keeping the society involved and effective. This task is clearly not possible for just any small or large community. Communities can manage routine operations and protection of the distribution infrastructure to some acceptable level. To make the CBDWS sustainable requires a holistic approach and diligent permanent institutions, which is beyond the scope of mere "community organizations". It shows that the existing model of community institutions may not be capable of making such systems sustainable. The most important reasons are the lack of technical and administrative capacity, and non-permanence of available volunteers. This leads to the requirement of umbrella institutions established on permanent and professional bases to guide, help, and improve the community institutions (Chapter 7).

CHAPTER 5. ENVIRONMENTAL SUSTAINABILITY OF CBDWS

[*This chapter deals with environmental sustainability of CBDWS in terms of capacity, reliability, quality, and protection of natural water sources. The status of natural water sources is presented and possible scenarios of "fallbacks" up to 2015 are developed.*]

5.1. INTRODUCTION

A model consisting of five main components for an overall sustainability of CBDWS was presented earlier (Chapter 4). The environmental sustainability component is quite critical as it is directly linked to the natural resources. As shown in the model in Figure 4.1, the capacity and reliability of existing sources (link 1 and 4), their quality (link 5) and their protection (link6) provide a foundation for sustainable CBDWS. In contrast with the other four components, environmental component is directly linked with natural water sources which are limited in terms of their renewable capacity and are sensitive in terms of their protection and quality. Table 4.2-A showed that environmental component is in a dire condition in the regions of study. A question arises: *To what extent an environmental component alone may affect the sustainability of drinking water systems provided to target population?*

5.2. METHODOLOGY

This chapter examines the status of environmental component of CBDWS sustainability on the basis of data collected during the fieldwork (See Chapter 3, Table 4.2 and Appendix A for details). The target for covering a proportion of population without access to safe drinking water set in the U.N. MDG was taken as the benchmark to study the impact of environmental sustainability. According to the United Nations

Development Program (UNDP), "Progress on environmental sustainability is mixed and too slow", and "reporting on environmental sustainability is a challenge for many countries, due primarily to unreliable and inaccessible data and a lack of statistical capacities and monitoring mechanisms"(Lee and Ghanime, 2005). In this situation, the results of the field study were extrapolated assuming similar conditions in other parts of the world without access to improved drinking water. The various scenarios for possible fall-backs due to permanent depletion of sources, insufficiency of water, and contamination of sources were developed. These "fall backs" were calculated assuming that all covered proportions are in rural areas of developing countries and that the population growth is uniform (Aslam et al., 2012).

5.3. RESULTS AND DISCUSSION

The results from the field data include types of water sources, their capacity to fulfil the population needs, variation in water availability with seasonal changes, depletion of existing water sources, protection from damage and contamination, and water quality of these sources. The results are discussed briefly. This section is presented in two sub-sections: (i) summary of relevant data and discussion, and (ii) future scenarios.

5.3.1. SUMMARY OF RELEVANT DATA

5.3.1.1. TYPES OF WATER SOURCES AND SELECTION

Selection of water sources had limitations in terms of funding and availability of alternate sources. Figure 5.1 shows that surface water sources (rivers, streams, springs, and open wells) comprise over 77% of all sources. Over 91% of these systems became operational in 1990 or later. About two–thirds of the sources are natural springs, which are the nearest available water bodies suitable to provide water by gravity flow to the communities in Northern Pakistan (Figure 5.1). Gravity flow is cost-effective and easy to manage as it does not require expensive and intermittent electric power for pumping, which may not be available for several hours owing to considerably discontinuous electric power supply. The second most common type of water sources are streams (8%). In addition, groundwater sources comprise 4% of all water sources.

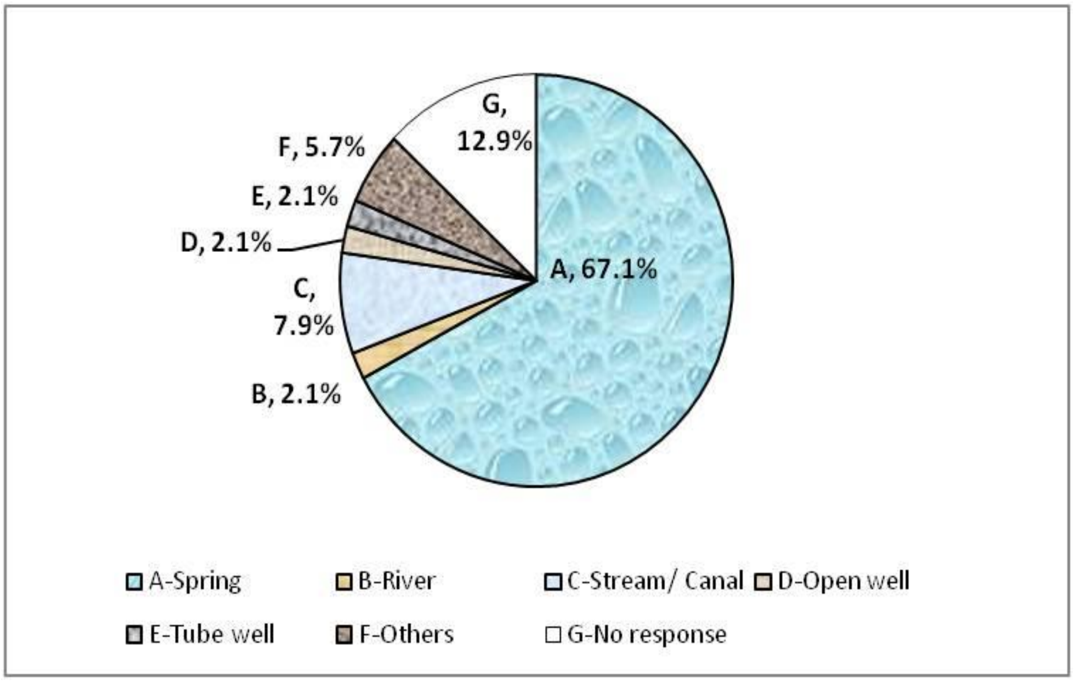


Figure 5.1: Types of water sources

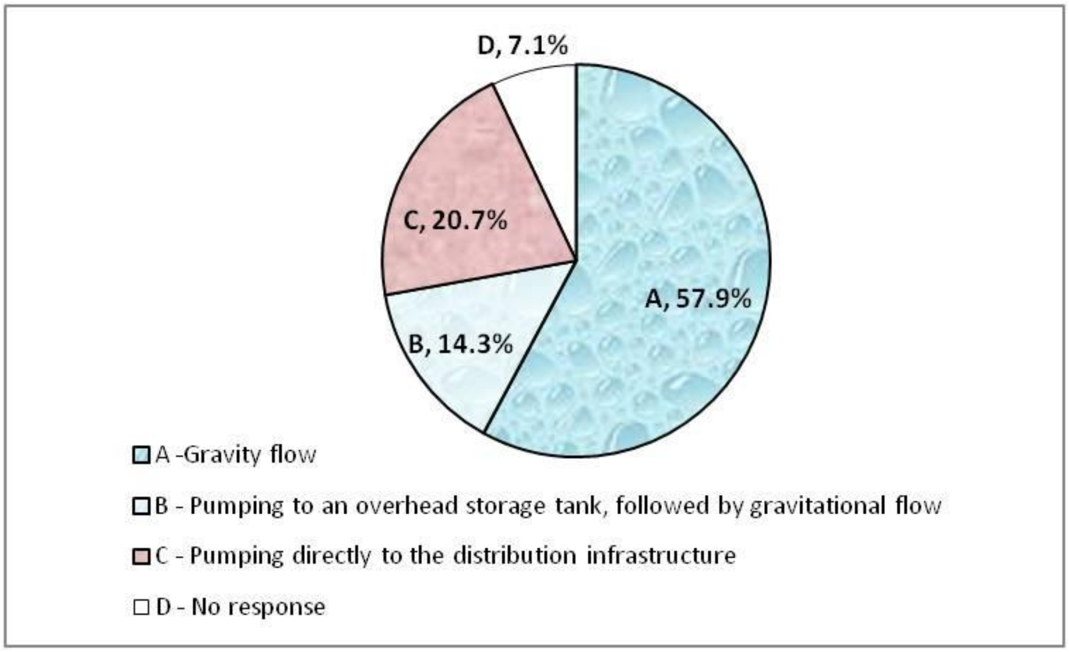
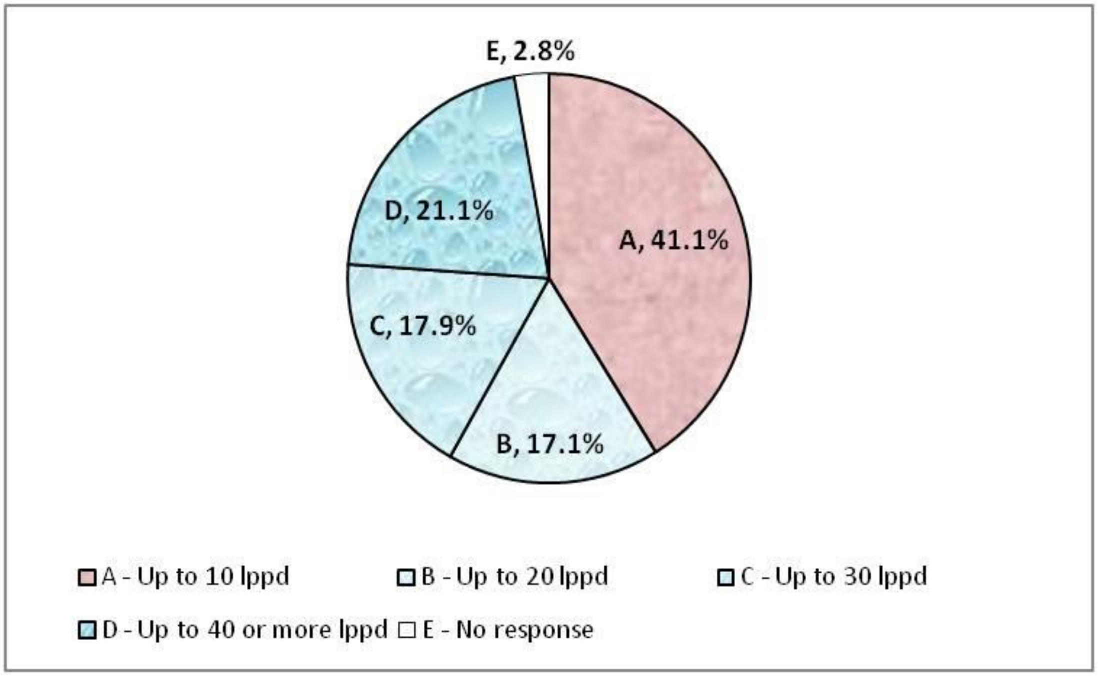


Figure 5.2: Water supply systems in different communities

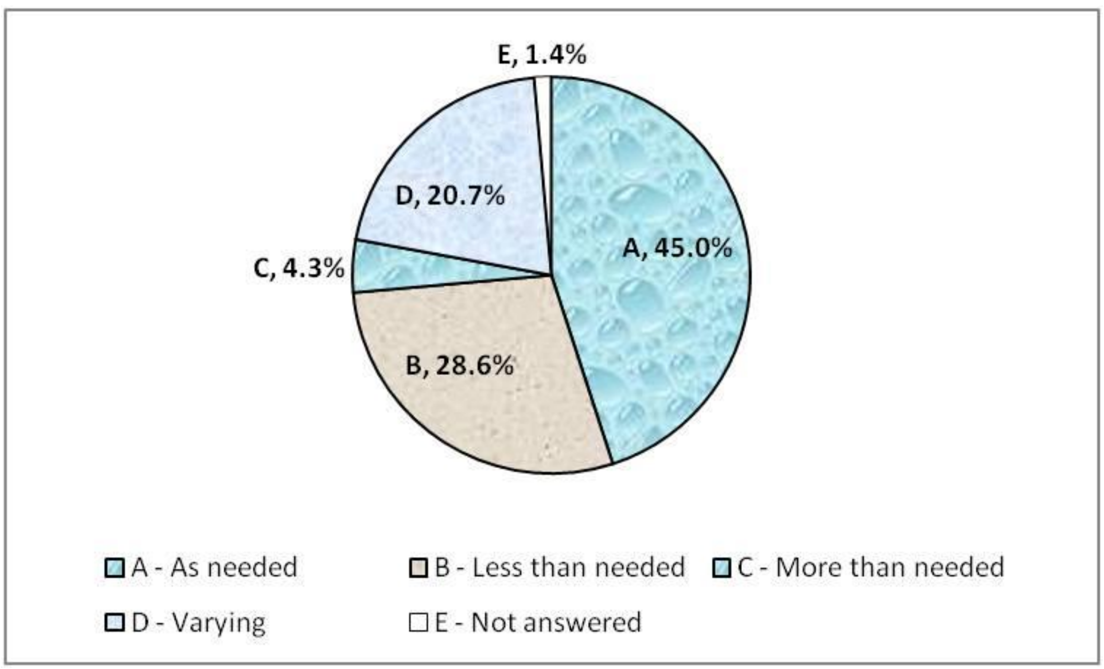
Gravity flow was achieved in about 58% of the communities (Figure 5.2). Another 14% of the communities were able to reduce their reliance on electric–powered pumping of water with the provision of an overhead storage tank.

5.3.1.2. Capacity of Water Sources with Respect to the Population Needs

In 58% of the communities, normal daily water needs were reported to be up to 20 litres for each person per day (Figure 5.3(a)), which is consistent with the bench mark of reasonable access to clean drinking water, defined by WHO and UNICEF (Oldfield, 2006). Field data (Figure 5.3(b), Segments B and D)) show that over 49 communities are receiving water quantities that are permanently or seasonally less than their needs.



(a)



(b)

Figure 5.3: (a) Daily needs of drinking water and (b) Water quantity available from sources

5.3.1.3. Reliability of Sources

The sources examined in this study face significant seasonal variations, and partial or permanent depletion over longer time intervals. The anecdotal reports from the communities on the basis of several years of observations suggest that 79% of sources are facing either seasonal variation in quantity and/or permanent depletion resulting in unreliability of sources, which would seriously affect the water supply to the communities in the future (Figure 5.4). Permanent depletion was reported in about 21% sources (Appendix A, Question 7), which shows that about 58% of the sources are facing seasonal variations. Therefore, presently and in the future, the overall availability of water had decreased in many communities where a number of natural streams had become dry. The problem was further compounded by sedimentation in streams and lakes. Silting is dependent on the prevailing environmental conditions, which are linked to deforestation and erosion of the upstream area, which can reduce the reservoir capacity.

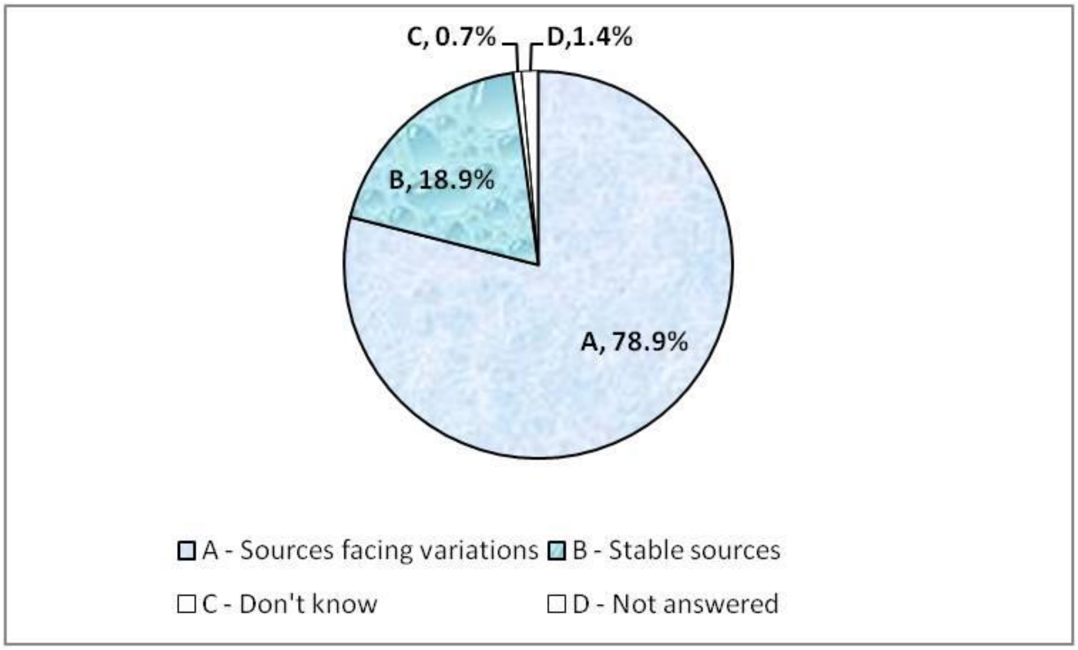


Figure 5.4: Variation in water quantity at sources

Interviews with experienced well diggers (skilled workers) showed that over the past 15 years, existing wells had to be excavated deeper by 1.5 to 2 m (5 to 7 ft) at 2 to 3 year intervals, because of the gradual lowering of the ground water level in the region. Deeper open well digging is extremely expensive; it also risks suffocation of well diggers at greater depths. Consequently, open wells have been replaced by bore holes; however, the pump intake had to be lowered periodically, which confirms the observations by the well diggers on the lowering of groundwater levels. This lowering of groundwater level is probably due to a reduction in precipitation recharge of the groundwater, and an overexploitation of the groundwater sources (Khan et al., 2008). In summary, it is indicative of an overall net loss of available water to the region.

The various causes of seasonal variation, noted during the field visits and random interviews include variation in the amount and frequency of precipitation in different seasons of the year, melting of snow glaciers, and increase in usage during warm weather. Also noted was permanent depletion due to higher usage and pumping rates as compared with recharge rates of these sources. The above observations are consistent with some of the hydrological studies conducted in the region where the main river flows are controlled by high altitude glacier melts, and stream flows are controlled by local precipitations (Archer, 2003). It has been established that for the period 1961–2000, the glacier melts at lower temperatures in the summer despite an overall warming trend for Pakistan as a whole (Fowler and D.R.Archer, 2006). In addition, the average annual precipitations did not change in the region for the same period, but the most important summer precipitations had decreased in comparison with the rest of Pakistan (Archer and Fowler, 2004, Hussain et al., 2005) . This problem of access to adequate water quantity caused by a changing climate is exacerbated by increasing pumping rates due to a rapid population growth and agricultural development, which results in overexploitation of the water sources characterized by 73% of the Indus River being abstracted for human activities(Archer et al., 2010).

5.3.1.4. PROTECTION OF WATER SOURCES

A majority of drinking water sources in the study area (over 77%) are surface springs, mixing with runoffs from surrounding areas and with untreated sewage. There is no significant industry in the region. Contamination is mostly “bacteriological” due to mixing of fecal matter either from surface through runoffs or due to mixing of untreated sewage from the communities. In rural areas, such run–offs are carriers of varying levels of microbiological contamination, resulting principally from animal and human wastes. Approximately 42% of the sources studied are not protected. At many locations, source protection is confused with collection tanks constructed to ensure continuity of gravity flow. Figure 5.5 is a combination of two photographs of a collection tank at source where water is flowing on the surface of the tank (Figure 5.5a) and a rusted lid with holes (Figure 5.5b), causing the contaminated water to mix with the source water. As a result of inadequate protection, highly turbid and contaminated water is delivered directly to the communities without any treatment. It is important to note that such sources were reported as "protected sources" by the communities because of the existence of a concrete structure and metallic lids/covers; however, in reality, they are unprotected and result in an increase in the proportion of unprotected sources in the communities.

(a)

(b)

Figure 5.5: (a) Collection/storage at a spring source, (b) Contamination before delivery.

5.3.1.5. WATER QUALITY AT SOURCE

Only 29% of sources were tested for water quality (Figure 5.6). Less than 19% of water sources were tested for the overall water quality before planning of the distribution systems. Over 65% of the sources were not tested at all even after commissioning of the projects.

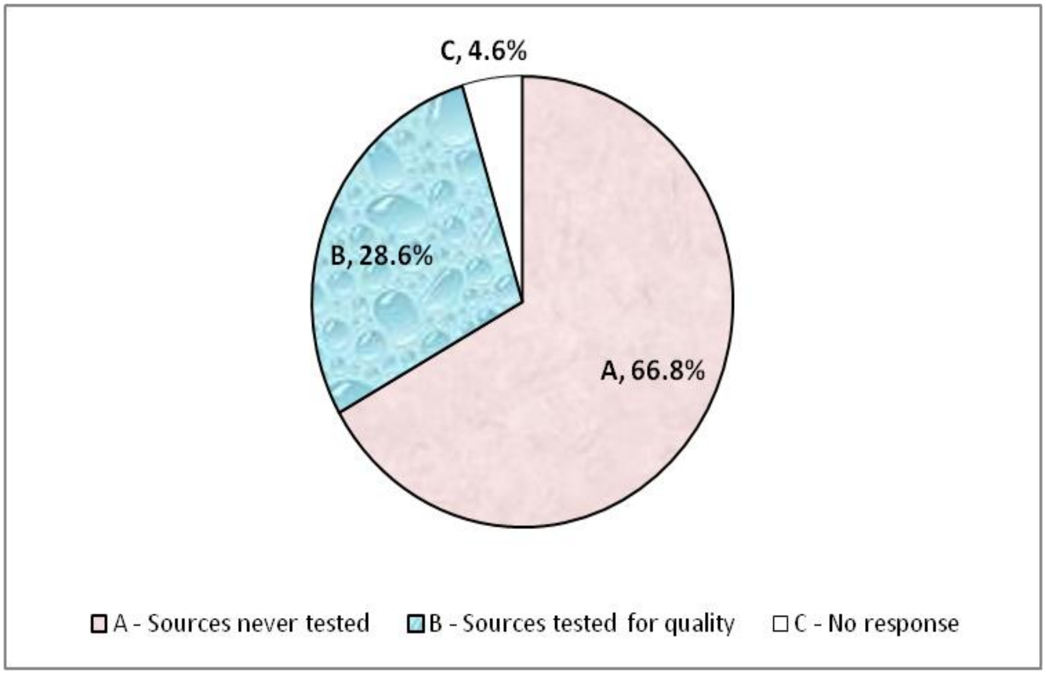


Figure 5.6: Water quality tests conducted for sources

The available documentary evidence shows that in some communities, water sources were unfit for consumption after initiation of the water supply. The official website of the Pakistan Council of Research in Water Resources (PCRWR, 2002) presents the findings of the Rural Water Quality Monitoring Project (RWQMP), which was started in 2002, covering 64 tehsils (sub–districts) in four provinces. The report showed that 80–85% of water samples from 48 sub–districts were bacteriologically unsafe for drinking, and contained higher values of TDS [Total Dissolved Solids] and turbidity. The same report also includes the results for 23 surface water bodies, showing that all of them were bacteriologically contaminated and with higher values of turbidity, TDS, nitrate and lead. A study conducted in the upper part of Khyber Pakhtunkhwa (KP) province and Northern Areas (Malik et al., 2010), close to the region being studied, showed that from 79% to 98% of the samples were unsafe for drinking purposes. Table 5.1 shows that 86% of 736 samples tested were contaminated with the most common presence of coli form bacteria, which is unacceptable for safety of drinking water.

Table 5.1 - Status of water quality in region

Description	Number of total samples	Number of contaminated samples	Percentage of contaminated samples
Direct collection of samples from 6 communities (2009)	6	5	83 %
Reports from 6 community records (2009)	6	6	100%
Pakistan Council of Research in Water Resources (PCRWR, 2008)	357	312	87%
Water quality in 5 districts of upper KP Province (Malik et al, 2010)	255	201	79%
Water quality in 5 districts in Northern Areas (Malik et al, 2010)	112	110	98%
Total	736	634	86%

Field observations showed that untreated domestic raw sewage was disposed directly into the water bodies. Open field defecation in the area had gradually decreased to 15% of the population in the communities, and a vast majority (84%) in these areas were using "flushing" toilets. Over

31% of the survey responses showed that sewage is a common source of pollution in drinking water in the communities.

Despite these bleak observations, there was not a single treatment plant in any of the 70 communities studied, and the water was delivered to the consumers in an untreated condition. Officials of the different service providing agencies (mostly NGOs) noted the serious limitations in the water supply budgets, along with limited options for alternate water sources in the vicinity.

According to the JMP Report (WHO/UNICEF, 2010), meaningful solutions are needed to ensure safe water supply to the households, which are beset by technical, logistic and financial difficulties. As mentioned earlier, the definition of improved drinking water sources is based on the nature of storage and supply infrastructure construction, without dealing with the actual quality of water at the source. It should be noted that any of the deep ground and surface water sources can be contaminated irrespective of the type of the construction used, which is a great challenge in providing sustainable access to safe drinking water.

5.3.2. FUTURE SCENARIOS

Table 5.2 and Figure 5.7 show the possible population water supply coverage scenarios on the basis of the JMP Report and the data in this chapter. According to the JMP report, the projected coverage is expected to be around 14%, which is ahead of the target of 11.5% set in the U.N. MDG. This report suggests that only 672 million people (9% of the world population, Point C) would be without access to safe drinking water by 2015 (WHO/UNICEF, 2010). On the basis of the data collected during this study, and considering the 9% of the population without water by 2015 as reference (Point C), different scenarios are presented in Figure 5.7.

Assuming similar conditions in other parts of the world without access to improved drinking water, the field data and the present trends show a possible "fall back" due to permanent depletion of sources (Point D), insufficiency of water (Point E), and contamination of sources (Point F). These "fall backs" are calculated assuming that all covered proportions are in rural areas of developing countries and the population growth is uniform.

Table 5.2 - Access to improved drinking water sources–proportion of the population from 1990 to 2015

I–Observed and target proportions reported in the JMP[1]

Description	**Year**	**Population without access to improved drinking water (%)**	**Point in figure 5.7**
Without access to improved drinking water sources in 1990	1990	23	A
Without access to improved drinking water sources in 2008	2008	13	B

II–Projected scenarios for proportion in 2015

Scenarios	**Possible fall-back (%)**	**Projected percentage population without access to improved drinking water (%)**	**Point shown in figure 5.7**
Projected proportion without access to improved drinking water sources by 2015 (without fall back)[1]	NA[2]	9[3]	C
With 21% permanently depleting sources	3[4]	12[5]	D
With 49% insufficient sources	7[4]	16[5]	E
With 86% contaminated sources	12[4]	21[5]	F

[1] (WHO and UNICEF, 2010)

[2] NA: Not Applicable

[3] Linear extrapolation based on proportions in the JMP report for 1990 and 2008:

2015 Projected proportion without access (without fall–back) [Point C] = (Point B−Point A)/18 years×25 years + Point A

[4] Possible Fall–back = (Point C−Point A) × Scenario Fall–back Proportion

[5] Projected Proportion = Point C + Possible Fall–back

Figure 5.7 shows a serious risk of "fall–back" in all 70 communities, if depletion, insufficiency, and contamination of the available water sources are not remedied. Points D, E, and F show the possible levels of such "fall–backs", which may lead to a situation similar to that in 1990. A total or partially fresh start would then be needed with fewer clean water sources being available. The different scenarios in Table 5.2 and Figure 5.7 can be refined when improved data becomes available in the future.

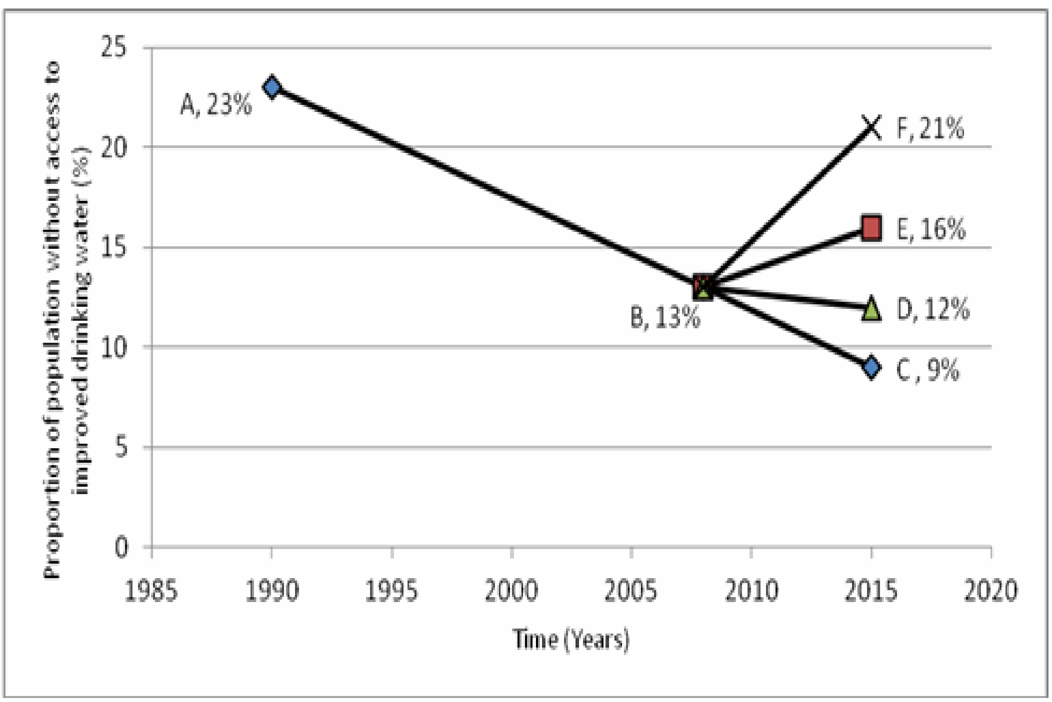


Figure 5.7: Projected population without access to improved drinking water– different scenarios for the year 2015

CHAPTER 6. STAKEHOLDER PERSPECTIVES

This chapter deals with establishing and revealing the stakeholder perspectives and priorities towards the sustainability of community-based drinking water systems (CBDWS).

6.1. INTRODUCTION

Promulgation of the concept of participatory approaches for community-based systems (CBS) was noticed especially in regions with shortage of resources and discriminatory patterns of water allocations, such as South Africa and Zimbabwe (SADC, 2002). The community-based development appeared "among the fastest growing mechanisms for challenging development assistance" in 1990s and 2000s (Mansuri and Rao, 2004). During the same period, community management models became popular throughout the Sub-Saharan Africa (Peter and Nkambule, 2012). Some examples of active participation of the communities in water management include the irrigation management in north-eastern Tanzania, flood management system for Alexandra community (South Africa), Mlazi river participatory catchment management program (South Africa), and the Mbongolwane wetland projects (South Africa) (SADC, 2002). Although, community-based systems are based on participatory approaches of involving stakeholders, no studies were found in the literature focusing on stakeholder perspectives and subjectivities about sustainability of CBDWS. This chapter deals with the evaluation of stakeholder subjectivities, and their intrinsic biases and priorities, which are aimed at developing a framework for evaluation of sustainability of CBDWS.

For this study, the survey respondents were stakeholders identified in Section 2.4.1 defined as follows:

- **Technical Stakeholders:** This group of stakeholders comprises mainly engineers and other professionals associated with the water distribution infrastructure, through its design, execution, maintenance and rehabilitation when needed, and decommissioning and disposal of the water distribution infrastructure.at the end of the asset service life.
- **Environmental Stakeholders:** This group of stakeholders comprises mainly professionals who are engineers, scientists, and technicians, dealing mainly with the planning and monitoring the capacity, reliability, quality of water resources. They are also concerned with water source protection and environmental impact assessment.
- **Economic Stakeholders:** This group of stakeholders comprises mainly professionals involved with financing and economic issues related to the water distribution systems. These professions are normally financiers, accounts managers, economists, and donor representatives.
- **Social Stakeholders:** This group of stakeholders comprises mainly social scientists, social organizers, and social workers, who are involved in social organization of the communities.
- **Institutional Stakeholders:** This group of stakeholders comprises individuals involved with community institutions as members, developers or organizers.

Proper long-term management of CBDWS requires a sustainable approach to the decision-making process, which relies on the various components, previously defined in Section 2.1.5 as: technical, environmental, economic, social, and institutional components. To facilitate decision-making towards a sustainable CBDWS, it is important to analyze and synthesize the stakeholder subjectivities and understand their intrinsic biases and priorities, which is the focus of this chapter.

Some efforts to develop a framework for evaluation of sustainability of urban drinking water systems were reported recently (Fagan et al., 2010, Hellström et al., 2000). Similar efforts were also made for sustainability of one or a few components of rural water supply systems (Jones and Silva, 2009, Lundin and Morrison, 2002, Nare et al., 2011). Unfortunately, these studies either did not consider the stakeholder perspectives (Giné and Pérez-Foguet, 2008), or they lacked the involvement of stakeholders to define priorities and subjectivities (or weights) for the various sustainability elements (components, factors and sub-factors) of CBDWS (Panthi and Bhattarai, 2008, Peter and Nkambule, 2012). Consequently, no data was found for comparison with the results of this study. However, these earlier studies provide a good start towards development of an evaluation framework, even if they lack the stakeholder context to be fully relevant for field applications.

To synthesize the stakeholder subjectivities, this study is based on a survey conducted to obtain stakeholder input to their priorities for the various elements of sustainability of CBDWS.

6.2. METHODOLOGY

A web-based, or an alternate paper-based version of the survey was used to elicit answers from stakeholders contacted randomly; the choice depended on the convenience of the respondents. Each respondent was required to make a number of pair-wise comparisons between five components, or between the two to three factors within each component (Appendix B). The Analytical Hierarchy Process (AHP) was used as a tool for ranking the various sustainability components and factors. The weights obtained using the AHP algorithm are a measure of the stakeholder subjectivities. The sub-factors were not made a part of the main survey; however, online respondents were provided with an option to deal with the sub-factors (Section 3.3.3). The survey questionnaire is presented in Appendix B.

The stakeholders were asked to report: (1) how they best define themselves as an individual belonging to one of the identified groups, that is, technical, environmental, social, economic, or institutional stakeholders, (2) their organizational and social affiliations (serving or representing academia and education, consultancies and the fields of infrastructure execution and management, governmental and non-governmental service providing agencies, and community institutions, such community organizations and their various sub-units), (3) the number of year of experience, and (4) their geographic origin (from Pakistan or elsewhere). The pair consisting of associations of stakeholder groups and their affiliations was tested by conducting a chi-square test of independence to examine the relationship between the identified groups of stakeholders and their reorganized grouping based on their affiliations as described above (Table 6.1). The pairs, consisting of association between each group of stakeholders and years of experience were tested using the univariate analysis of variance (ANOVA) with years of experience for the quantitative response (Sokal and Rohlf, 1994) (see section 3.2 for details).

The weights between the stakeholders groups were compared using multivariate analysis of variance (MANOVA) for components and factors within each technical component. These comparisons were performed using ANOVA for the factors within the other components as the choice was between only two factors (i.e., only one degree of freedom in the attributions of weights) (Sokal and Rohlf, 1994), using the raw weights for each response. Once the overall null-hypothesis of no difference between the groups was rejected ($p<0.05$), the similarity between the groups was tested using contrasts for the components, or using the Duncan pairwise multiple comparison for the factors (Sokal and Rohlf, 1994) (see section 3.2 for details).

6.3. RESULTS

6.3.1. SURVEY RESPONSES

Over 450 randomly selected individuals were approached for completing the responses to the survey questionnaire. The response rate was a little over 50%, with a total of 232 responses from the various stakeholder groups (Figure 6.1(a)), including 55 women (31.5%) and 177 men (68.5%). The respondents from the technical, environmental, and social groups of stakeholders were similar in numbers, and slightly higher in numbers than the ones from the institutional and economic groups of stakeholders (Figure 6.1(a)), which represents the degree of difficulty in contacting the stakeholders in equal numbers in each category. Despite this effort, the respondents from the academia/education sector were more receptive, and they responded in slightly higher numbers (Figure 6.1(b)). The proportion of the respondents from service providing agencies was the lowest.

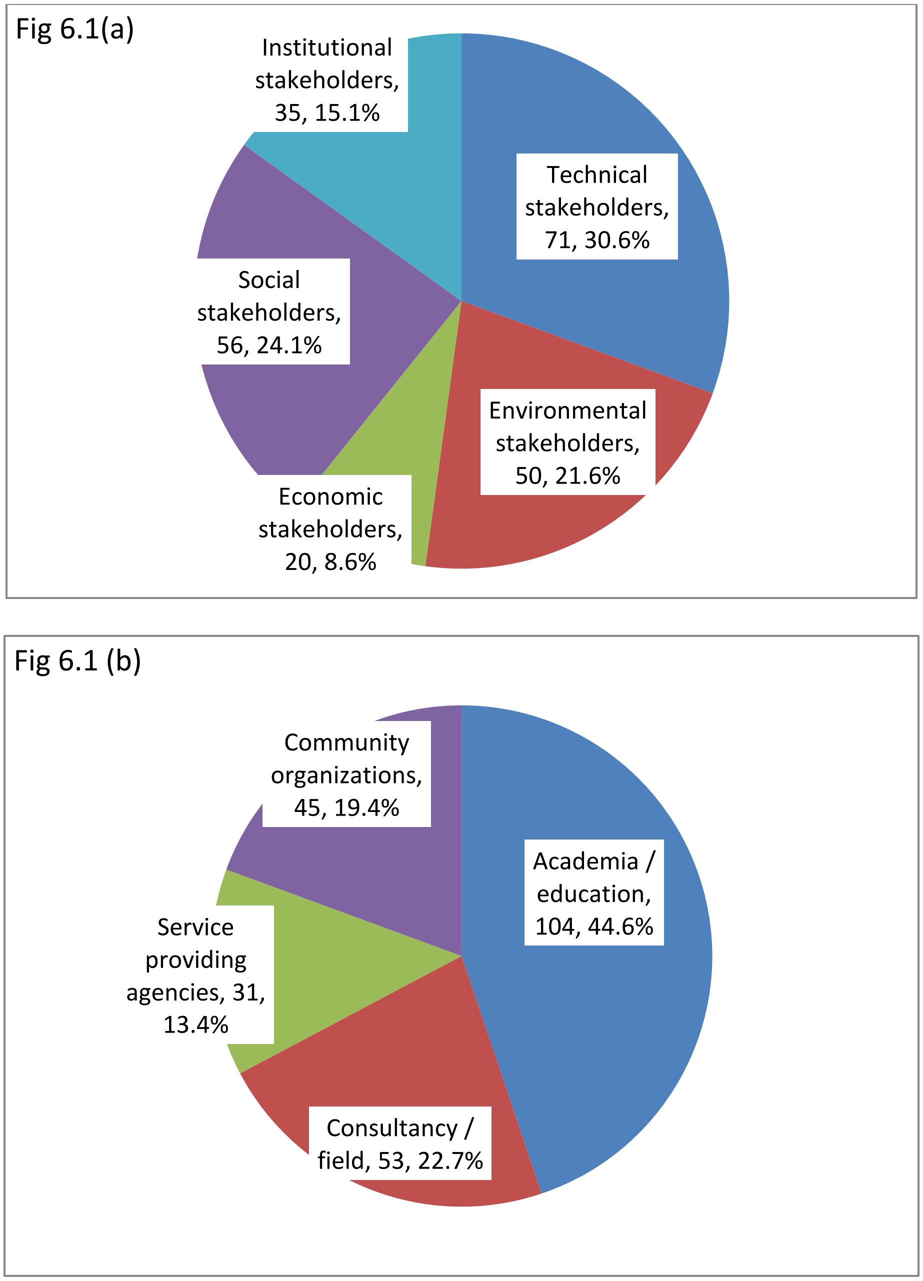


Figure 6.1: (a) Number of respondents from the various groups of stakeholders, (b) Number of respondents on the basis of their organizational affiliation

Relatively higher response rate was observed from the groups of stakeholders affiliated with academia and education, excepting for the institutional stakeholders group who demonstrated the highest response rate (Figure 6.2).

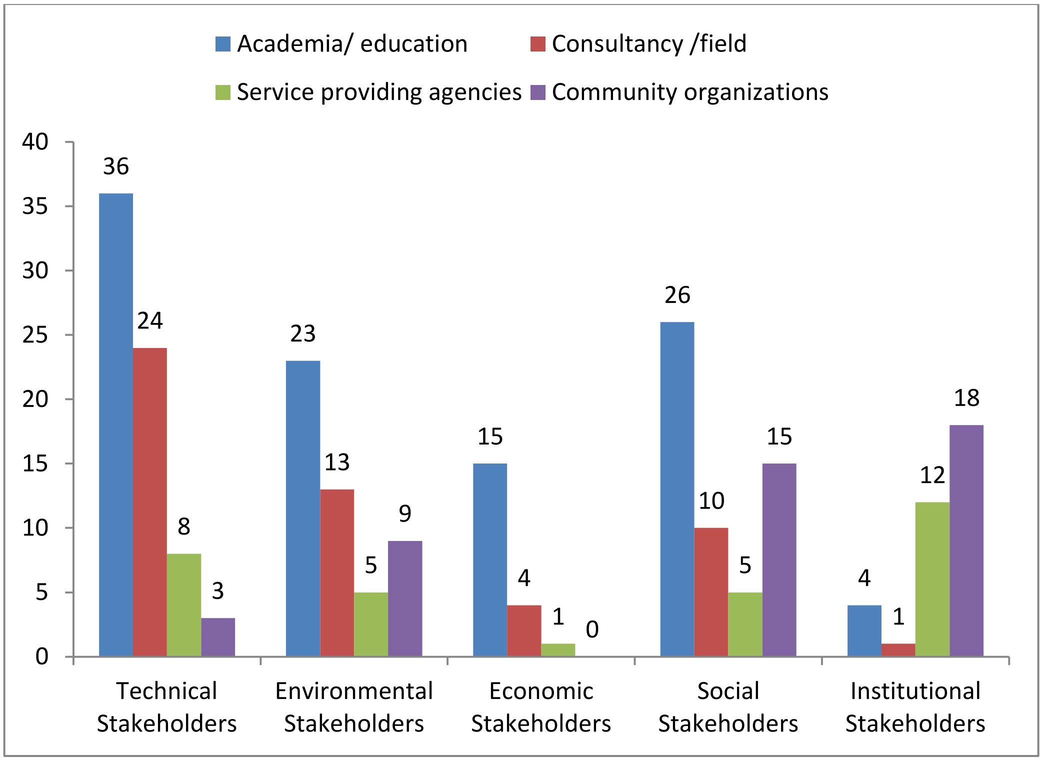


Figure 6.2: Number of respondents in each group showing their organizational affiliations

There was also a significant association ($p < 0.05$) between the various groups of respondents and the number of years of experience (Figure 6.3 and Table 6.1). Technical, environmental, and economic respondents had similar average number of years of experience, with the averages ranging from 5.9 to 7.0 years. However, social and institutional respondents had somewhat more experience with averages of 9.3 to 10.0 years, respectively. Finally, about 93% of the respondents originated from Pakistan (Figure 6.4).

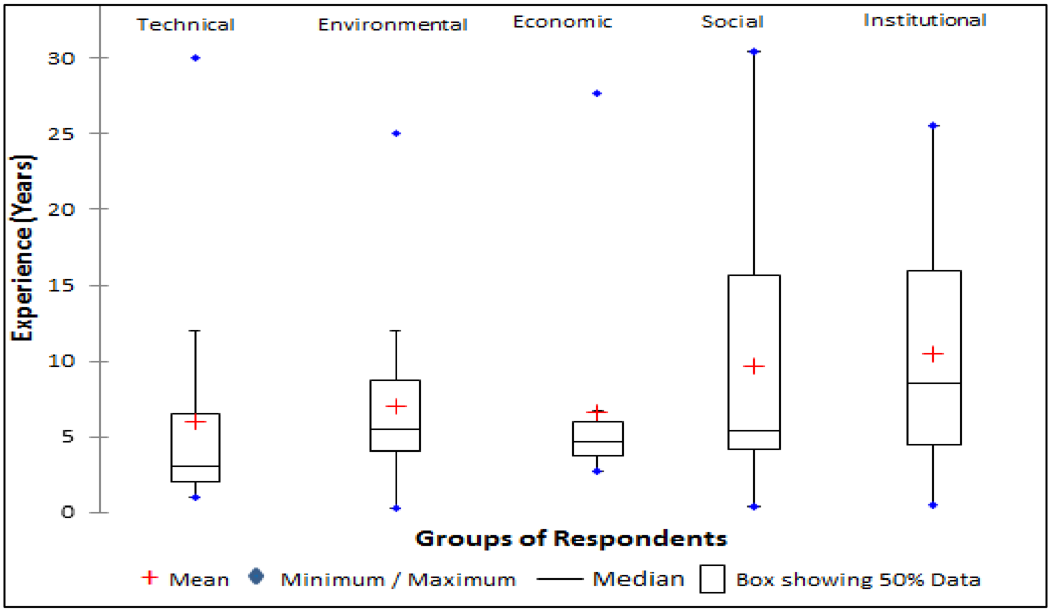


Figure 6.3: Years of experience for the various groups of stakeholders

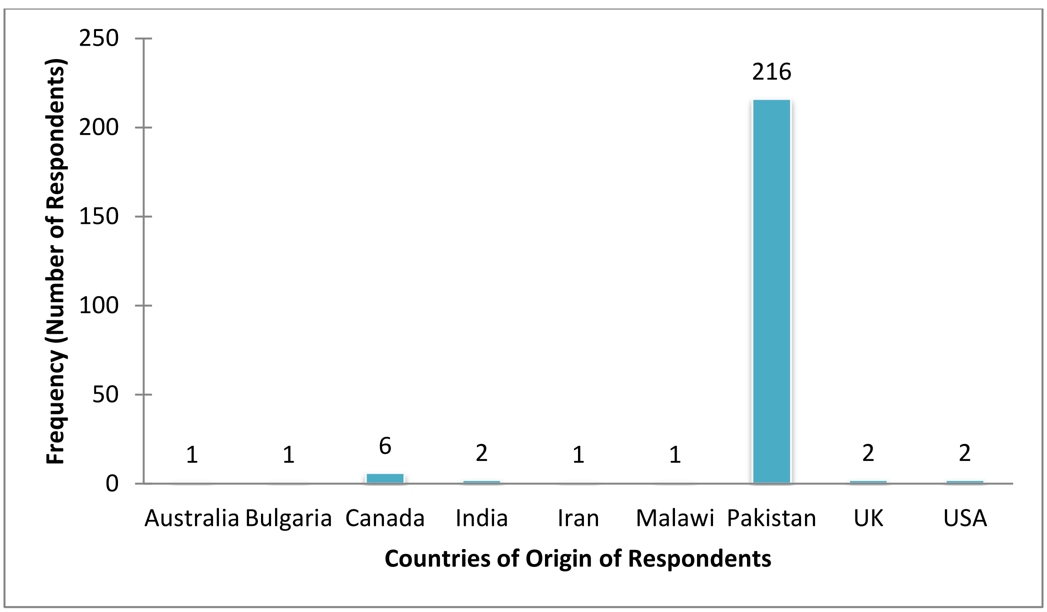
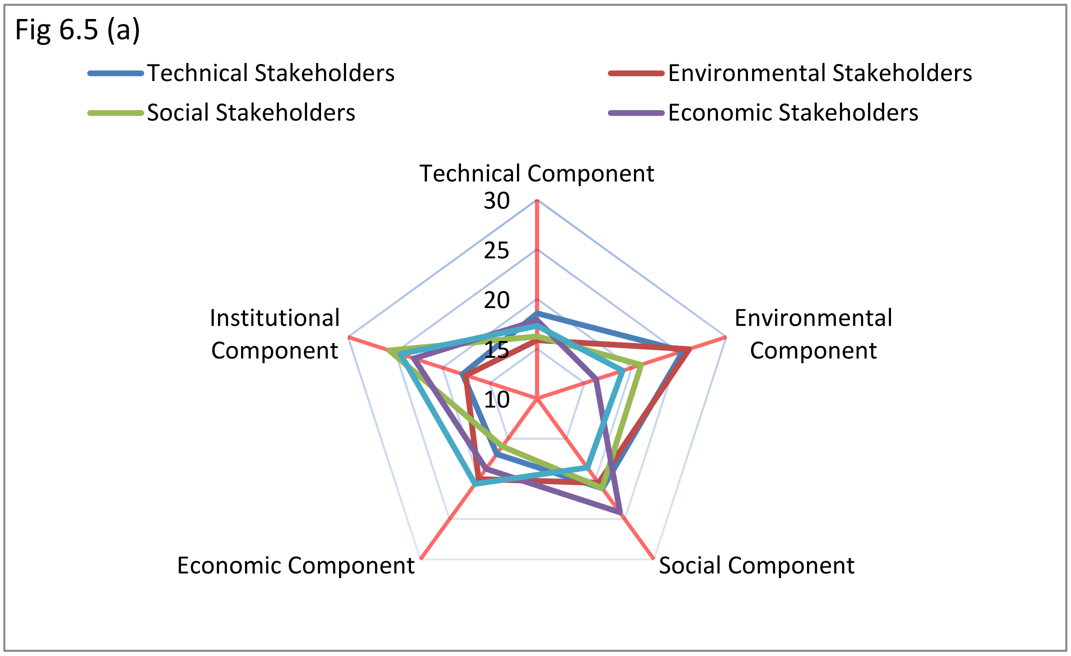


Figure 6.4: Numbers of respondents according to their countries of origins

6.3.2. WEIGHTS FOR SUSTAINABILITY COMPONENTS

The expressed weights assigned to the sustainability components of the sustainability model and the average for the identified stakeholder groups and their organizational affiliations are presented in Figure 6.5(a) and 6.5(b), respectively.



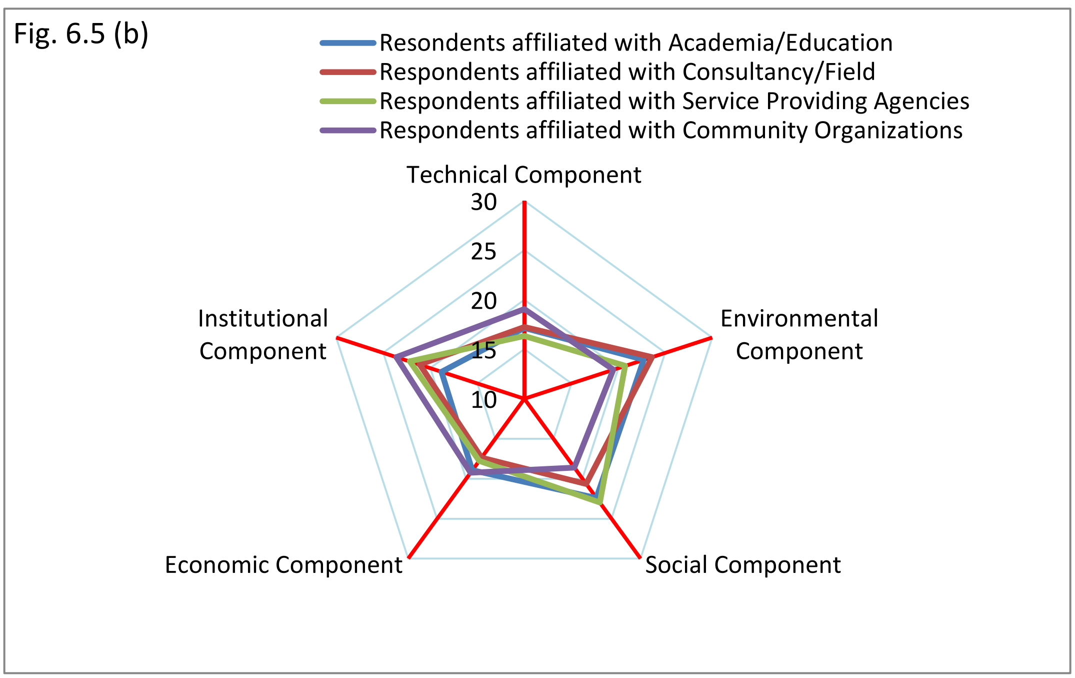


Figure 6.5: (a) Average weights for components based on stakeholder grouping, b): Average weights for components based respondents' affiliations

When the average weights were compared on the basis of the stakeholder attributes (groups, affiliation, years of experience, and country of origin), only the groups were statistically significant from each other (Table 6.1). Two groups of homogeneous weight profiles can be observed: technical and environmental stakeholders expressed weight preferences similar to each other, social and institutional stakeholders agreed with each other for the average components weight profiles. The weight profiles from the two groups were significantly different ($p<0.05$) from each other, but the weight profiles for either group were not significantly different ($p>0.05$) from the average profile for the economic respondents.

Table 6.1: MANOVA and ANOVA test results for weights of components and factors vs. respondent features

Classification	***Df****	**Sustainability Components**		**Sustainability Factors**									
				Technical Factors		**Environmental Factors**		**Social Factors**		**Economic Factors**		**Institutional Factors**	
		Wilk's Lambda	***p* value**	**Wilk's Lambda**	***p* value**	**F value**	***p* value**	**F Value**	***p* value**	**F value**	***p* value**	**F value**	***p* value**
Defined stakeholder groups	4	**0.852**	**0.017**†	0.949	0.529	0.44	0.780	0.29	0.885	**2.72**	**0.031**	**3.21**	**0.014**
Professional affiliations	3	0.942	0.585	0.979	0.870	0.23	0.878	0.45	0.720	1.39	0.247	2.41	0.068
Years of experience	1	0.973	0.312	0.977	0.183	2.19	0.141	0.18	0.669	**8.06**	**0.005**	2.68	0.103
Country of origin	1	0.967	0.190	0.998	0.937	0.01	0.927	2.97	0.086	0.13	0.723	1.44	0.231
Contrast: Technical and Environmental vs. Social and Institutional	1	**0.894**	**<0.01**	NA		NA		NA		1.33	0.251	**3.95**	**0.048**

*Df = Degree of freedom

†Bold entries were judged to be statistically significant ($p < 0.05$)

The results show some clear biases and agreements among the various groups of stakeholders, as follows:

A clear bias can be noticed by examining the highest weights for some components, assigned by the group of respondents with professional or experience with inclination toward a specific component. The environmental component received the highest average weight from the environmental and technical respondents (26.1% and 25.4%, respectively); social component received the highest average weight from social respondents (24.2%), institutional components received the highest average weights from social and institutional respondents (25. 7% and 24.5%, respectively) Overall, it was observed that all groups of respondents assigned significantly lower ($p<0.05$) weights to the technical component than to the other components.

6.3.3. WEIGHTS FOR FACTORS

The average weight profiles for factors within each sustainability component were examined for differences between stakeholders attributes (Table 6.1). The average weight profiles for factors related to technical (Figure 6.6), environmental (Figure 6.7) and social components (Figure 6.8) were not significantly different ($p>0.05$) for any of the attributes (Table 6.1). Among the three factors belonging to the technical component (Figure 6.6), the stakeholders generally assigned an overall average weight of 40% to the factor *Water Quality in Distribution System*, while the factors *Design and Distribution Infrastructure, and Maintenance* received almost equal average weights with 29% and 31%, respectively. For the factors defining the environmental component (Figure 6.7), the respondents provided a slightly higher priority to the *Source Water Quality* (average weight 54%) over the *Source Water Capacity* (average weight 46%). Finally, among the two factors defining the social component (Figure 6.8), there was a slightly higher average weight for the *Social Awareness* factor (53%) compared to the *Social Involvement* factor (47%).

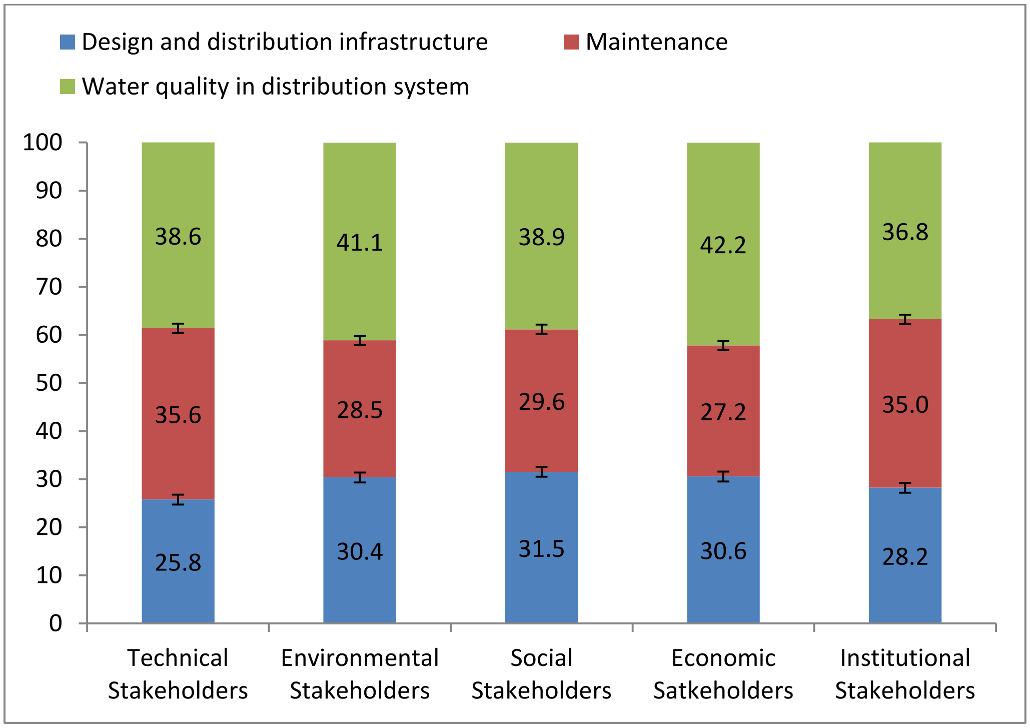


Figure 6.6: Average weights assigned by the various groups of stakeholders for the factors defining the technical component. Error bars indicate standard errors.

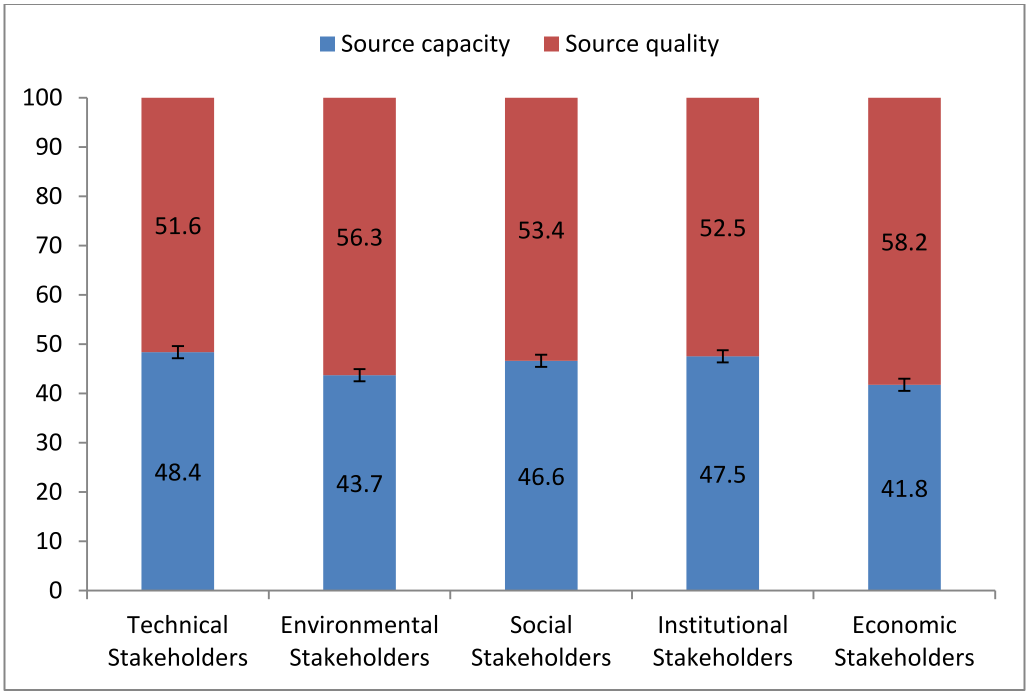


Figure 6.7: Average weights assigned by the various groups of stakeholders for the factors defining the environmental component. Error bars indicate standard errors.

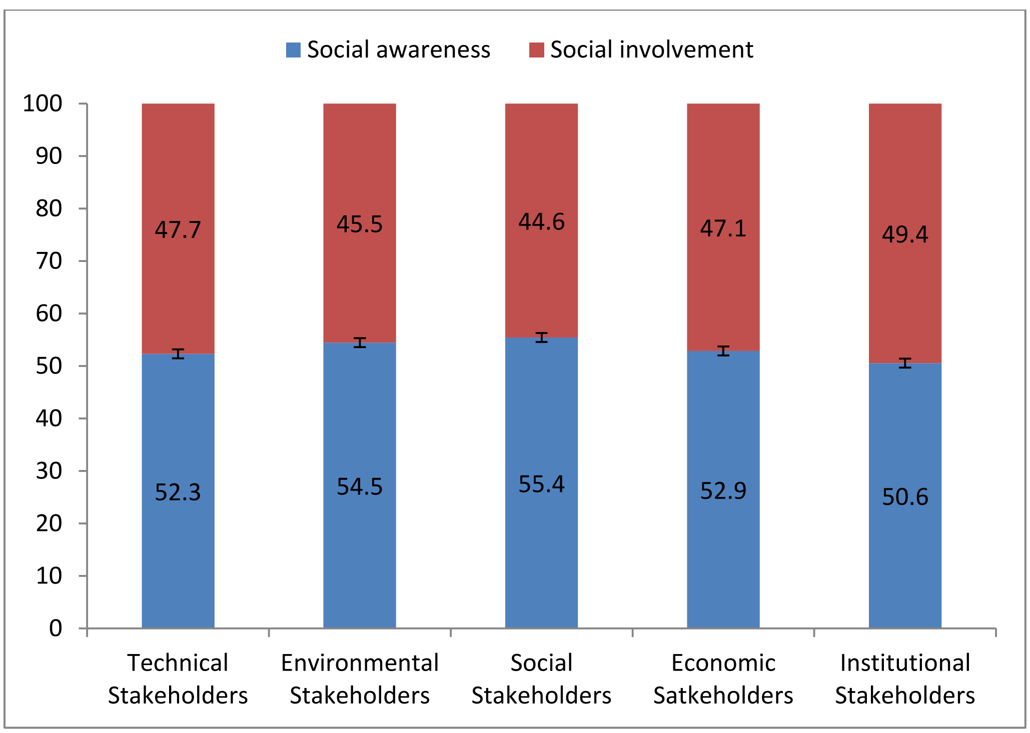
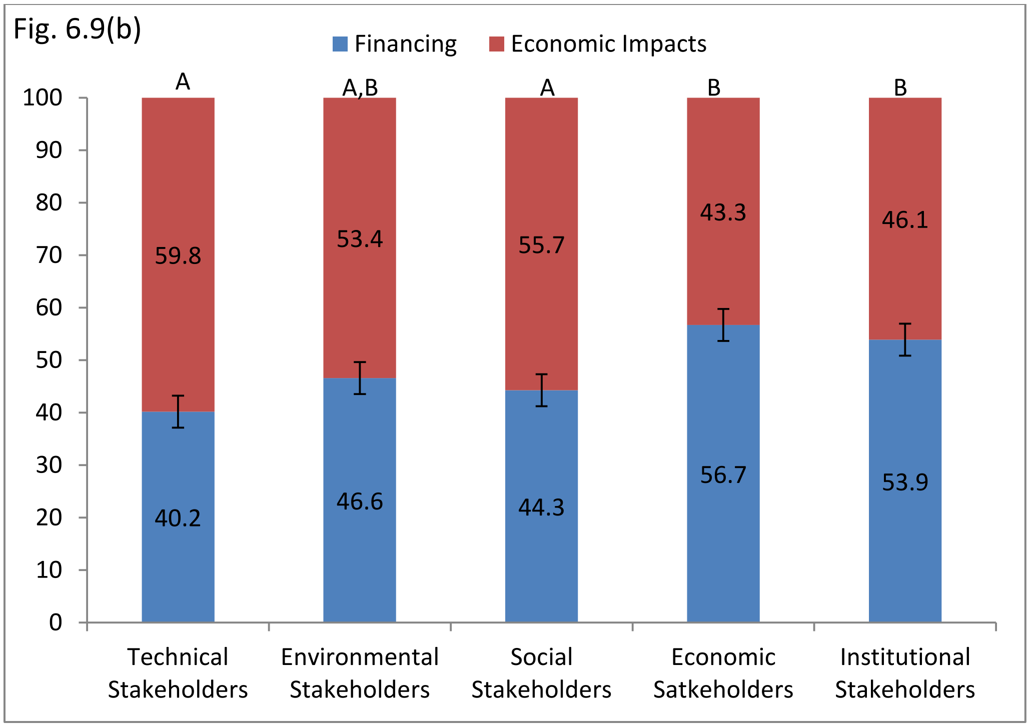


Figure 6.8: Average weights assigned by the various groups of stakeholders for the factors defining the social component. Error bars indicate standard errors.

Analysis of the weight profiles for the factors associated with the economic component revealed significant effects ($p<0.05$) for two of the stakeholder features: stakeholder groups and years of experience (Table 6.1). When comparing the relative weights associated with the *Financing Factor* (Figure 6.9(a)) and the *Economic Factor* (note that the sum of the weights associated with these two factors is 100%) with respect to the years of experience, and considering stakeholder groups, it was observed that the importance of the *Financing Factor* increased on average by 0.76% per year of experience (Figure 6.9(a)). Based on the *years of experience* feature, the technical, environmental and social stakeholders have assigned a higher weight to the *Economic Impact Factor*, whereas economic and institutional stakeholders expressed a higher priority for the *Financing Factor* (Figure 6.9(b)).

Fig. 6.9 (a)

(a)



(b)

Figure 6.9: (a) Variation in weights attributed to the financing factor defining the economic component with variations in the year of experience of respondents, (b) The average weights for the factors associated with the economic component by the various groups of stakeholders for the factors defining the economic component. Error bars indicate standard errors.

The weights for the factors related to the institutional component are shown in Figure 6.10. The institutional stakeholders, who are related principally to the community institutions, have clearly assigned a higher weight (64.3%) to the *Operation and Maintenance Units* factor. The technical and environmental stakeholders have also assigned relatively higher weight (53.8 and 52.3%, respectively) to the same factor. The social stakeholders have clearly favoured the socially organized *Community Organizations* factor, with a weight of 57.1%.

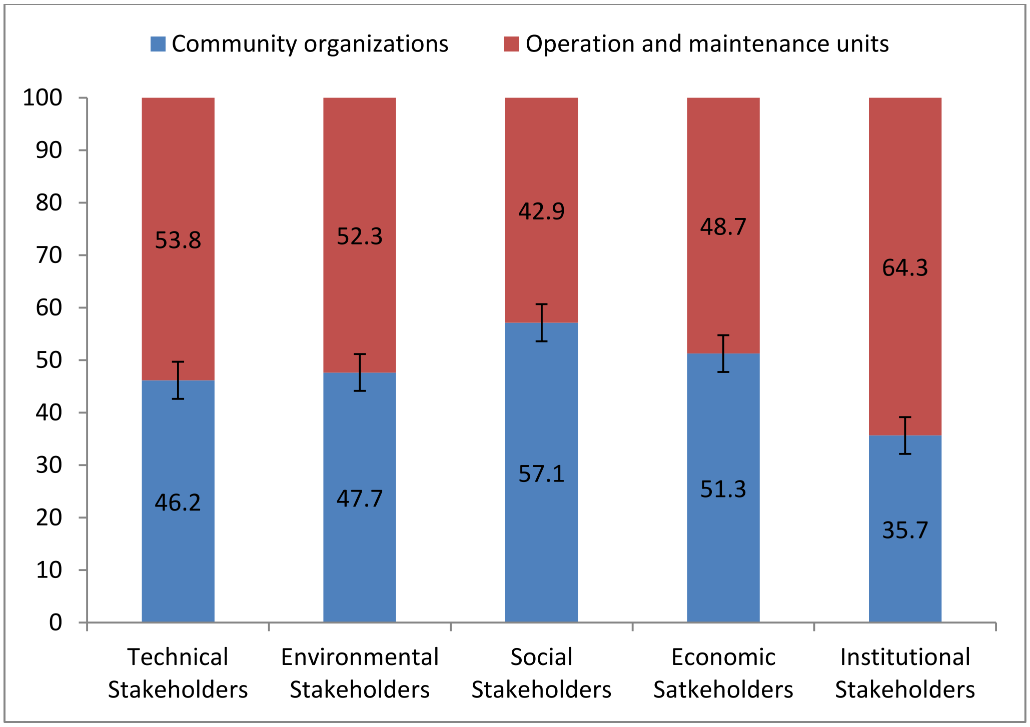


Figure 6.10: Average weights assigned by the various groups of stakeholders for the factors defining the institutional component. The bars with the same letters are not significantly different (p<0.05) according to Duncan pair-wise multiple comparison. Error bars indicate standard errors.

6.4. DISCUSSION

Two clusters of groups were observed based on statistical differences in average weight profiles assigned to the components: Cluster 1 comprised technical and environmental stakeholders, while Cluster 2 included social, economic, and institutional stakeholders. The summary of the weights assigned by the two clusters of groups are presented in Figure 6.11. Cluster 1 with a background of engineering sciences assigned a higher priority to the environmental component, while Cluster 2, with a background of social sciences, clearly favoured the institutional component as its top priority.

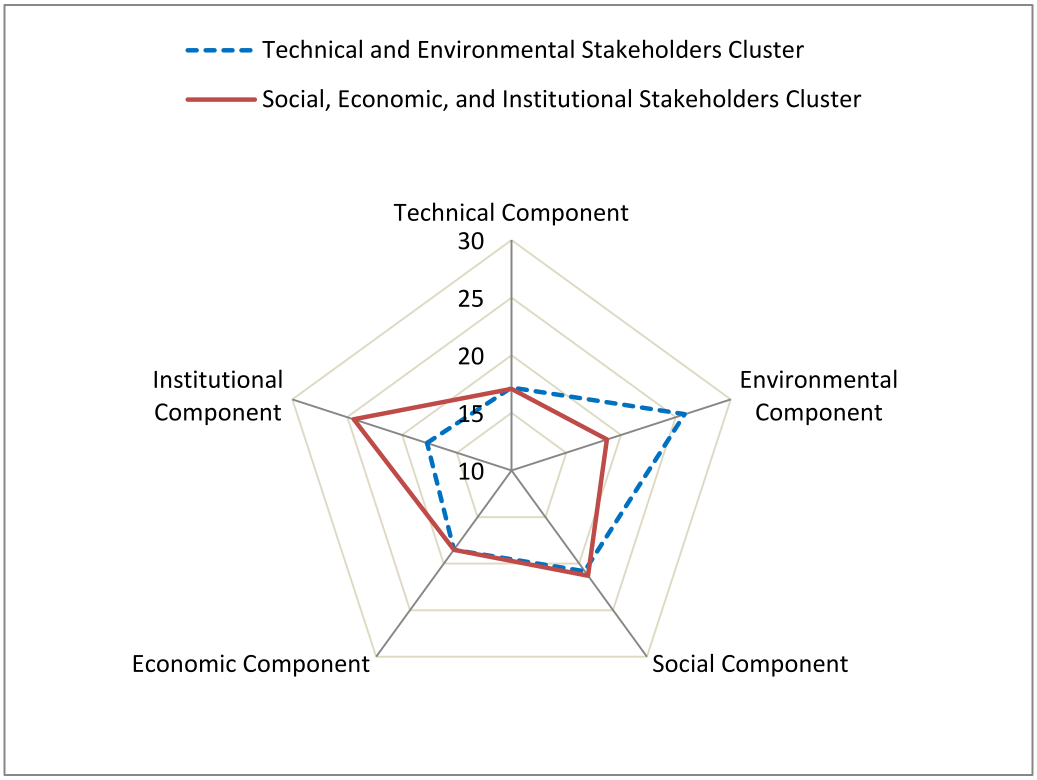


Figure 6.11: Comparison of weights between main clusters

The environmental and institutional components appeared as top priorities among the stakeholders. Examining the contrasts and clustering of like-minded stakeholders showed that environmental component is the top priority among stakeholders with natural sciences and engineering backgrounds, whereas institutional component (related to community institutions) is a top priority for stakeholders with social sciences backgrounds. These differences are understandable in view of the stakeholder involvement and exposure to the preferred components. Natural water sources and effective institutions appeared to be critical for sustainability of CBDWS. The field study results presented in Chapters 4 and 5 also support this trend. Depletion and contamination of natural water sources and failure of the community institutions has been detrimental to access to safe and sufficient clean drinking water. This finding also supports the proposed improvement and upgrading of the community institutions by reinforcing them through umbrella institutions (Chapter 4 and 7).

A trend of assignment of higher priorities to the components can be noticed from the higher weights assigned to some components by specific groups, directly related to these components. For example, the environmental component received the highest (26.1%) weight from the environmental respondents; institutional components received the maximum (25.7% and 24.5%) weights from the social and institutional respondents, respectively, and the technical component obtained maximum weight of 18.6% from the technical respondents.

As mentioned earlier, no studies were found in the literature with data for stakeholder subjectivities, to enable a direct comparison with the present study; however, Panthi and Bhattarai (2008) assigned some weights to the elements of sustainability for evaluation of sixteen rural water supply projects in Nepal. They assigned 50% weight to the technical component, which was the highest among all five components. The term "technical component" in their work included the technical and environmental factors (reliability, adequacy, depletion, and water quality at source) as used in the present study. In spite of the similarities between combined technical and environmental weights for the components, the weights profiles assigned by Panthi and Bhattarai (2008) are quite different from the stakeholders subjectivities synthesized in this study, with the exception of the weights for the institutional components which are quite close in both studies. These weights are 20% in the Panthi and Bhattarai (2008) study, and 21% in the present study. More studies are needed in other developing countries in the various regions of the world to verify these trends.

Such situations can occur in real life conditions, and these biases can cause some problems in smooth functioning of sustainable CBDWS. Therefore, some mechanisms to overcome these difficulties and to develop consensus among the stakeholders need to be developed. A possible solution can be obtained by synthesizing stakeholder priorities, using a synergistic approach of combining individual opinions of stakeholders to form group opinions (Chapter 7). This can be achieved by aggregating stakeholder judgments into group judgments, instead of aggregating individual stakeholder weights (Saaty, 2008).

6.5. SUMMARY

Based on the analysis results, this chapter synthesized and presented the stakeholder perspectives and priorities towards sustainable CBDWS. Although some comparisons were made with the findings of Panthi and Bhattarai (2008), the importance of specification of the sustainability elements at the time of the survey was noted; if these considerations are not handled carefully, it could seriously affect the sustainability of the systems.

In summary, all groups of stakeholders have a consensus on the relative priorities for three factors: (1) design and execution of infrastructure for the technical component (Figure 6.6), (ii) source quality for the environmental component (Figure 6.7) and, (iii) awareness for the social component (Figure 6.8). Translating this unanimous agreement among all group of stakeholders to the most agreed and prioritized requirements of sustainable CBDWS leads to the conclusion that *clean drinking water sources, appropriate design and quality execution of distribution infrastructure and socially aware consumer communities* are vital for a sustainable CBDWS. This finding can help to establish direction for policy making and future investments towards sustainable CBDWS. Factors such as social awareness are normally ignored while developing a policy, and designing and execution of drinking water infrastructure projects. These factors need to be considered carefully; otherwise sustainability of the entire system will be affected.

CHAPTER 7. APPLIED FRAMEWORK

[*This chapter presents an applied framework for monitoring, evaluation, and enhancement of sustainability of CBDW (termed "applied framework"). Procedural details involved in development of this framework can facilitate understanding, applying, and independently replicating the proposed applied framework for various regions and situations by involving various stakeholders from the regions of application.*]

7.1. CONCEPT

Sustainability of CBDWS is dependent on a complex assemblage of different components or sub-systems, which makes it a multi-criteria phenomenon. Evaluation of sustainability of an integrated system with multi-criteria components requires an applied framework with a capacity to quantitatively assess the sustainability status of the various components in equivalent and comparable units. This requires two major inputs: (i) the weight of each component in the system and (ii) the status (condition/performance) of the component at the time of evaluation. The status of the component can be evaluated independently; however, the weight for a component is a calculated value based on the stakeholders input considering the entire system. For estimation of weights, a mechanism of relative importance can be used utilizing a common pre-defined scale. Once the weights for components of a close system (with $\sum$weights = 1 or 100%) are estimated, sustainability of the system can be evaluated by integrating the products of weights and status of each component for the entire system.

The challenge lies in estimation of the weights on the basis of their relative importance, which is subjective in nature. As CBDWS are based on a participatory approach, it is important to involve all stakeholders to develop their input (using pair-wise comparison) for estimation of weights. As mentioned earlier, AHP can be used to synthesize the stakeholder judgments utilizing an approach for group decision making.

The proposed applied framework can assist engineers, policy makers, and other stakeholders to:

1) Monitor and evaluate the sustainability of existing CBDWS,

2) Enhance sustainability of any future CBDWS, and

3) Make decisions for making sustainable choices amongst the various complex alternatives for a CBDWS.

7.2. APPLIED FRAMEWORK

Figure 7.1 shows an overall layout for development of an applied framework, which commences with defining the objective of the framework, followed by structuring the target system in a hierarchy (Table 2.1). This was followed by stakeholder judgments in terms of relative importance of the elements of sustainability, which were then synthesized to obtain the weights for the various elements shown in the hierarchical structure. In the final step, these elements, along with their weights, were organized in a user-friendly manner for application to evaluate sustainability scores. Summary of these steps is presented as follows (Table 7.1), whereas, the details of these steps and a step-wise procedure for estimation of weights is summarized in Appendix C.

Defining	Developing an applied framework for evaluation of sustainability of CBDWS
Structuring	Hierarchy of the sustainability elements (components, factors, and sub-factors)
Processing	Involving stakeholders for their input for the relative priorities/ weights for the various elements
Synthesizing	Applying appropriate technique to synthesize the stakeholder input
Concluding	Providing a complete applied framework

Figure 7.1: Layout for development of applied frame work for monitoring and evaluation of sustainability of CBDWS

7.3. Applied Framework

7.3.1. Definition

The applied framework is a tool to help monitor, evaluate, and improve sustainability of CBDWS.

7.3.2. Structure

A hierarchical structure for the various elements of sustainability of CBDWS, originally developed in Table 2.1 (and reproduced as a part of Table 7.2), was adopted here.

7.3.3. Process

Because of the participatory nature of CBDWS, stakeholders were asked to provide their inputs through surveys as described in Chapter 3 and Appendix B.

7.3.4. SYNTHESIS

Stakeholder inputs (judgments) were synthesized using AHP (Section 2.3.2). Procedural details are presented in Appendix C.

7.3.5. MECHANISM

Table 7.1 demonstrates the mechanism involved in the applied framework, followed by its description.

Table 7.1 - Evaluation framework (general format)

Goal	Components (C)	Weights (w_c)	Factors (F)	Weight (w_F)	Sub-factors (f)	Weights (w_f)	Observed status of sub-factor (%)	Sustainability score	Component sustainability results	Conclusion
1	2	3	4	5	6	7	8	9 = (8*7)/100	10	11
To evaluate sustainability of a community-based drinking water system (project)	C_1	w_1	F_{11}	w_{11}	f_{111}	w_{111}	St_{111}	s_{111}	$\sum_{s111}^{s133} S1$	Sustainable / Partially Sustainable / Not Sustainable
					f_{112}	w_{112}	St_{112}	s_{112}		
					f_{113}	w_{113}	St_{113}	s_{113}		
					f_{114}	w_{114}	St_{114}	s_{114}		
			F_{12}	w_{12}	f_{121}	w_{121}	St_{121}	s_{121}		
					f_{122}	w_{122}	St_{122}	s_{122}		
					f_{123}	w_{123}	St_{123}	s_{123}		
			F_{13}	w_{13}	f_{131}	w_{131}	St_{131}	s_{131}		
					f_{132}	w_{132}	St_{132}	s_{132}		
					f_{133}	w_{133}	St_{133}	s_{133}		
	C_2	w_2	F_{21}	w_{21}	f_{211}	w_{211}	St_{211}	s_{211}	$\sum_{s211}^{s222} S2$	
					f_{212}	w_{212}	St_{222}	s_{222}		
			F_{22}	w_{22}	f_{221}	w_{221}	St_{221}	s_{221}		
					f_{222}	w_{222}	St_{222}	s_{222}		
	C_3	w_3	F_{31}	w_{31}	f_{311}	w_{311}	St_{311}	s_{311}	$\sum_{s311}^{s322} S3$	
					f_{312}	w_{312}	St_{312}	s_{312}		
					f_{313}	w_{313}	St_{313}	s_{313}		
			F_{32}	w_{32}	f_{321}	w_{321}	St_{321}	s_{321}		
					f_{322}	w_{322}	St_{322}	s_{322}		
	C_4	w_4	F_{41}	w_{41}	f_{411}	w_{411}	St_{411}	s_{411}	$\sum_{s411}^{s422} S4$	
					f_{412}	w_{412}	St_{412}	s_{412}		
			F_{42}	w_{42}	f_{421}	w_{421}	St_{421}	s_{421}		
					f_{422}	w_{422}	St_{422}	s_{422}		
	C_5	w_5	F_{51}	w_{51}	f_{511}	w_{422}	St_{511}	s_{511}	$\sum_{s511}^{s524} S5$	
					f_{512}	w_{512}	St_{512}	s_{512}		
			F_{52}	w_{52}	f_{521}	w_{521}	St_{521}	s_{521}		
					f_{522}	w_{522}	St_{522}	s_{522}		
					f_{523}	w_{523}	St_{523}	s_{523}		
					f_{524}	w_{524}	St_{524}	s_{524}		

Column 1 of Table 7.1 defines the goal as "evaluation of sustainability of CBDWS," which is linked with the evaluation of the components (or sub-systems) presented in Column 2. These components are based on related factors (Column 4), and each factor consists of a specific number of sub-factors (Column 6). Columns 3, 5 and 7 present the weight of each element (in the same row). Evaluation in the field starts with the consideration of sub-factors at the lower end of the hierarchy. The status of the sub-factors in Column 8 is estimated as they exist on the day of evaluation -- on a scale of zero to 100% where zero shows a non-existence or absolute non-functionality of the sub-factor, while 100% reflects perfect conditions for it. The status of each sub-factor is evaluated independently by considering it to be a sub-system of the main CBDWS. The sustainability score for each sub-factor is then calculated as product of the weight and the status of that sub-factor (Column 9). The results in Column 10 accumulate the score for all sub-factors for each component to determine the component sustainability (CS). The overall sustainability (OS) is then evaluated by summation of all CS values. Equations 7.1 and 7.2 show the relationships for CS and OS, respectively, as:

Component sustainability (CS)

$$\boldsymbol{CS}_i = W_{C_i}\left[\sum_{j=1}^{n_{F_i}} W_{F_{ij}}\left\{\sum_{k=1}^{n_{f_{ij}}}\left(St_{ijk}W_{f_{ijk}}\right)\right\}\right] \tag{7.1}$$

Overall sustainability (OS)

$\boldsymbol{OS} = \sum_{i=1}^{n_c} \boldsymbol{CS}_i$, or

$$\boldsymbol{OS} = \sum_{i=1}^{n_c} W_{C_i}\left[\sum_{j=1}^{n_{F_i}} W_{F_{ij}}\left\{\sum_{k=1}^{n_{f_{ij}}}\left(St_{ijk}W_{f_{ijk}}\right)\right\}\right] \tag{7.2}$$

where nc = number of components

n_{F_i}= number of factors in i^{th} component

$n_{f_{ij}}$= number of sub factors in j^{th} factor of i^{th} component

W_{C_i}= weight of i^{th} component (expressed as percentage)

$W_{F_{ij}}$= weight of j^{th} factor of i^{th} component (expressed as percentage)

$W_{f_{ijk}}$= weight of k^{th} sub-factor of j^{th} factor of i^{th} component (expressed as percentage)

St_{ijk}= status of k^{th} sub-factor of j^{th} factor of i^{th} component (expressed as percentage)

7.4. APPLICATION IN THE FIELD -- SUSTAINABILITY FRAMEWORK FOR CBDWS

Table 7.1 shows the general format for the evaluation process. Table 7.2 presents a specific form of the applied framework as an application for evaluation of sustainability of CBDWS.

Two major inputs are required for evaluation of each element, which is represented by the weights and the existing status of a sub-factor at the lower end of the hierarchy. This status is evaluated in terms of a percentage of a perfect condition of the particular sub-factor assigning values between zero (for a non-existing or absolutely non-functional condition) and 100 percent (for perfect condition). It should be noted that no comprehensive document (guidelines, code or a handbook) exists presently to ensure a uniform and comparable mechanism for evaluation of the existing status of sub-factors of CBDWS, which depend on multiple criteria. Therefore, further research is required. However, some guidelines are available for monitoring and inspection of most of these sub-factors in different fields of study. No specific study to evaluate the status of integrated elements was found in the literature. It is proposed that until such comprehensive guidelines are available, inspection techniques to observe the status of a sub-factor should be based on the available capacity of the monitoring institutions, or agencies. However, these inspection techniques must be pre-defined and they must remain consistent for all CBDWS studies for rational conclusions. Once the existing status of the sub-factors is formalized with defined weights, a simple mechanism can be used to evaluate the sustainability scores for the various components and the overall system.

The criteria for evaluation of sustainability of CBDWS by Panthi and Bhatarai (2008) were adopted with minor adjustments (Table 7.3). It is suggested that the environmental component which deals with capacity, reliability, quality, and protection of natural water sources, should be examined critically for the conclusion of sustainability status of a CBDWS. This component provides the base for any drinking water system and appeared as the most important component among stakeholder priorities with 22.16% weight (Table 7.2).

It should be noted that the weights for factors and sub-factors presented in Table 7.2 are based on consideration of the entire system. The weights expressed in percentages are presented in Appendix C (Table C-5). Equation 7.1 and 7.2 can be applied to weights expressed in percentages. Table 7.2 can be utilized directly in a simple spread sheet format to calculate the sustainability score (Column 9) as a product of values in Column 7 and Column 8.

Table 7.2 - Framework for evaluation of sustainability of CBDWS

Goal	Components	Weights (W_c)	Factors (F)	Weights (W_F)	Sub-factors (f)	Weights (W_f)	SF status (%)	Sustainability score	Sustainability results	Conclusion
1	2	3	4	5	6	7	8	9	10	11
To evaluate sustainability of a community-based drinking water system (project)	Technical	16.64	Design and execution of distribution infrastructure	4.69	Design optimization	1.17	St_{111}	s_{111}	$\sum_{S111}^{S133} S1$	Sustainable / Partially Sustainable / Not Sustainable
					Available pressure at delivery point	1.17	St_{112}	s_{112}		
					Protection from external pollution	1.17	St_{113}	s_{113}		
					Safety against threats/disasters	1.17	St_{114}	s_{114}		
			Maintenance	5.46	Physical condition	1.82	St_{121}	s_{121}		
					Service interruptions	1.82	St_{122}	s_{122}		
					Preventive and remedial measures	1.82	St_{123}	s_{123}		
			Water quality in distribution system	6.75	Existence of treatment facilities	2.25	St_{131}	s_{131}		
					Efficiency of treatment facilities	2.25	St_{132}	s_{132}		
					Quality at consumer end	2.25	St_{133}	s_{133}		
	Environmental	22.16	Source capacity	10.71	Present capacity of the source	5.36	St_{211}	s_{211}	$\sum_{S211}^{S222} S2$	
					Reliability of the source	5.36	St_{222}	s_{222}		
			Source quality	11.39	Water quality at source	5.70	St_{221}	s_{221}		
					Source protection	5.70	St_{222}	s_{222}		
	Economic	18.79	Financing	9.54	Available for operation/maintenance	3.20	St_{311}	s_{311}	$\sum_{S311}^{S322} S\,3$	
					Depreciation (cost of asset)	3.13	St_{312}	s_{312}		
					Reliability and continuity of finances	3.21	St_{313}	s_{313}		
			Economic Impact	9.25	Direct benefits	4.35	St_{321}	s_{321}		
					Indirect benefits	4.90	St_{323}	s_{323}		
	Social	21.36	Social awareness	10.84	Awareness of water-related issues	5.23	St_{411}	s_{411}	$\sum_{S411}^{S422} S4$	
					Water usage practices	5.61	St_{413}	s_{413}		
			Social involvement	10.52	Population coverage - Quantitative	5.27	St_{421}	s_{421}		
					Equity/Inclusion (different sectors)	5.25	St_{422}	s_{422}		
	Institutional	21.04	Community organizations	10.64	Existence of organizations	5.32	St_{511}	s_{511}	$\sum_{S511}^{S524} S5$	
					Effectiveness of organizations	5.32	St_{512}	s_{512}		
			Operation and maintenance (O&M) units	10.16	Existence of O&M units	2.54	St_{521}	s_{521}		
					Skills and training	2.54	St_{522}	s_{522}		
					Transparency in utilization of funds	2.54	St_{523}	s_{523}		
					Inventories/records for maintenance	2.54	St_{524}	s_{524}		

Table 7.3 - Grading criteria for sustainability

Overall Grading	Accumulative Sustainability Score	Sustainability Status
A – Excellent	85 – 100%	Sustainable
B – Good	70 – 84%	
C – Acceptable	50 – 69%	Partially sustainable
D – Acceptable with improvements	40 – 49%	
E – Not acceptable	<40%	Not sustainable

7.5. RECOMMENDATIONS FOR FUTURE WORK

7.5.1. CODES/GUIDELINES FOR EVALUATION OF SUB-FACTORS

The proposed evaluation framework provides a relatively comprehensive practice-oriented tool for evaluation of sustainability of CBDWS. However, further research is needed, especially to develop codes and guidelines to quantify the status of the various sub-factors.

7.5.2. ESTABLISHMENT OF UMBRELLA INSTITUTIONS (UI)

As mentioned previously (Section 4.3.6), there is a need to establish umbrella institutions on permanent and professional bases to guide, help, and improve the community institutions. An objective, conceptual framework for a proposed umbrella institution is recommended as follows.

Umbrella institutions (UI) are required not only to fill the vacuum of management for existing community institutions responsible for running a CBDWS, but also to plan and monitor the overall sustainability of all natural resources and quality of life at a broader level. All community institutions should be linked in a hierarchy with the UIs possessing a permanent professional structure, capable of dealing with sustainability issues using a holistic approach. Involvement of stakeholders is very basic; however, it is important to understand the limited capacity of the various individuals, groups, and institutions. The existing community institutions are important and they must continue to work; however, they must not be overloaded with expectations beyond their capacity. These institutions can deliver the best possible routine activities. However, long term support, monitoring, data management, updated solutions, and crisis management cannot be implemented through existing institutions consisting of part-time volunteers only. It is recommended further that regional UI must be connected to the state-of-the-art provincial or state UIs, established for similar purposes. No long-term policies can be effectively formulated without reliable data and the needed research. Therefore, UIs must be designed to help in data collection and management on a permanent basis in partnership with the various research institutions. Specific details can be worked out, based on the requirements of the different regions and countries; however, following features need to be considered for proposed UIs:

1. They must be permanent, legal, and authoritative with long term policies.
2. They must be based on a scientific system for monitoring, evaluation and improvement.
3. They must be responsible for a region or cluster of communities (to make UIs cost-effective and capable of social and environmental linkages).

4. They must be accessible, guiding and helpful to community organizations (the existing community institutions).
5. They must be autonomous and capable of handling a holistic approach towards sustainability; for instance, not only should it be linked to drinking water systems, but it should also be capable of dealing with other issues, such as sanitation problems, any negative practices affecting natural water resources, awareness issues on as-needed basis, and matters related to bridging the gaps between small communities and appropriate governmental and non-governmental agencies

The hierarchy of umbrella units must have a direct representation at three various levels of government and related authorities. Figure 7.2 shows the conceptual hierarchy, which can be modified according to the specific requirements of a country or a region.

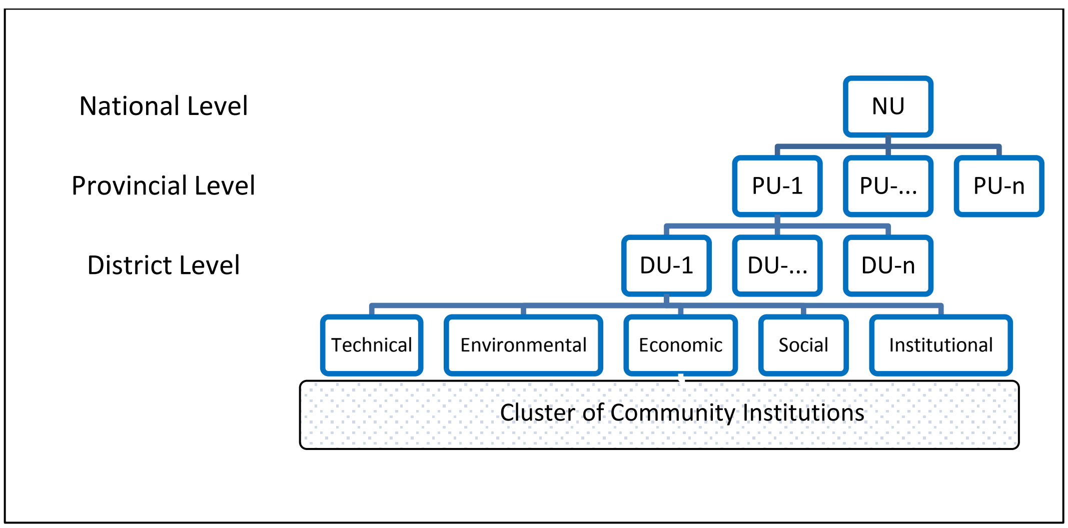


Figure 7.2 : Conceptual hierarchy for umbrella institutions

For example, a special unit, a National Umbrella (NU) can be developed at the level of a federal ministry dealing with environment, or else the role of an existing institution can be reviewed and improved with the establishment of special units to deal with all needed sustainability issues. This can also be achieved with interaction among existing research and implementation agencies, for example, Universities and Environmental Protection Agencies. The ministry of environment may need to review or develop national level policies with a required focus on water and sanitation along with other elements. Provincial (or territorial) umbrellas (PUs) can be developed in a similar fashion at the second level of hierarchy. PUs should be linked with NU on one side and District Umbrellas (DUs) on the other side. Major responsibility should be left with the DUs for monitoring and improvement of water, sanitation, and the environment in the districts through direct involvement of major stakeholders. This may require at least one qualified and regular member for each aspect, that is,, technical, environmental, economic, social, and community-institutional members. All community organizations should be linked to DU with an identifiable legal status. A number of DUs can operate in a district, depending on the needs, based on the district area, population and the status of drinking water and sanitation systems. It must be emphasized that DUs or other umbrella units will not be limited to drinking water and sanitation systems only. These units must work using a holistic approach for sustainability of the overall environment, including water and sanitation, and protection of other natural resources. Data collection and management must be designed to provide a data bank for research, development and implementation. A continuous development and improvement of the community institutions must be made an integral part of their task. Similar provisions should be made for other components; however, it must be implemented through integrated, legal and permanent umbrella units.

CHAPTER 8. SUMMARY AND CONCLUSIONS

8.1. SUMMARY

This thesis deals with sustainable access to safe drinking water, which is a basic human need for survival. However, as discussed earlier, despite several serious international efforts, about a billion people around the world are still living without sustainable access to safe drinking water. This has resulted in poor quality of life, pre-mature deaths and several associated socio-economic and environmental problems and serious losses in the deprived regions and communities.

Through interactions at the international level, the concept of *participatory approaches* was promulgated to address water issues throughout the world. An agreement emerged on the principle that "water development and management should be based on participatory approach, involving users, planners and policy makers at all levels"(WMO-UN, 1992). This led to the development of a number of participatory models for different water resources management systems, including Community-Based Drinking Water Systems (CBDWS) (SADC, 2002). The complexity of effective and efficient CBDWS sustainability requires scientific study of all relevant technical factors for their integration in holistic design of any engineering infrastructure asset design. This study attempts to fulfill this need.

The principal difficulties in answering the question on sustainability of CBDWS were mainly due to the lack of clear definitions, poor understanding of the subjective aspects, and frameworks for monitoring and evaluation of sustainability of CBDWS. This research program dealt with these difficulties through detailed fieldwork on existing CBDWS in some random communities, survey of the various stakeholders, and developing a cost-effective and user friendly framework for monitoring and evaluation of CBDWS.

8.2. CONCLUSIONS

The results of the studies in this thesis can be summarized and conclusions drawn as follow:

1) A sustainable CBDWS was defined with its components, factors and sub-factors.

   Properly maintained sources, proper infrastructure, aware society, stable economy, and effective institutions are necessary and linked components of a sustainable CBDWS, and failure of any of these component can affect the sustainability of the entire system.

2) Existing water sources in the area of study in Northern part of Pakistan are highly vulnerable and are rapidly moving towards fragility, and are threatening sustainable access to safe drinking water at the very basic level. Only half of the sources have adequate capacity to fulfill the needs, commonly agreed at 20 litres per person per day.

3) Protection of sources is not ensured in terms of either quality or quantity. Majority of sources potentially face increasing levels of contamination.

4) Water delivered to the consumers in most of the rural areas of Northern Pakistan is mostly contaminated and unsafe for drinking purposes. The data for the various diseases, premature deaths, and disabilities were not available at the community levels. However,

the related studies clearly show that the contaminated and polluted water has resulted in a number of diseases, deaths, and associated socio-economic losses.

5) Major sources of contamination are untreated raw sewage and contaminated surface run-offs, which pollute drinking water sources.

6) Optimum design on the basis of available sources and demands of the consumers is not practiced in the existing systems. Considerably generalized and over-simplified design approaches are commonly used to design CBDWS.

7) Physical condition and safety of the distribution infrastructure are compromised in most communities. Deferred maintenance is a major cause for the poor condition of distribution infrastructure. Savings for maintenance funds, as commonly agreed in the contracts between organizations of consumer communities and service providing agencies, are rare. The common practice is to make the required arrangements after failure of the system. Contrary to the numerous reports of financial corruption in the various institutions of developing countries, the community organizations or institutions actually show reasonable transparency in utilization of finances.

8) The community organizations (CO) work diligently to achieve the established CBDWS goals, and remain active during the period of active involvement of the Service Providing Organizations in the region. However, soon after the completion of such projects, all

stimuli, which were utilized to develop the community institutions, start disappearing. Community institutions have no legal status and members of the communities have no contract-based legal bindings in any court of law. These institutions must be provided a legal status and a disciplined hierarchy with the proposed umbrella institutions to ensure sustainability of CBDWS.

9) Environmental sustainability in terms of capacity, quality, reliability and protection of drinking water sources is critical. Projection of the field study to a broader level shows that unless urgent measures are undertaken, serious fallbacks may occur in the established targets. In the context of MDG, such fallbacks have the capability of reversing the situation to the starting point.

10) The environmental component, in terms of the capacity of drinking water sources, reliability of these sources for continuity, quality of water at source and protection of drinking water sources, is the most crucial component for sustainability of drinking water systems. The present practices, especially in developing countries, where a vast majority of drinking water issues exist, need a complete review to ensure sustainability.

11) Examination of stakeholder input, subjectivity, and synthesized relative priorities or weights for the various elements of sustainability of CBDWS lead to the following:

a) The environmental and institutional components appeared as top priorities among the stakeholders.

b) Depletion and contamination of natural water sources and failure of the community institution has been detrimental. This finding also supports the proposed improvement and upgrading of the community institutions by reinforcing them through umbrella institutions (Chapter 4 and 7).

c) Stakeholders have a consensus on the relative priorities for three factors: (1) design and execution of infrastructure for the technical component, (ii) source quality for the environmental component and, (iii) awareness for the social component. It can be concluded that *the clean drinking water sources, appropriate design and quality execution of distribution infrastructure and, socially aware consumer communities* are vital for sustainable CBDWS.

d) The ten sub-factors (out of 29) that were assigned the highest weights, are source protection, indirect economic impact, water quality at source, direct economic benefits, reliability of water sources, capacity of water sources, water usage practices, effectiveness of community institutions, awareness of water-related issues, and the existence of community organizations respectively. This also shows the nature of inter-dependence of the various elements from different fields to ensure sustainable systems. Present practices need a complete review in the context of sustainability.

8.3. ORIGINAL CONTRIBUTIONS

The original contributions of this research work are:

1. Development of a definition for a sustainable CBDWS

2. Development of a model for overall sustainability of CBDWS and its validation on the basis of a field study

3. Prediction of possible scenarios for the projected population that would be without access to improved drinking water in 2015

4. Revealing stakeholder subjectivities and priorities for the various elements of sustainability of CBDWS

5. Development of a cost-effective and user-friendly applied framework for monitoring and evaluation of CBDWS, capable of accommodating field data of various quality levels

8.4. FUTURE WORK

This research program has identified the basic needs of policy making, and engineering practices to execute and to maintain CBDWS. This work is first of its nature in many aspects and further research will help to refine and improve the understanding of CBDWS and frameworks for their monitoring, evaluation and enhancement of sustainability. The following fundamental and applied research is recommended for the near future:

1. Replication of the survey on stakeholders with a special focus on sub-factors

2. Development of guidelines for evaluation of the status of various sub-factors in the field as presented in Section 7.5.1.

3. Development of detailed framework for establishment of umbrella institutions to ensure permanence and improvement of existing community institutions, as well as the improvement in overall sustainability of all natural resources in the regions. This should be executed as an extension of the conceptual framework presented Section 7.5.2.

4. Development of cost-effective systems to acquire, manage, and store the scientific data for CBDWS on a permanent basis

5. Development of a framework for major changes in the curriculum to enhance knowledge and application of sustainable development in engineering and other disciplines. This needs research to develop inter-disciplinary approaches for creating an overall awareness of water- related issues and possible solutions at every level of society, especially at the educational institutions.

REFERENCES

Aczél, J. and Saaty, T.L., (1983). "Procedures for Synthesizing Ratio Judgements." *Journal of Mathematical Psychology* **27**(1): 93-102.

Archer, D., (2003). "Contrasting Hydrological Regimes in the Upper Indus Basin." *Journal of Hydrology* **274**(1–4): 198-210.

Archer, D.R., Forsythe, N., Fowler, H.J. and Shah, S.M., (2010). "Sustainability of Water Resources Management in the Indus Basin under Changing Climatic and Socio Economic Conditions." *Hydrology and Earth System Sciences* **14**: 1669-1680.

Archer, D.R. and Fowler, H.J., (2004). "Spatial and Temporal Variations in Precipitation in the Upper Indus Basin, Global Teleconnections and Hydrological Implications." *Hydrology and Earth System Sciences* **8**(1): 47-61.

ASCE/UNESCO, (1998). *Sustainability Criteria for Water Resources Systems*, Task Committee on Sustainability Criteria, Water Resources Planning and Management Division, ASCE, and Working Group of UNESCO/IHP IV Project M-4.3, American Society of Civil Engineers (ASCE), USA.

Aslam, M.S., Mirza, M.S. and Frigon, D., (2012). "Environmental Sutainability of Rural Community-Based Drinking Water Systems in Developing Countries." *The International Journal of Environmental Sustainability* **1**.

Black, M., (1998). *Learning What Works: A 20 Year Retrospective View on International Water and Sanitation Cooperation 1978-1998*, UNDP-United Nations Development Programme, European Office.

CEB, (1992). *Durable Concrete Structures*, Comite Euro-International du Beton, Design Guide, Report No. 183, Thomas Telford, London, UK

CESCR, (2003). The Right to Water - Genral Comment No. 15 (2002). *Comittee on Economic, Social and Cultural Rights (CESCR) - Twenty-ninth session*. 11-29 November 2002, Geneva, Office of the United Nations High Commissioner for Human Rights Geneva, Switzerland

CIDA, (2006). Drinking Water Supply Schemes Managed by Tehsil Municipal Administrations and Communities: A Review of Success and Failures, Canadian International Development Agency Devolution Support Project.

Conrad, C. and Daoust, T., (2008). "Community-Based Monitoring Frameworks: Increasing the Effectiveness of Environmental Stewardship." *Environmental Management* **41**(3): 358-366.

Conservation Ontario. (2009). "Protect Water." from http://conservation-ontario.on.ca/source_protection/.

Cortner, H.J., Wallace, M.G., Burke, S. and Moote, M.A., (1998). "Institutions Matter: The Need to Address the Institutional Challenges of Ecosystem Management." *Landscape and Urban Planning* **40**(1–3): 159-166.

Costanza, R. and Patten, B.C., (1995). "Defining and Predicting Sustainability." *Ecological Economics* **15**(3): 193-196.

Fagan, J.E., Reuter, M.A. and Langford, K.J., (2010). "Dynamic Performance Metrics to Assess Sustainability and Cost Effectiveness of Integrated Urban Water Systems." *Resources, Conservation and Recycling* **54**(10): 719-736.

Forman, E. and Peniwati, K., (1998). "Aggregating Individual Judgments and Priorities with the Analytic Hierarchy Process." *European Journal of Operational Research* **108**(1): 165-169.

Fowler, H.J. and D.R.Archer, (2006). "Conflicting Signals of Climate Change in the Upper Indus Basin." *Journal of Climate* **19**: 4276-4293.

Foxon, T.J., Mcilkenny, G., Glimour, D., C.Oltean-Dumbrava, Souter, N., R.Ashley, D.Butler, P.Pearson, P.Jowitt and J.Moir, (2002). "Sustainability Criteria for Decision Support in the Uk Water Industry." *Journal of Environmental Palnning and Management* **45**(2): 285-301.

Freeman, R.E. and Reed, D.L., (1983). "Stockholders and Stakeholders: A New Perspective on Corporate Governance." *California Management Review* **25**(3): 88-106.

Furey, S.G. and Lutyens, B.C., (2008). "Developing an Integrated Water Management Strategy to Overcome Conflicts between Urban Growth, Water Infrastructure and Environmental Quality: A Case Study from Ashford, Kent." *Water and Environment Journal*(22): 42-53.

Garfì, M., Ferrer-Martí, L., Bonoli, A. and Tondelli, S., (2011). "Multi-Criteria Analysis for Improving Strategic Environmental Assessment of Water Programmes. A Case Study in Semi-Arid Region of Brazil." *Journal of Environmental Management* **92**(3): 665-675.

Giné, R. and Pérez-Foguet, A., (2008). "Sustainability Assessment of National Rural Water Supply Program in Tanzania." *Natural Resources Forum* **32**(4): 327-342.

Gleick, P.H., (1998). "The Human Right to Water." *Water Policy* **1**(5): 487-503.

Gleick, P.H., (2002). Dirty-Water: Estimated Deaths from Water-Related Diseases 2000-2020. Oakland, USA, Pacific Institute for Studies in Development, Environment, and Security.

Goodland, R., (1995). "The Concept of Environmental Sustainability." *Annual Review of Ecology and Systematics* **26**(ArticleType: research-article / Full publication date: 1995 / Copyright © 1995 Annual Reviews): 1-24.

Hajkowicz, S. and Higgins, A., (2008). "A Comparison of Multiple Criteria Analysis Techniques for Water Resource Management." *European Journal of Operational Research* **184**(1): 255-265.

Haysom, A., (2006). A Study of the Factors Affecting Sustainability of Rural Water Supplies in Tanzania. Bedfordshire, UK, Cranfield University.

Hellström, D., Jeppsson, U. and Kärrman, E., (2000). "A Framework for Systems Analysis of Sustainable Urban Water Management." *Environmental Impact Assessment Review* **20**(3): 311-321.

Hoko, Z. and Hertle, J., (2006). "An Evaluation of the Sustainability of a Rural Water Rehabilitation Project in Zimbabwe." *Physics and Chemistry of the Earth, Parts A/B/C* **31**(15–16): 699-706.

Huang, I.B., Keisler, J. and Linkov, I., (2011). "Multi-Criteria Decision Analysis in Environmental Sciences: Ten Years of Applications and Trends." *Science of The Total Environment* **409**(19): 3578-3594.

Hussain, S.S., Mudasser, M., Sheikh, M.M. and Manzoor, N., (2005). "Climate Change and Variability in Mountain Regions of Pakistan Implications for Water and Agriculture." *Pakistan Journal of Meteorology* **2**(4): 75-90.

ICWE. (1992). "The Dublin Statement on Water and Sustainable Development - " *International Conference on Water and the Environment* Retrieved October 4, 2012, from http://www.un-documents.net/h2o-dub.htm.

Jones, S.A. and Silva, C., (2009). "A Practical Method to Evaluate the Sustainability of Rural Water and Sanitation Infrastructure Systems in Developing Countries." *Desalination* **248**(1–3): 500-509.

Jonsson, A.C., Andersson, L., Alkan Olsson, J. and Johansson, M., (2011). "Defining Goals in Participatory Water Management: Merging Local Visions and Expert Judgements." *Journal of Environmental Planning and Management* **54**(7): 909-935.

Kao, J.-J., Pan, T.-C. and Lin, C.-M., (2009). "An Environmental Sustainability Based Budget Allocation System for Regional Water Quality Management." *Journal of Environmental Management* **90**(2): 699-709.

Khan, F.J. and Javed, Y., (2007). Delivering Access to Safe Drinking Water and Adequate Sanitation in Pakistan. *PIDE Working Papers 2007:30*. Islamabad, Pakistan, Pakistan Institute of Development Economics.

Khan, S., Rana, T., Gabriel, H.F. and Ullah, M.K., (2008). "Hydrogeologic Assessment of Escalating Groundwater Exploitation in the Indus Basin, Pakistan." *Hydrogeology Journal* **16**(8): 1635-1654.

Kolb deWilde, C., Milman, A., Flores, Y., Salmerón, J. and Ray, I., (2008). "An Integrated Method for Evaluating Community-Based Safe Water Programmes and an Application in Rural Mexico." *Health policy and planning* **23**(6): 452-464.

Kundzewicz, Z.W., (1997). "Water Resources for Sustainable Development." *Hydrological Sciences Journal* **42**(4): 467-480.

Kyessi, A.G., (2005). "Community-Based Urban Water Management in Fringe Neighbourhoods: The Case of Dar Es Salaam, Tanzania." *Habitat International* **29**(1): 1-25.

Lant, C., (2010). "Water Resources Sustainability: An Ecological Economics Perspective." *Journal of Contemporary Water Research and Education* **127**(1): 4.

Lee, B., Jones, D. and Peterson, H., (2003). Septic System Failure. Home and Environment, Department of Agronomy andDepartment of Agricultural andBiological Engineering, Prude University.

Lee, E. and Schwab, K., (2005). "Deficiencies in Drinking Water Distribution Systems in Developing Countries." *J Water Health* **3**: 109-127.

Lee, L. and Ghanime, L., (2005). Environmental Sustainability in 100 Millennium Development Goal Country Reports. Bureau for

Development Policy,, United Nations Development Programme (UNDP).

Legendre, P. and Legendre, L., (1998). *Numerical Ecology*. Amsterdam, The Netherland, Elsevier Science B.V. Amsterdam, The Netherland.

Linkov, I., Sahay, S., Kiker, G., Bridges, T. and Seager, T.P., (2005). Multi-Criteria Decision Analysis: A Framework for Managing Contaminated Sediments, Strategic Management of Marine Ecosystems. E. Levner, I. Linkov and J.-M. Proth, Springer Netherlands. **50:** 271-297.

Lundin, M. and Morrison, G.M., (2002). "A Life Cycle Assessment Based Procedure for Development of Environmental Sustainability Indicators for Urban Water Systems." *Urban Water* **4**(2): 145-152.

Malik, M.A., Azam, M. and Saboor, A., (2010). Water Quality Status of Upper Kpk and Northern Areas of Pakistan. Islamabad, Pakistan.

Malley, Z.J.U., Taeb, M., Matsumoto, T. and Takeya, H., (2009). "Environmental Sustainability and Water Availability: Analyses of the Scarcity and Improvement Opportunities in the Usangu Plain, Tanzania." *Physics and Chemistry of the Earth, Parts A/B/C* **34**(1–2): 3-13.

Mansuri, G. and Rao, V., (2004). "Community-Based and -Driven Development: A Critical Review." *The World Bank Research Observer* **19**(1): 1-39.

Mirza, M.S., (2005). Durability and Sustainability of Infrastructure. *33rd Annual General Conference of Canadian Society of Civil Engineering, First Speciality Conference on Infrastructure Technologies, Management and Policy,* . Toronto,June 2-4, 2005.

Mirza, S., (2006). "Durability and Sustainability of Infrastructure-a State-of-the-Art Report." *Canadian Journal of Civil Engineering* **33**(6): 639-649.

Montgomery, M.A., Bartram, J. and Elimelech, M., (2009). "Increasing Functional Sustainability of Water and Sanitation Supplies in Rural Sub-Saharan Africa." *Environmental Engineering Science* **26**(5): 1017-1023.

Montgomery, M.A. and Elimelech, M., (2007). "Water and Sanitation in Developing Countries: Including Health in the Equation." *Environmental Science & Technology* **41**(1): 17-24.

Mujwahuzi, M.R., (2002). Defining and Mainstreaming Environmental Sustainability in Water Resources Management in South Africa. R. Hiriji, P. Johnson, P. Maro and T. M. Chiuta. Maseru/Harare/Washington DC, SADC, IUCN, SARDC, World Bank.

Nare, L., Odiyo, J.O., Francis, J. and Potgieter, N., (2011). "Framework for Effective Community Participation in Water Quality Management in Luvuvhu Catchment of South Africa." *Physics and Chemistry of the Earth, Parts A/B/C* **36**(14–15): 1063-1070.

National Academy of Sciences. (2008). "Safe Drinking Water Is Essential ", from http://www.drinking-water.org/html/en/Overview/Reliability.html.

Oldfield, J., (2006). Community-Based Approaches to Water and Sanitation: A Survey of Best, Worst, and Emerging Practices. *Water Stories: Expanding Opportunities in Small-Scale Water and Sanitation Projects.* . Washington, DC, Woodrow Wilson International Center for Scholars.

Panthi, K. and Bhattarai, S., (2008). "A Framework to Assess Sustainability of Community-Based Water Projects Using Multi-Criteria Analysis." *Construction in Developing Countries*: 464.

PCRWR. (2002). "Water Quality Monitoring and Management." Retrieved July 25, 2013, from http://www.pcrwr.gov.pk/water%20quality.aspx.

Pearson, L., Coggan, A., Proctor, W. and Smith, T., (2010). "A Sustainable Decision Support Framework for Urban Water Management." *Water Resources Management* **24**(2): 363-376.

Peter, G. and Nkambule, S.E., (2012). "Factors Affecting Sustainability of Rural Water Schemes in Swaziland." *Physics and Chemistry of the Earth, Parts A/B/C* **50–52**(0): 196-204.

Prugh, T. and Assadourian, E., (2003). What Is Sustainability, Anyway? *World Watch Magazine, Washington DC*. Washington, DC, World Watch Institute.

Ramanathan, R. and Ganesh, L.S., (1994). "Group Preference Aggregation Methods Employed in Ahp: An Evaluation and an Intrinsic Process for Deriving Members' Weightages." *European Journal of Operational Research* **79**(2): 249-265.

Saaty, T.L., (1990). "How to Make Decision: The Analytical Hierarchy Process." *European Journal of Operational Research* **48**: 9-26.

Saaty, T.L., (2008). "Decision Making with the Analytic Hierarchy Process " *International Journal of Services Sciences* **1**(1): 83-98.

SADC, (2002). Defining and Mainstreaming Environmental Sustainability in Water Resources Management in South Africa. R. Hiriji, P. Johnson, P. Maro and T. M. Chiuta. Maseru/Harare/Washington DC, SADC, IUCN, SARDC, World Bank.

Sahely, H.R., Kennedy, C.A. and Adams, B.J., (2005). "Developing Sustainability Criteria for Urban Infrastructure Systems." *Can. J. Civ. Eng. 32: 72–85*

Sipos, C., (2011). *Gis- Inventory and Condition Rating of Water Supply System at Mcgill Downtown Campus*, Japan Association for Earthquake Engineering.

Sokal, R. and Rohlf, F., (1994). *Biometry: The Principles and Practice of Statistics in Biological Research*. W.H. Freeman, San Francisco.

Spiegel, J.M., Bonet, M., Yassi, A., Molina, E., Concepcion, M. and Mast, P., (2001). "Developing Ecosystem Health Indicators in Centro Habana: A Community-Based Approach." *Ecosystem Health* **7**(1): 15-26.

Srdjevic, Z., Kolarov, V. and Srdjevic, B., (2007). "Finding the Best Location for Pumping Station in the Glovica Drainage Area of Serbia: The Ahp Approach for Sustainable Development." *Business Strategy and the Environment*.

Tahir, M., Bhatti, M. and Majeed, A., (1994). "Survey of Drinking Water Quality in the Rural Areas of Rawalpindi District." *Pakistan Council for Research in Water Resources, Islamabad*.

UN, (2005). Water for Life Decade (2005-2015). New York, USA.

UN, (2013). "Population Estimates and Projections." 2013, from http://esa.un.org/unpd/wpp/unpp/p2k0data.asp.

UNICEF/WHO, (2012). Progress on Drinking Water and Sanitation: 2012 Update, Retrieved from www.unicef.org/media/files/JMPreport2012.pdf

Vairavamoorthy, K., Gorantiwar, S.D. and Pathirana, A., (2008). "Managing Urban Water Supplies in Developing Countries – Climate Change and Water Scarcity Scenarios." *Physics and Chemistry of the Earth, Parts A/B/C* **33**(5): 330-339.

WCED, (1987). Our Common Future. *UN World Commission on Environment and Development Report*. Switzerland.

WHO. (2008). "Access to Improved Drinking-Water Sources and to Improved Sanitation , *WHO Statistical Information System (Whosis)*,." Retrieved January 23, 2012, from http://www.who.int/whosis/indicators/compendium/2008/2wst/en/.

WHO/UNICEF, (2010). Progress on Sanitation and Drinking-Water - 2010 Update. Geneva, Switzerland, World Health Organization.

WMO-UN. (1992). "The Dublin Statement on Water and Sustainable Development." Retrieved January 25, 2013, from http://www.wmo.int/pages/prog/hwrp/documents/english/icwedece.html.

WWF, (2007). Pakistan's Waters at Risk. Lahore, Pakistan, Freshwater & Toxic Programme, WWF-Pakistan.

Zahoorullah, Akhtar, T. and Zai, S., 2003. Quality of drinking water in rural Peshawar. Pak. J. Med. Res., 42(3).

APPENDICES

APPENDIX A: SUSTAINABILITY OF COMMUNITY-BASED DRINKING WATER INFRASTRUCTURE IN DEVELOPING COUNTRIES

A.1. FIELDWORK QUESTIONNAIRE

Water-related problems, especially drinking water problems, are becoming increasingly complex in developing countries, and need serious and dedicated efforts for finding suitable sustainable solutions, in consultation with the local communities. This questionnaire is designed to develop a framework for sustainable solutions to the drinking water infrastructure problems in your community.

A research program has been initiated with the objective of making community-based drinking water systems more effective, useful and sustainable. Your observations, experiences and opinions by way of responses to the questionnaire will be quite useful to achieve the goals of developing sustainable drinking water infrastructure in your community. You are, therefore, asked to please respond as accurately and honestly to the questions as possible. This survey is a part of research program undertaken by the Department of Civil Engineering, McGill University, Montreal (Canada) and supported by N-W.F.P University of Engineering & Technology, Peshawar (Pakistan).

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For researcher use only

Project Code: ________________________

Date of handing over: ________________

Received back on: ____________________

Notes:

CONSENT

The research data will be used for the Ph.D. thesis of the candidate, Muhammad Sagheer Aslam, and in research publications and related articles in conference proceedings and presentations. It should be understood that these documents will be publically available; however, the data will be presented in the aggregate and no name(s) or other information will be included which could result in anyone being identified. If you do not wish to answer any question(s) or the entire questionnaire, you have an open option. If you decide to answer this survey questionnaire on a voluntary basis, it will be considered as a written consent on your part to permit us to utilize the data for the stated purposes. If you do not agree and if you are unable to provide your consent, you can simply decline our request for participation without giving any reason, and withdraw from survey. It will take about 30 to 40 minutes for individual responses to the questionnaire.

The information related to projects and subjects will be strictly in the possession of the investigator and the research supervisors. Once the data is analyzed, the personal information will be deleted/destroyed and only the relevant data will be kept without any personal or community information or identification. It will be strictly ensured that data does not show any personal information at all. That will be accessible to investigator, research committees and will be published in papers and thesis of the candidate, Muhammad Sagheer Aslam. There is no risk involved in participating in this study.

Your honest responses to the questions, however, will definitely be a great service and contribution to enable amelioration of the existing drinking water infrastructure in your community and to develop a framework for sustainable drinking water infrastructure system in rural areas in developing countries. Thank you.

Name: ____

Gender: Male/Female Age__________ years Education______________

Occupation__________

Village/Town ________________________ Tehsil________________

District_______________

Contact Number (optional) ___________________________

e-mail (optional) ____

Field Questionnaire

Q. No.	Question / Answer	Percentage	Guidelines / Notes
1	*From which source you are getting drinking water?*		If other, please specify here
	River	2.14	
	Stream / Canal	7.86	
	Spring	67.14	
	Open well	2.14	
	Tube well	2.14	
	Other?	5.71	
	Not Reported	12.86	
2	*How often do you visit the water source?*		If never visited skip to Q-4
	Once a year	31.07	
	Twice a year	19.29	
	More than thrice a year	45.36	
	Never visited	2.86	
	Not reported	1.43	
3	*Since when you are watching this particular water source?*		
	5 years or less	26.07	
	5 - 10 years	27.14	
	11 - 15 years	17.86	
	16 years or more	24.64	
	Not Reported	4.29	
4	*Was the source kept under observation for depletion before final selection?*		

	Yes	72.86	
	No	18.57	
	Don't know	5.71	
	Not reported	2.86	
5	*Did you notice any depletion?*		
	Yes	78.93	
	No	18.93	
	Don't know	0.71	
	Not reported	1.43	
6	*How do you make this assessment (of depletion)?*		History means authentic information from elders and seniors of the community and Observation is your own
	By Observation	74.29	
	By Observation and history both	18.57	
	By history	1.43	
	Not reported	5.71	
7	*If depletion is observed, how do you rate it?*		
	Temporary	69.29	
	Permanent	20.71	
	Don't know	1.43	
	Not reported	8.57	
8	*What is an estimated rate of depletion in terms of depth if the source is "groundwater source"?*		Answer involves the increase in depth of water from ground level per year, that is, how many feet per year water level is going
	Less than a ft per year	36.43	
	1 ft to 2 ft per year	16.43	
	2 ft to 3 ft per year	8.57	
	Other? Specify	11.43	

	Not reported	27.14	down from ground level
9	*Does the source provide sufficient water to cover the needs of present population?*		
	Yes	31.43	Such disputes may include the disputes between individuals and/or adjacent communities about permission to use this particular source, and/or due to future of the source owning community, and/or due to any other reason of socio-economic and/or environmental issues.
	May be	16.07	
	No	51.07	
	Don't know	1.43	
10	*Is this source a protected one?*		Question is about protection of the source from dust/soil sediments, leaves, animals, rain flow from surrounding into the source, and other bacteriological and chemical contamination
	Yes	55.36	
	No	41.79	
	Don't know	1.43	
	Not reported	1.43	

11	*Was there ever a dispute or significant disagreement about this source?*		Such disputes may include the disputes between individuals and/or adjacent communities about permission to use this particular source, and/or due to future of the source owning community, and/or due to any other reason of socio-economic and/or environmental issues.
	Yes	22.5	
	No	76.07	
	Don't know	1.43	
12	*What is the system involved in conveyance of water to your community?*		
	Gravity Flow	57.86	
	Pumping to an overhead storage tank and then gravitational flow	14.29	
	Pumping directly to the distribution infrastructure	20.71	
	Not reported	7.14	
13	*What is the most common storage system adapted by the people in your community?*		
	Overhead tanks	69.29	
	Containers and buckets	22.86	
	No storage	7.86	

14	*Is overflow from storage tanks?*	
	Wasted	18.21
	Utilized	28.93
	No overflow	48.57
	Not reported	4.29
15	*How many days per week do you receive the water?*	
	1-2 days	7.14
	3-4 days	14.29
	5-6 days	15
	7 days	60.71
	Not reported	2.86
16	*How many hours per day do you receive water?*	
	3 hours or less	17.86
	More than 3 to 8 hrs	13.57
	More than 8 to 16 hrs	12.86
	More than 16 to 24 hrs	51.43
	Not reported	4.29
17	*What is the normal daily need of clean drinking water?*	
	Up to 10 litres/person	41.07
	Up to 20 litres/person	17.14
	Up to 30 litres/person	17.86
	Up to 40+ litres/person	21.07
	Not reported	2.86

18	*What quantity of water are you getting now?*	
	Less than needed	28.57
	According to needed	45
	More than needed	4.29
	Varying seasonally	20.71
	Not reported	1.43
19	*Who is responsible for operational activities?*	
	Valve man	47.86
	No body	45
	Don't know	2.86
	Not reported	4.29
20	*What is the frequency of service interruptions?*	
	Once in 7 days	26.07
	Once in 15 days	9.29
	Once in 30 days	22.86
	Once in more than a month	34.64
	Not reported	7.14
21	*Distribution infrastructure is maintained?*	
	Regularly	6.43
	On failure only	77.14
	Mostly delayed	9.29
	Not sure	2.86
	Not reported	4.29

22	*What looks more dangerous for distribution infrastructure?*		
	Earthquake		28.06
	Land-sliding		64.33
	Terrorism		0.47
	Don't know		2.86
	Not reported		4.29
23	*Do you feel that efforts are made to secure infrastructure from threats mentioned in/ similar to those mentioned in previous question?*		
	Yes		17.14
	Partially yes		43.93
	No		36.07
	Not reported		2.86
24	*Is there any concept of inventories or records for maintenance activities?*		
	Yes		25.71
	Partially yes		26.07
	No		39.64
	Don't know		4.29
	Not reported		4.29
25	*How would you rate the quality of water in terms of?*		
	1- Color	a)Good	77.9
		b)Poor	7.9
		c)Not reported	14.2
	2-Odour	a)Good	71.8

		b)Poor	5.7	
		c)Not reported	22.5	
	3- Taste	a)Good	78.6	
		b)Poor	2.1	
		c)Not reported	19.3	
	4- Overall	a)Good	83.2	
		b)Poor	1.4	
		c)Not reported	15.40	
26	*Are there any potential chances of contamination/further contamination of existing source in future?*			These chances may be due to Industrial growth in the vicinity, poor sewerage system, fertilizers, pesticides/insecticides, Petrol-Oil-Lubricants and any other reason of similar nature.
	Yes		58.2	
	May be		17.1	
	No		22.7	
	Don't know		1.9	
27	*Do you feel any health or comfort problems after drinking the water from this particular distribution infrastructure?*			
	Yes		16.1	
	Rarely		49.3	
	Not at all		23.2	
	Not sure		11.4	
28	*What is the nature of the storage containers, if other than overhead tanks?*			
	Open bucket type		36.2	
	Open coolers with proper covers		31.4	

	Narrow bottle head type	5.5
	Bigger drums type	25.5
	Not reported	1.4
29	*How often do you clean the overhead / storage tanks?*	
	Once a year	29.3
	Twice a year	26.1
	Rarely	31.4
	Any other? Specify	3.2
	No overhead storage exists	8.6
	Not reported	1.4
30	*Were quality tests conducted for selected source?*	
	Yes	28.6
	No	66.8
	Don't know	4.6
31	*If quality tests were conducted, when were they?*	
	Before final selection	18.9
	After selection	11.1
	After distribution infra	7.1
	Don't know	22.9
	Not	40
32	*Were quality tests conducted at consumer end after the start of water supply?*	
	Once only	21.4
	Once a year	0.7

	Once in two years	0	
	Once in three years or more	4.3	
	Never after start of supply	50.7	
	Not reported	22.9	
33	*What sanitation system is in practice?*		
	Flush toilet	83.6	
	Dry pit	2.1	
	Open field	12.9	
	Not reported	1.4	
34	*Do you think that sewage is polluting the drinking water?*		This pollution may be due to open field defecation mixing with rainwater and joining water source and/or due to poor condition of pipelines of sewerage and drinking water placed close to each other and/or due to bad drainage system and/or due to any other reason/cause of similar nature.
	Yes	31.4	
	No	57.1	
	Don't know	8.6	
	Not reported	2.9	
35	*How do you pay for delivered water?*		
	Monthly bills	12.86	
	When demanded	8.57	
	Only in emergency	23.21	

	It is free of cost	55.36	
36	*Do you save or pay anything to your community organization for operation and maintenance?*		The savings are generally made by the people and recorded by the community organization on periodic basis. This is normally dealt like bank savings but mostly non interest based. The question deals with that part of savings which may act as treasure for operation and maintenance of drinking water infrastructure
	Never	15.71	
	Casually	56.43	
	Regularly	20.71	
	Don't know	5.71	
37	*What do you pay for maintenance per month?*		Partially open ended, as open ended will give much better idea, and ranges will be specified on the basis of answers.
	Periodic monthly amount	13.1	
	Only when needed	70.11	
	Nothing	15.36	
	Not reported	1.43	
38	*What is your view of the manner in which the maintenance funds are used?*		**Transparent** – if important financial decisions are made with consultations of community members and records are
	Transparently	68.57	
	Ambiguously	14.64	
	Dishonestly	1.43	
	Don't know anything	11.07	

	Not reported	4.29	presented for audit, **Ambiguous** – if financial decisions are made by few influential individuals and not discussed or presented for audit in front of community; **Dishonestly** – if there is an evidence of financial corruptions in maintenance funds
39	*How are the maintenance funds monitored by the various parties overseeing the maintenance operations?*		
	By involving majority of the community	48.21	
	Through audit committees	29.29	
	Randomly without any system	6.79	
	No monitoring at all	11.43	
	Not reported	4.29	
40	*Are the funds for operation and maintenance dependent on external resources from the government and/or non-governmental organizations?*		
	Yes	32.39	
	No	54.76	
	Don't know	8.57	
	Not reported	4.29	

41	*If answer is yes in previous question, do u think that such external resources are reliable and serve the purpose?*	
	Yes	24.29
	Partially	23.57
	Not at all	12.14
	Not sure	4.29
	Not reported	35.71
42	*What was the average fetching time per day before presence of existing system*	
	1-2 hours	53.93
	3-4 hours	27.5
	5-6 hours	7.86
	6 hours or more	9.29
	Not reported	1.43
43	*Who was responsible for fetching water before the presence of existing system?*	
	Children	1.14
	Female	36.07
	Male	15.71
	Combined male and female	27.5
	Combined female and children	16.43
	On payment	1.71
	Not reported	1.43
44	*If water was provided on payment before presence of existing system, what was the monthly payment?*	
	Less than 500 Rupees	21.43
	500 – 1000 Rupees	10

	1000 – 1500 Rupees	1.43
	Other? Specify	2.86
	Never on payment	37.14
	Not reported	27.14
46	*What is your view about water use?*	
	Use according to availability	6.07
	Use according to need	47.99
	Optimize use and availability	12.61
	Avoid wastage only and use whatever you want to use	33.33
47	*What do you think about availability of water resources for domestic usage?*	
	Unlimited and not going to decrease	43.93
	Limited and decrease if wasted	40.36
	Don't know	12.86
	Not reported	2.86
48	*How does your community deal with overflow from storage tanks?*	
	Wasted	11.07
	Utilized	40.71
	No overflow	48.21
49-a	*Water available through present system is equally available for rich and poor?*	
	Yes	72.14
	No	7.86
	Not answered	4.29

	Not reported	1.43
49-b	*Water available through present system is equally available to different ethnic groups?*	
	Yes	20
	No	10
	Not answered	4.29
	Not reported	65.71
50	*Is school attendance affected due to water related issues?*	
	Yes	39.29
	No	55.71
	Not sure	5
	Don't know	0
51	*Do you think that any of diseases existing/existed in your house are water related?*	
	Yes	32.5
	No	43.93
	Not sure	19.29
	Don't know	1.43
	Not reported	2.86
52	*Which of the following diseases are more common in your house? (Put "**1**" for most common, "**12**" for least common but existing and "**0**" for nonexistent)*	

Disease	Kids below 5 years	Above 5 years of age
Diarrhea		
Typhoid		
Cholera		
Dysentery		
Hepatitis A		
Hepatitis E		
Malaria		
Dengue		
Whooping cough		
tuberculosis		
Gastritis		
Misc Stomach problems		

Not reported

53 *Mention if any disease other than mentioned in Q-52 exists/existed in your house?*

1-

2-

3-

Not reported

54 *Did you know that diseases mentioned in Q-52 are water related?*

Yes

Partially

No

Not reported

55 *Any death in your family due to water related diseases during last 15 years?*

	None	76.43	
	One	12.86	
	two	0	
	More than two	6.43	
	Not reported	4.29	
56 and 57	Open ended questions for comments only		
58	*Are you a regular member of your Community Organization?*		A community organization is an organized institution of males and/or females of the community, headed by their own trusted activists and involved in need identification, execution and maintenance of existing drinking water infrastructure. Such institutions are commonly formed with the help of some NGO and maintained by the communities.
	Yes	83.93	
	No	10.36	
	Casually regular	2.86	
	It's not important	0	
	Not reported	2.86	
59	*How does the maintenance committee work?*		The working of maintenance committee can be termed as efficient if it continue
	Efficiently	58.93	
	Inefficiently	28.93	
	No committee exists	9.29	

			monitoring and routine maintenance, and always respond without any delays to emergencies. If such responses are rare and delays occur due to any reason, but ultimately it gets done, then tick “inefficiently”. If nothing is done practically by any such committee even if it exists in files and papers, term it as “No committee exists”.
	Not reported	2.86	
60	*How do you rate your community organization?*		Strong if properly organized, open for debate and participation and face no financial or budgetary problems and so on for average and weak according to present status.
	Excellent	50.47	
	Good	37.03	
	Weak	8.21	
	Non-functional	1.43	
	Not reported	2.86	
61	*Which organization is stronger in your community?*		Comparing both organizations in terms of response, attendance, savings etc.
	Male organization	87.26	
	Female organization	7.03	
	Don’t know	1.43	
	Not reported	4.29	

62	*How you rate the response of maintenance committee towards solution of problems?*	
	Excellent	42.61
	Good	47.26
	Poor	2.61
	Very Poor	0
	There is no such committee	1.79
	Not reported	5.71
63	*Are you satisfied with trainings given to community members to operate and maintain the system?*	
	Yes	40.36
	Partially	16.79
	No	5
	Don't know	7.14
	No training	25
	Not reported	5.71
64	Any other comment? (Optional)	

URDU TRANSLATION OF THE QUESTIONNAIRE

سروے/سوالنامہ

تعارف:-

ترقی پذیر ممالک میں پانی کے مسائل گھمبیر شکل اختیار کرتے جارہے ہیں اور بالخصوص پینے کے پانی کے حوالے سے بہت سارے مسائل خطرناک حد تک پیچیدہ ہو رہے ہیں۔ان مسائل کے حل کے لئے ہمہ جہت کوششوں کی ضرورت ہے۔آپ کے ہاتھوں میں موجود سوالنامہ بھی اسی سلسلے کی ایک اہم کوشش کا حصہ ہے۔

لوگوں کے تعاون سے بنائے گئے پینے کے پانی کے نظاموں (Community-Based Drinking Water Systems) کو زیادہ مفید، مناسب اور ممکنہ حد تک طویل المعیاد اور دائمی (Sustainable) بنانے کے لئے ایک تحقیقی کام کا آغاز ہوا ہے جس کی افادیت کو بڑھانے اور زیادہ بامقصد بنانے کے لئے آپ کا مشاہدہ، تجربہ اور رائے بہت اہمیت کے حامل ہیں۔جنہیں اس سوالنامے میں موجود مختلف سوالوں کی صورت میں آپ سے پوچھا گیا ہے اور آپ سے دیانتدارانہ اور بروقت جوابات کے لئے درخواست کی جارہی ہے۔

یہ خالصتاً ایک تحقیقی کام ہے جسے انجنیئرنگ یونیورسٹی پشاور (پاکستان) اور مک گل (McGill) یونیورسٹی مانٹریال (کینیڈا) کا تعاون اور نگرانی حاصل ہے ہر ممکن کوشش کی جائے گی کہ آپ کے جوابات اور رائے کو صرف تحقیقی مقاصد کے لئے استعمال کیا جائے اور آپ کے نام، پتہ اور دیگر کوائف کو محفوظ رکھا جائے۔آپ نے تمام جوابات اپنی بستی میں موجود پینے کے پانی کے نظام کے حوالے سے دینے ہوں گے۔اور اگر ان سوالات میں سے تمام یا کچھ کے جوابات نہیں دینا چاہتے تو اس کا فیصلہ آپ اپنی مرضی سے کرسکتے ہیں۔آپ کے دیانت دارانہ جوابات انسانیت کی ایک بڑی خدمت میں آپ کا حصہ ہوگا۔شکریہ

نام------------------------ ولدیت------------------------ جنس: مرد/عورت عمر---------- سال

تعلیم---------- پیشہ---------- گاؤں---------- تحصیل---------- ضلع---------- صوبہ---------- (پاکستان)

رابطہ نمبر (اختیاری)-------------------- ای میل (Email)--

پانی کا موجودہ نظام کس ادارے کے تعاون سے قائم کیا گیا ہے--

پانی کا موجودہ نظام کب قائم ہوا ہے؟--

ادارے کے استعمال کے لئے

سوالنامہ نمبر---------------- پراجیکٹ کوڈ---------------- تاریخ----------------

برائے رابطہ/وضاحت:

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سوالنامہ -یونٹ 1

پراجیکٹ کوڈ-----------------سوالنامہ نمبر-----------------------تاریخ-----------------تا------------------

نمبر شمار	سوال / جواب (درست جواب کے سامنے نشان لگائیں)	رہنمائی کیلئے نوٹس
1	آپ پینے کا پانی کس ذریعہ سے حاصل کرتے ہیں؟ دریا ☐ ندی / نالہ ☐ چشمہ ☐ ٹیوب ویل ☐ ان کے علاوہ کوئی ذریعہ ☐	اگر کوئی دوسرا ذریعہ ہے تو برائے مہربانی تحریر کریں۔
2	آپ پانی کے منبع (جہاں سے پانی نکلتا ہے) کو کتنی دفعہ دیکھتے ہیں؟ سال میں ایک بار ☐ سال میں دو بار ☐ سال میں تین سے زیادہ بار ☐ کبھی نہیں دیکھتے ☐	اگر نہیں دیکھتے تو سوال نمبر 7 پر جائیں
3	آپ کب سے پانی کے منبع کو دیکھ رہے ہیں؟ 5 یا اس سے کم سالوں سے ☐ 5 تا 10 سالوں سے ☐ 11 تا 15 سالوں سے ☐ 16 یا اس سے زیادہ سالوں سے ☐	
4	کیا پانی کا منبع آخری انتخاب سے پہلے زیر مشاہدہ رکھا گیا تھا؟ ہاں ☐ نہیں ☐ نہیں معلوم ☐	
5	کیا آپ نے پانی کی مقدار میں کمی مشاہدہ کی؟ ہاں ☐ نہیں ☐ نہیں معلوم ☐	

سوالنامہ -یونٹ 1

پراجیکٹ کوڈ ______________ سوالنامہ نمبر ______________________ تاریخ ______________ تا ______________

نمبر شمار	سوال/جواب (درست جواب کے سامنے نشان لگائیں)	رہنمائی کیلئے نوٹس
6	آپ پانی کی کمی کا جائزہ کیسے لیتے ہیں؟ مشاہدہ کے ذریعے تاریخ اور مشاہدہ کی روشنی میں تاریخ کے ذریعے	تاریخ سے مراد بزرگ شہریوں، اخبارات یا دیگر رپورٹوں سے حاصل شدہ علم ہے اور مشاہدہ آپ کا ذاتی ہوسکتا ہے۔
7	اگر کمی دیکھی گئی تو آپ کے خیال میں یہ کمی کیسی ہے؟ عارضی مستقل نہیں معلوم	
8	زمین کے اندر سے حاصل ہونے والے پانی میں کمی کی نسبت کیا ہے؟ سال میں ایک فٹ سے کم سال میں ایک سے دو فٹ سال میں دو سے تین فٹ ان کے علاوہ	جواب زمین کی سطح سے پانی کی گہرائی کے کے حساب سے دیں یعنی پانی کا لیول ہر سال زمین کی سطح سے کتنا دور چلا جاتا ہے۔
9	کیا پانی کا منبع موجودہ آبادی کی ضروریات کے لئے کافی ہے؟ جی ہاں شاید نہیں نہیں معلوم	
10	کیا یہ منبع محفوظ ہے؟ ہاں نہیں نہیں معلوم	یعنی کیا منبع گرد/مٹی، پتوں، جانوروں اور بارش کے پانی آلودگیوں اور کیمیائی مادوں سے محفوظ ہے؟
11	کیا پانی کے موجودہ منبع پر کبھی کوئی تنازعہ یا اختلاف رائے ہوا؟ ہاں نہیں نہیں معلوم	تنازعہ افراد کا آپس میں یا دو معاشروں کا آپس میں پانی کے استعمال کی اجازت لینے یا کسی معاشرہ کی پانی کے منبع کی ملکیت سے متعلقہ تنازعہ یا کسی دوسرے معاشرتی و معاشی یا ماحولیاتی وجوہات کی بنا پر ہوسکتا ہے۔

سوالنامہ -یونٹ 1

پراجیکٹ کوڈ------------سوالنامہ نمبر----------------------تاریخ----------------تا----------------

نمبر شمار	سوال / جواب (درست جواب کے سامنے نشان لگائیں)	رہنمائی کیلئے نوٹس
12	آبادی کو پانی پہنچانے کیلئے کیا نظام موجود ہے؟ ثقلی بہاؤ (بغیر پمپ) ☐ کسی اونچی جگہ پر پمپ کر کے ثقلی بہاؤ ☐ آبادی کو براہ راست پمپ کر کے ☐	اگر ان کے علاوہ کوئی نظام ہو تو یہاں درج کریں۔
13	آپ کی آبادی کیلئے پانی کے ذخیرہ کیلئے کونسا طریقہ استعمال کیا جاتا ہے؟ اونچے ٹینکوں میں ☐ برتنوں میں ☐ ذخیرہ نہیں کیا جاتا ☐	
14	سٹوریج ٹینک سے اضافی پانی کہاں جاتا ہے؟ ضائع ہوتا ہے۔ ☐ استعمال ہوتا ہے۔ ☐ کوئی اضافی پانی نہیں گرتا ☐	
15	آپ کو ہفتے میں کتنے دن پانی ملتا ہے؟ 1 سے 2 دن ☐ 3 تا 4 دن ☐ 5 تا 6 دن ☐ 7 دن ☐	
16	آپ کو روزانہ کتنے گھنٹے پانی ملتا ہے؟ 3 یا اس سے کم گھنٹے ☐ 3 تا 8 گھنٹے ☐ 8 تا 16 گھنٹے ☐ 16 تا 24 گھنٹے ☐	

سوالنامہ - یونٹ 1

پراجیکٹ کوڈ______________سوالنامہ نمبر__________________________تاریخ______________تا______________

نمبر شمار	سوال / جواب (درست جواب کے سامنے نشان لگائیں)	رہنمائی کیلئے نوٹس
17	روزانہ پینے کے صاف پانی کی ضرورت کتنی ہوتی ہے؟ 10 لیٹر فی کس تک ☐ 20 لیٹر فی کس تک ☐ 30 لیٹر فی کس تک ☐ 40 یا اس سے زیادہ لیٹر فی کس ☐	
18	آپ کو پانی کی کتنی مقدار مل رہی ہے؟ ضرورت سے کم ☐ ضرورت کے مطابق ☐ ضرورت سے زیادہ ☐ موسم کے حساب سے کم وبیش ☐	
19	پانی کی سپلائی کو جاری کرنے اور روکنے کا ذمہ دار کون ہے؟ والومین ☐ کوئی بھی نہیں ☐ نہیں معلوم ☐	
20	عام طور پر سپلائی کے نظام میں رکاوٹ کتنی بار پیدا ہوتی ہے؟ 7 دنوں میں ایک بار ☐ 15 دنوں میں ایک بار ☐ 30 دنوں میں ایک بار ☐ مہینے سے زیادہ کے عرصہ میں ایک بار ☐	
21	پانی کی تقسیم کے ڈھانچہ (پائپ لائن وغیرہ) کی دیکھ بھال کیسے ہوتی ہے؟ باقاعدہ ☐ خرابی کی صورت میں ☐ تاخیر کے ساتھ ☐ یقین سے نہیں کہہ سکتے ☐	

سوالنامہ -یونٹ 1

پراجیکٹ کوڈ-------------------سوالنامہ نمبر-----------------------------تاریخ--------------------تا-------------------

نمبر شمار	سوال/جواب (درست جواب کے سامنے نشان لگائیں)	رہنمائی کیلئے نوٹس
22	تقسیم کے ڈھانچہ کیلئے کونسی چیز زیادہ خطرناک ہے؟ زلزلہ ☐ لینڈ سلائیڈنگ ☐ دہشت گردی ☐ نہیں معلوم ☐	
23	کیا آپ سمجھتے ہیں کہ مندرجہ بالا خطرات سے نمٹنے کیلئے کوششیں ہو رہی ہیں؟ جی ہاں ☐ کسی حد تک ☐ نہیں ☐	مندرجہ بالا خطرات سے مراد سوال نمبر 22 میں دیئے گئے یا اسی طرح کے دیگر خطرات ہیں
24	کیا پائپ لائن وغیرہ کی مرمت اور دیکھ بھال کا باقاعدہ ریکارڈ رکھا جاتا ہے؟ جی ہاں ☐ کسی حد تک ☐ نہیں ☐ نہیں معلوم ☐	

سوالنامہ - یونٹ2

پراجیکٹ کوڈ------------------سوالنامہ نمبر--------------------------تاریخ------------------تا--------------

نمبر شمار	سوال/جواب	رہنمائی کیلئے نوٹس
25	آپ کو موجودہ سکیم سے ملنے والا پانی کیسا ہے؟	

	اچھا	بُرا
رنگ		
بُو		
ذائقہ		
مجموعی طور پر		

نمبر شمار	سوال/جواب	رہنمائی کیلئے نوٹس
26	کیا مستقبل میں پانی کو آلودہ اور خراب کرنے کے امکانات موجود ہیں؟	یہ امکانات صنعتوں کے بڑھنے، نکاسی کے برے نظام، کھادوں، کیمیائی مادوں یا اسطرح کی دیگر وجوہات کی بنا پر ہو سکتے ہیں اگر جواب ہاں ہے تو براہِ مہربانی یہاں وجہ بھی بیان کریں۔ ------------------------- -------------------------

ہاں	
شاید	
نہیں	
نہیں معلوم	

نمبر شمار	سوال/جواب	رہنمائی کیلئے نوٹس
27	کیا آپ موجودہ نظام کے ذریعے فراہم کیئے جانے والے پینے کے پانی سے کوئی بیماری یا تکلیف محسوس کرتے ہیں؟	

ہاں	
کبھی کبھار	
بالکل نہیں	
یقین سے نہیں کہہ سکتے	

نمبر شمار	سوال/جواب	رہنمائی کیلئے نوٹس
28	پانی زخیرہ کرنے والے برتنوں کی نوعیت کیسی ہے؟	

کھلا بالٹی نما برتن	
کھلے کولر نما ڈھکن کے ساتھ	
تنگ بوتل کی طرح کے	
بڑے ڈرم کی طرح کے	

پراجیکٹ کوڈ________________سوالنامہ نمبر________________تاریخ________________تا________________

نمبر شمار	سوال/جواب	رہنمائی کیلئے نوٹس
29	آپ پانی زخیرہ کرنے والے بڑے ٹینک کو کتنی دفعہ صاف کرتے ہیں؟	
	سال میں ایک بار	
	سال میں دو بار	
	کبھی کبھار	
	ان کے علاوہ	
	ٹینک استعمال نہیں کرتے	
30	کیا موجودہ منبع سے پانی کے معیار کو جانچنے کے لئے ٹیسٹ لئے گئے تھے؟	
	ہاں	
	نہیں	
	نہیں معلوم	
31	اگر پانی کے معیار جانچنے کیلئے ٹیسٹ کیا گیا تو کب؟	
	منبع کے انتخاب سے پہلے	
	منبع کے انتخاب کے بعد	
	پانی کی فراہمی شروع کرنے کے بعد	
	نہیں معلوم	
32	کیا صارفین کو پانی فراہم ہونے کے بعد فراہم شدہ پانی کا ٹیسٹ لیا گیا؟	
	صرف ایک بار	
	سال میں ایک بار	
	دو سال میں ایک بار	
	تین یا زیادہ سالوں میں ایک بار	
	پانی کی فراہمی کے بعد کبھی نہیں	

سوالنامہ - یونٹ2

پراجیکٹ کوڈ-------------سوالنامہ نمبر-----------------------تاریخ------------------تا---------------

نمبر شمار	سوال/جواب	رہنمائی کیلئے نوٹس
33	بیت الخلاء (Toilets) کا کون سا نظام استعمال ہو رہا ہے؟ فلش/ٹوائلٹ خشک گڑھے کھلے کھیت	
34	کیا سیوریج کا نظام پینے کے پانی کو آلودہ کر رہا ہے؟ ہاں نہیں نہیں معلوم	یہ آلودگی کھلے کھیتوں میں پڑی گندگی کے بارش وغیرہ کے پانی کے ساتھ مل کر پانی میں ملنے اور/یا پائپوں کی خراب حالت اور گندے پانی کی قربت اور/یا نکاسی کے ناقص انتظام اور/یا اسی طرح کی کسی اور وجہ سے ہو سکتی ہے۔

پراجیکٹ کوڈ----------------سوالنامہ نمبر-------------------------تاریخ-----------------تا-------------

نمبر شمار	سوال / جواب		رہنمائی کیلئے نوٹس
35	آپ مہیا ہونے والے پانی کا معاوضہ کیسے دیتے ہیں۔؟		
	ماہانہ بل کی صورت میں		
	مطالبہ پر		
	ایمرجنسی کی صورت میں		
	معاوضہ نہیں دیتے		
36	کیا آپ اپنی عوامی تنظیموں کو پانی کے نظام کی مرمتی یا درست رکھنے کیلئے ادائیگی یا بچت کرتے ہیں؟		یہ بچت عام طور پر لوگ کرتے ہیں اور تنظیمیں اس کا باقاعدہ ریکارڈ رکھتی ہیں اور یہ بنک سیونگ کی طرح ہوتی ہے لیکن اس پر سود یا منافع نہیں ہوتا۔ یہ سوال ایسی بچت کے متعلق ہے۔
	کبھی نہیں		
	کبھی کبھی		
	باقائدگی سے		
	نہیں معلوم		
37	آپ پانی کے نظام کو درست رکھنے کیلئے ماہانہ کیا ادائیگی کرتے ہیں؟		رقم کی صورت میں اندراج کریں۔
	ماہانہ رقم مبلغ=		
	صرف ضرورت پڑنے پر		
	کچھ نہیں ادا کرتے		
38	پانی کے موجودہ نظام کی دیکھ بھال اور مرمت کے فنڈز کا استعمال کیسے ہوتا ہے؟		شفاف سے مراد یہ ہے کہ رقم کے خرچ سے متعلق فیصلے عوامی نمائندے کرتے ہیں اور اس کا احتساب ہوتا ہے۔ غیر واضح سے مراد یہ ہے کہ فیصلے اثر و رسوخ رکھنے والے افراد کرتے ہیں۔ اور حساب سے آگاہ نہیں کرتے بدیانتی سے مراد دیکھ بھال اور مرمت کی رقم کا غلط استعمال ظاہر ہوگا۔
	شفاف طریقہ اور دیانتداری سے		
	غیر واضح طور پر اور مشکوک طریقہ سے		
	بددیانتی سے		
	نہیں معلوم		
39	دیکھ بھال اور مرمت کے فنڈز کی جانچ پڑتال کیسے کی جاتی ہے؟		
	عوام کی اکثریت کو شامل کر کے		
	آڈٹ کمیٹیوں کے ذریعے		
	بغیر کسی ترتیب اور نظام کے		
	جانچ پڑتال نہیں ہوتی		

سوالنامہ - یونٹ3

پراجیکٹ کوڈ________________سوالنامہ نمبر____________________تاریخ__________________تا________________

نمبر شمار	سوال/جواب	رہنمائی کیلئے نوٹس
40	کیا دیکھ بھال اور مرمتی کیلئے رقم جمع کرنے کا انحصار بیرونی ذرائع یا حکومت یا نجی تنظیموں پر ہوتا ہے؟ ہاں | نہیں | نہیں معلوم |	
41	اگر پچھلے سوال کا جواب ہاں ہے تو کیا یہ ذرائع قابل اعتبار ہیں اور مقصد کو پورا کرتے ہیں؟ ہاں | جزوی طور پر | نہیں | یقین سے نہیں کہہ سکتے |	
42	موجود نظام کی دستیابی سے پہلے پانی لانے پر یومیہ کتنا وقت لگتا تھا؟ ۱ سے ۲ گھنٹے | ۳ سے ۴ گھنٹے | ۵ سے ٦ گھنٹے | ٦ یا اس سے زیادہ گھنٹے |	
43	موجودہ نظام سے پہلے پانی بھرنے اور لانے کی ذمہ دار کس کی تھی؟ بچوں کی | عورتوں کی | مردوں کی | مردوں اور عورتوں دونوں کی | عورتوں اور بچوں کی | معاوضہ دیکر منگوایا جاتا تھا۔ |	

سوالنامہ - یونٹ 3

پراجیکٹ کوڈ-------------سوالنامہ نمبر-------------تاریخ-------------تا-------------

نمبر شمار	سوال/جواب	رہنمائی کیلئے نوٹس
44	اگر موجودہ نظام سے پہلے پانی معاوضہ پر حاصل کیا جاتا تھا تو یہ معاوضہ ماہانہ کتنا تھا؟	

500روپے سے کم	
500روپے سے 1000روپے تک	
1000روپے سے 1500روپے تک	
اگر 1500 سے زیادہ تو کتنا	

نمبر شمار	سوال/جواب	رہنمائی کیلئے نوٹس
45	اگر آپ اپنی بستی اور لوگوں کے بارے میں جانتے ہیں تو بتائیں کہ بستی میں	

کل آبادی کتنی ہے؟	
پانی سے متعلقہ بیماریوں کے مریض کتنے ہیں؟	
ان بیماریوں کی وجہ سے ماہانہ فی کس کتنا وقت ضائع ہوتا ہے؟	
ایسی بیماریوں کی وجہ سے مرنے والے 5 سال سے کم عمر بچوں کی تعداد کتنی ہے؟	
لوگوں کی اوسط عمر کتنی ہے؟	

پراجیکٹ کوڈ________سوالنامہ نمبر________تاریخ________تا________

رہنمائی کیلئے نوٹس	سوال/جواب	نمبر شمار
	پانی کے استعمال کے متعلق آپ کی کیا رائے ہے؟ ☐ جتنا دستیاب ہو اتنا استعمال ہونا چاہیئے ☐ جتنی ضرورت ہو اتنا استعمال چاہیئے ☐ استعمال اور دستیابی دونوں کو موزوں بنانا چاہیئے ☐ پانی ضرورت کے حساب سے استعمال ہونا چاہیئے اور ضائع نہیں ہونا چاہیے	46
	پینے کے پانی کے ذرائع کے بارے میں آپ کا کیا خیال ہے؟ ☐ غیر محدود اور نہ کم ہونے والے ☐ محدود اور ضائع ہونے کی صورت میں کم ہونے والے ☐ نہیں معلوم	47
	آپ کی بستی میں لوگ زائد پانی کے ساتھ کیا کرتے ہیں؟ ☐ ضائع کرتے ہیں ☐ استعمال میں لاتے ہیں ☐ زائد پانی نہیں ہوتا	48
	موجودہ نظام سے دستیاب پانی کی فراہمی کی نوعیت کیا ہے؟ ☐ امیر غریب سب کو برابر ہے ☐ تمام مکاتب فکر کو برابر دستیاب ہے ☐ برابر دستیاب نہیں ہے	49

پراجیکٹ کوڈ۔۔۔۔۔۔۔۔۔۔۔۔۔سوالنامہ نمبر۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔تاریخ۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔تا۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔

<table>
<tr><th>نمبر شمار</th><th>سوال/جواب</th><th>رہنمائی کیلئے نوٹس</th></tr>
<tr><td>50</td><td>کیا پانی سے متعلق مسائل کی وجہ سے سکول کی حاضری متاثر ہوتی ہے؟
<table>
<tr><td>ہاں</td><td></td></tr>
<tr><td>نہیں</td><td></td></tr>
<tr><td>یقین سے نہیں کہہ سکتے</td><td></td></tr>
<tr><td>نہیں معلوم</td><td></td></tr>
</table></td><td></td></tr>
<tr><td>51</td><td>کیا آپ کے خیال میں پانی سے متعلقہ کوئی عرض کسی کولاحق ہے؟
<table>
<tr><td>ہاں</td><td></td></tr>
<tr><td>نہیں</td><td></td></tr>
<tr><td>یقین سے نہیں کہہ سکتے</td><td></td></tr>
<tr><td>نہیں معلوم</td><td></td></tr>
</table></td><td></td></tr>
<tr><td>52</td><td>مندرجہ ذیل میں سے کونسی بیماریاں آپ کی بستی میں عام ہیں۔ جو زیادہ عام ہوں ان کیلئے "1" جو اس سے کم ہو "2" اسطرح سب سے کم کیلئے "11" لکھیں۔ اور اگر کوئی بیماری موجود نہ ہو تو "0" لکھیں
<table>
<tr><th>بیماری</th><th>5 سال سے کم عمر</th><th>5 سال سے زیادہ</th></tr>
<tr><td>دست / پیچش</td><td></td><td></td></tr>
<tr><td>ٹائیفائیڈ</td><td></td><td></td></tr>
<tr><td>ہیضہ</td><td></td><td></td></tr>
<tr><td>یرقان A</td><td></td><td></td></tr>
<tr><td>یرقان E</td><td></td><td></td></tr>
<tr><td>ملیریا</td><td></td><td></td></tr>
<tr><td>ڈینگی بخار</td><td></td><td></td></tr>
<tr><td>کھانسی</td><td></td><td></td></tr>
<tr><td>ٹی بی</td><td></td><td></td></tr>
<tr><td>گیسٹرو</td><td></td><td></td></tr>
<tr><td>معدہ کی دیگر امراض</td><td></td><td></td></tr>
</table></td><td></td></tr>
</table>

پراجیکٹ کوڈ________سوالنامہ نمبر________تاریخ________تا________

نمبر شمار	سوال/جواب	رہنمائی کیلئے نوٹس
53	اگر سوال نمبر 9 میں دی گئے امراض کے علاوہ کوئی اور مرض آپ کے گھر میں موجود ہے تو لکھیں۔ 1......... 2......... 3.........	
54	کیا آپ کو پتہ تھا کہ سوال نمبر 52 میں دی گئیں بیماریاں پانی سے متعلقہ ہیں؟ ہاں ☐ جزوی طور پر ☐ نہیں ☐	
55	کیا گزشتہ پندرہ سالوں میں آپ کے خاندان میں پانی سے متعلقہ بیماری سے کسی کی موت واقع ہوئی؟ کسی کی نہیں ☐ ایک ☐ دو ☐ اگر اس سے زیادہ تو کتنی ☐	
56	پینے کے موجودہ دستیاب پانی کے فائدے تحریر کریں؟ 1......... 2......... 3.........	
57	پینے کے موجودہ دستیاب پانی کی کیا خامیاں ہیں؟ 1......... 2......... 3.........	

سوالنامہ-یونٹ 5

پراجیکٹ کوڈ۔۔۔۔۔۔۔۔۔۔سوالنامہ نمبر۔۔۔۔۔۔۔۔۔۔تاریخ۔۔۔۔۔۔۔۔۔۔تا۔۔۔۔۔۔۔۔۔۔

نمبر شمار	سوال/جواب	رہنمائی کیلئے نوٹس
58	کیا آپ اپنی عوامی تنظیم کے باقاعدہ ممبر ہیں؟ ہاں، باقاعدہ ممبر ہوں باقاعدہ نہیں ہوں ممبر نہیں ہوں یہ بات اہم نہیں	عوامی تنظیم سے مراد ایک منظّم ادارہ ہے جو معاشرے کے مردوں یا/اور خواتین پر مشتمل ہوتا ہے اور اپنے فعال ممبران کی زیرنگرانی چلتا ہے۔اور عوام کی ضروریات کا تعین کرنے کے ساتھ ساتھ پانی کے نظام کی دیکھ بھال اور ڈھانچہ کی مرمت کرتا ہے۔ یہ ادارہ عوام عام طور پر NGO کے تعاون سے بناتی ہے۔
59	دیکھ بھال کی کمیٹی پانی کے نظام کو کس طرح درست رکھتی ہے؟ مستعد طریقہ سے غیر مستعد طریقہ سے کمیٹی نہیں ہے	"مستعد" سے مراد ہے کہ کمیٹی نظام کی باقاعدہ دیکھ بھال اور نگرانی کرتی ہے اور ایمرجنسی کی صورت میں بروقت عمل کرتی ہے۔ اور غیر مستعد سے مراد عمل درآمد میں تاخیر ہونا اور دہرے کام سرانجام دینا اور اگر کام صرف کاغذوں کی حد تک ہوتا ہے یا کمیٹی کا وجود نہ ہو تو اس کا مطلب ہے " کمیٹی نہیں ہے "
60	آپ اپنی عوامی تنظیم کو کیسا پاتے ہیں؟ بہت اچھی اور مضبوط مضبوط کمزور ناکارہ/غیر فعال	اگر باقاعدہ منظّم ہے تو مراد مضبوط ہے مضبوط تنظیم وہ ہے جو آمنے سامنے بحث مباحثہ کر کے اپنے معاملات عوام کے سامنے لاتی ہے اور کسی قسم کے مالی مسائل کا شکار نہیں ہوتی۔اسی طرح سے کمزور، اور غیر فعال کو سمجھا جائے۔
61	آپکی کمیونٹی میں کونسی تنظیم مظبوط ہے؟ مردوں کی عورتوں کی نہیں معلوم	دونوں تنظیموں کا سرگرمیوں، حاضریوں اور بحث کے حساب سے موازنہ کریں۔
62	دیکھ بھال کی کمیٹی کو مسائل کے حل میں آپ کیا جانتے ہیں؟ بہت اچھی اچھی بری بہت بری	

سوالنامہ-یونٹ 5

پراجیکٹ کوڈ-------------سوالنامہ نمبر--------------------تاریخ--------------------تا---------------

رہنمائی کیلئے نوٹس	سوال/جواب	نمبر شمار
	کیا آپ پانی کے نظام کو درست رکھنے کے سلسلہ میں دی گئی ٹریننگ سے مطمئن ہیں؟ ہاں جزوی طور پر نہیں نہیں معلوم	63
	کیا آپ مندرجہ بالا سوالات کے علاوہ کچھ کہنا چاہتے ہیں جو پانی کے موجود نظام کی بہتری کے لئے اہم ہو؟ -- -- --	64

APPENDIX B: SUSTAINABILITY OF COMMUNITY-BASED DRINKING WATER SYSTEMS

Muhammad Sagheer Aslam is presently working on his Ph.D. research program on *Sustainability of Community-based drinking water systems in developing countries* under the direction of Professors Saeed Mirza and Dominic Frigon. The research program is aimed at developing a framework for evaluating and enhancing the sustainability of these drinking water systems. The *Analytical Hierarchy Process* (AHP) is being used to conduct the Multi Criteria Analysis (MCA). One of the most important phases of AHP is to make a pair-wise comparison of the different components (Table B.3) and factors (Table B.5). This comparison provides the base for development of the required weights for different elements and factors.

Based on your background and experience, we need your input to enable us to derive weights for the different elements and factors involved in sustainability of community-based drinking water systems. We would like to ask you to undertake a pair-wise comparison of the importance of the different pairs of components (Table B.3) and factors (Table B.5). Please establish this relative importance based on the protocol proposed in (B.1). It is important to note that the tables are dealing with the relative importance of different elements and factors, considering them as a part of one integrated framework; otherwise, every element has its own importance and cannot be compared. For instance, there is no logic to compare the technical element to environmental element, in absolute terms. Relative importance will help to define a relative weight of each element or factor, to evaluate its share within the system. Please complete Table B.4 and B.6 and return these by e-mail to:

muhammad.aslam2@mail.mcgill.ca, or return it to the point from where you have received it. If you have the internet facility, please go to the website http://will.icanucanvcan.com/ to fill this survey, which is easier and more efficient.

Please note that the participation in the survey is voluntary and you may withdraw it at any time. Furthermore, please feel free to refuse to answer any question.

We thank you in advance for your cooperation. If you are willing to respond this survey, which may take 25 to 30 minutes on totally voluntarily bases, your formal consent is needed as follows:

CONSENT

I am willing to respond on a voluntarily basis and allow the researchers to use the information provided by me for the present and future research programs, and for the inclusion of my responses for any analysis, and the inclusion of the results of such an analysis in the Ph.D. thesis of Mr. Muhammad Sagheer Aslam, and any related technical publications and presentations in electronic and hard formats. I clearly understand that my identity or that of my organization will not be disclosed to any one, excluding the graduate student and the supervisors involved in this research program.

I do understand that I have the option of not responding to this survey, however, I have chosen to respond to this survey on a voluntary basis. Furthermore, in responding to the survey, if I feel at some stage that I cannot continue with my responses, I clearly understand that I can withdraw at any stage of the survey. I also understand that if I complete the responses to the survey and return them by e-mail to the researchers, this will constitute agreement on my part to participate in the survey.

Name: ________________ Profession: ________________ Experience: _____ years

Country (current):_________________ Province/State: _____________________

*Have you lived in any other country? Yes/No. _____

If Yes, Name of Country: _________________________

E-mail: ____

Signature: ______________ Location: __________ Dated: __________

OPTIONAL

What is your definition of "sustainability" with reference to sustainability of drinking water systems?

Any other comments/suggestions

Table B.1: Scale of relative importance for Tables B.3 and B.5

Relative importance of components or factors in any Pair	Encircle (value depending on your judgment and experience)*
Equally important	1
Slightly more important	2 or 3
Clearly more important	4 or 5
Significantly more important	6 or 7
Dominantly / extremely important	8 or 9

*Please encircle only one value in each comparison. If the selected value is not equal to 1 (equally important), Select the values in the direction of relatively more important element or factor.

Please note that the pair-wise comparison of different elements and factors is a technical requirement in the presented format; however, the relative importance does not show, in any case, that the element/factor having higher priority is needed and having lower priority is to be ignored. The purpose of the whole exercise is to define the relative importance of each element/factor within a system, assuming that all components/factors are part of one integrated system. Table B.2 shows the complete hierarchy of the system, to have a clear idea of the total picture.

Table B.2: Table showing complete hierarchy of components, factors and sub factor for evaluation of sustainability of community-based drinking water systems in developing countries

Components	Factors	Sub Factors
Technical	Design and execution of distribution infrastructure	Design optimization
		Available pressure at delivery points
		Protection from external pollution
		Safety against threats/disasters
	Maintenance	Physical condition
		Service interruptions
		Preventive and remedial maintenance
	Water quality in distribution system	Existence of treatment facilities
		Efficiency of treatment facilities
		Quality at consumer end
Environmental	Source capacity	Present capacity of the source
		Reliability of the source
	Source quality	Water quality at source
		Source protection
Social	Social awareness	Awareness of water-related issues
		Water usage practices
	Social involvement	Population coverage - Quantitative
		Equity/Inclusion (different sectors)
Economic	Financing	Available for operation and maintenance
		Depreciation – recovery of cost of asset over its useful life
		Reliability and continuity of finances
	Economic Impacts	Direct benefits
		Indirect benefits
Institutional	Community organizations	Existence of community organizations
		Effectiveness of community organizations
	Operation and maintenance units	Existence of operation and maintenance committees/units
		Skills and training of committee members
		Transparency in utilization of funds
		Inventories and records for maintenance activities

Table B.3: Brief description of components given in Table B.4

Elements	Mainly includes / deals with
Technical	Optimization of design, ensuring needed pressure at delivery point, safety against threats and protection from external pollution/contamination , maintenance of distribution infrastructure and quality of water in distribution system
Environmental	Present capacity of drinking water source and reliability of the source considering depletion (if any), water quality at source, and protection of source from external pollution and damage
Social	Awareness of water related issues and water usage practices, population coverage both in terms of numbers and sectors of the society
Economic	Required funds and finances required for operation and maintenance of the system and economic impacts of having a drinking water system
Institutional	Existence of community institutions (such as community organizations), their functioning and transparency

Table B.4: Pair-wise comparison of elements*

Technical									IMPORTANCE								Economic
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
	Extreme		Significant		Clear		Slight		Equal	Slight		Clear		Significant		Extreme	

Technical									IMPORTANCE								Environmental
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
	Extreme		Significant		Clear		Slight		Equal	Slight		Clear		Significant		Extreme	

Technical									IMPORTANCE								Social
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
	Extreme		Significant		Clear		Slight		Equal	Slight		Clear		Significant		Extreme	

Technical									IMPORTANCE								Institutional
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
	Extreme		Significant		Clear		Slight		Equal	Slight		Clear		Significant		Extreme	

Economic									IMPORTANCE								Environmental
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
	Extreme		Significant		Clear		Slight		Equal	Slight		Clear		Significant		Extreme	

Economic									IMPORTANCE								Social
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
	Extreme		Significant		Clear		Slight		Equal	Slight		Clear		Significant		Extreme	

Economic									IMPORTANCE								Institutional
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
	Extreme		Significant		Clear		Slight		Equal	Slight		Clear		Significant		Extreme	

Environmental									IMPORTANCE								Social
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
	Extreme		Significant		Clear		Slight		Equal	Slight		Clear		Significant		Extreme	

Environmental									IMPORTANCE								Institutional
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
	Extreme		Significant		Clear		Slight		Equal	Slight		Clear		Significant		Extreme	

Social									IMPORTANCE								Institutional
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
	Extreme		Significant		Clear		Slight		Equal	Slight		Clear		Significant		Extreme	

Table B.5: Brief description of factors given in Table B.6

Factor	Represents / deals with
A1	**Design and execution** of distribution infrastructure(Design optimization, actual pressures at consumers end, protection from external pollution and safety against threats)
A2	**Maintenance** of distribution infrastructure (Preventive and remedial maintenance, physical condition of the infrastructure and service interruptions)
A3	**Water quality** in distribution system (Existence and efficiency of treatment facilities if needed, and quality of water at consumer end)
B1	**Capacity of water source** (Availability of water at source as compared to present requirements and its reliability in terms of depletion and decrease, if any)
B2	**Quality of water at source** (Quality of water at source and protection of water source from external pollution and damage of any kind)
C1	**Social awareness** (about water related issues and water usage practices)
C2	**Social involvement** (Population coverage by the existing infrastructure and involving all different sectors and segments of the society)
D1	**Financing** (Availability and reliability of finances required for operation and maintenance, and to cover the depreciation of the infrastructure)
D2	**Economic impacts** (Economic impacts and benefits of having the present drinking water system)
E1	**Community Organizations** (Existence and working of community organizations which are the main institutions responsible for running the system)
E2	**Operation and maintenance – O&M units** (Existence and effectiveness of operation and maintenance units within the community organizations, transparency in utilization of funds and maintaining inventories and records)

Table B.6: Pair-wise comparison of factors*

Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor
	⟵							IMPORTANCE								⟶		
Design & Execution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Maintenance
	Extreme		Significant		Clear		Slight		Equal	Slight		Clear		Significant		Extreme		
	⟵							IMPORTANCE								⟶		
Design & Execution	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Water quality
	Extreme		Significant		Clear		Slight		Equal	Slight		Clear		Significant		Extreme		
	⟵							IMPORTANCE								⟶		
Maintenan ce	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Water quality
	Extreme		Significant		Clear		Slight		Equal	Slight		Clear		Significant		Extreme		
	⟵							IMPORTANCE								⟶		
Source capacity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Source quality
	Extreme		Significant		Clear		Slight		Equal	Slight		Clear		Significant		Extreme		
	⟵							IMPORTANCE								⟶		
Social awareness	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social involveme nt
	Extreme		Significant		Clear		Slight		Equal	Slight		Clear		Significant		Extreme		
	⟵							IMPORTANCE								⟶		
Availability of finances	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic Impacts
	Extreme		Significant		Clear		Slight		Equal	Slight		Clear		Significant		Extreme		
	⟵							IMPORTANCE								⟶		
Communit y organizatio	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	O& M units
	Extreme		Significant		Clear		Slight		Equal	Slight		Clear		Significant		Extreme		

*see Table 1 for guidance

How do you best define yourself	**Tick**
Technical (Design/execution-water supplies)	
Environmental	
Economist	
Social	
Institutional	
Serving with / Representing	**Tick**
Academia/Education	
Consultancy/ Field Work	
Service Providing Organization	
Community Organization	
Other (mention)	

APPENDIX C: ESTIMATION OF WEIGHTS FOR ELEMENTS OF SUSTAINABILITY OF CBDWS

This appendix summarizes outlines the procedure for estimation of weights in Chapters 6 and 7. The procedure is common for estimation of weights for both chapters; however, there are minor differences in the approaches, as explained in Chapter 3. In Chapter 6, the input matrix (Table C.1) was developed for each respondent separately and the weights were estimated for analysis. In Chapter 7, geometric means of the judgments were calculated for each group (technical, environmental, social, economic, and institutional) to develop a single input matrix (Table C.1) for each group. The results for the weights of the various components, factors, and sub-factors are presented based on the survey conducted with the stakeholders. The results presented in this appendix were utilized in Chapter 7 to develop the applied framework.

C.1. WEIGHTS OF COMPONENTS BASED ON CATEGORIES OF RESPONDENTS

To synthesize the respondent judgments using AHP, a unit input matrix for components (5 x 5) was utilized (Table C.1), with the values in the upper half of the matrix representing the geometric mean of the judgments made through pair-wise comparison on a scale of 1 to 9, as explained earlier. The values below the diagonal (in italics) are the inverse of the corresponding values above the diagonal. This is based on the fact that if X is 3 times more important than Y, then Y should be 1/3 times as important as X. The required pair-wise comparison for the various elements is shown in the survey format in Appendix B. Table C.1(a) presents a general format of the input matrix based on the survey format, while Table C-1(b) demonstrates an example based on the actual inputs (geometric means of judgments made through pair-wise comparisons) from one group of stakeholders. Technical stakeholder data is considered in Table C.1(b) as an example to explain the procedure. Table C.2 presents the input matrix (same as Table C.1(b) and the output (weights). Abbreviations used in the tables for the various components are as: T (Technical), N (Environmental), E (Economic), S (Social), and I (Institutional).

Table C.1 - Comparison matrix (Judgments)

a) General Format

	T	N	E	S	I
T	1	(T,N)	(T,E)	(T,S)	(T,I)
N	*(N,T)*	1	(N,E)	(N,S)	(N,I)
E	*(E,T)*	*(E,N)*	1	(E,S)	(E,I)
S	*(S,T)*	*(S,N)*	*(S,E)*	1	(S,I)
I	*(I,T)*	*(I,N)*	*(I,E)*	*(I,S)*	1

b) Based on Respondent Data from Technical Category

	T	N	E	S	I
T	1.000	0.562	0.495	1.652	1.238
N	*1.779*	1.000	1.452	1.198	1.492
E	*2.020*	*0.689*	1.000	1.323	1.067
S	*0.605*	*0.835*	*0.756*	1.000	0.900
I	*0.808*	*0.670*	*0.937*	*1.111*	1.000

Table C.2 presents the estimate of weights based on the input shown in Table C.1(b). The nature of individuals is considered to be synergistic, and therefore judgments are aggregated to obtain a group input, using a geometric mean, as explained earlier. After repeating the same process for all groups of stakeholders, the groups were considered as new entities and their priorities are aggregated through an arithmetic mean to synthesize the weights. Similar procedure was applied to estimate the weights of factors and sub-factor on the basis of the available survey data. A summary of all weights is presented in the table at the end of this appendix (Table C.5).

Table C.2 - Estimated weights based on input matrices for all respondents

Respondents		Input (Judgments): Comparison Matrix (Based on GM)					Output (Weights or Priorities): Normalized Comparison Matrix						
		T	N	E	S	I		T	N	E	S	I	Weight
Technical	**T**	1.000	0.562	0.495	1.652	1.238	**T**	0.161	0.150	0.107	0.263	0.217	**0.1796**
	N	1.779	1.000	1.452	1.198	1.492	**N**	0.286	0.266	0.313	0.191	0.262	**0.2636**
	E	2.020	0.689	1.000	1.323	1.067	**E**	0.325	0.183	0.216	0.211	0.187	**0.2244**
	S	0.605	0.835	0.756	1.000	0.900	**S**	0.097	0.222	0.163	0.159	0.158	**0.1598**
	I	0.808	0.670	0.937	1.111	1.000	**I**	0.130	0.178	0.202	0.177	0.176	**0.1726**

C.2. CONSISTENCY OF RESPONSES

A response would be ideally consistent in making comparisons, if a component, for example, C1 is more important than another component C2, and C2 is more important than component C3, then C1 should be more important than C3. Also, this relationship should be reflected through a numerical value based on the relative (comparative) values assigned to these components on a scale of 1 to 9. In practice, an ideal situation does not exist, when the different elements are compared, and inconsistencies in subjective responses are likely to be expected. Saaty (1990) argued that the "inconsistency throughout the matrix can be captured by a single number (λ_{max} – n), which measures the deviation of the judgments from the consistent approximation". He presented a theorem that a square matrix "is consistent, if and only if, λ_{max} = n" where n is the size of the matrix and λ_{max} is principal eigen-value of the input (square) matrix A. The consistency index of A is given by:

$$(CI) = (\lambda_{max} - n)/(n-1) \qquad \text{(C.1)}$$

This index is compared with the random index (RI), "obtained as an average over large number of reciprocal matrices of the same order whose entries are random" (Saaty, 1990). The comparison of these two indices is termed the consistency ratio (CR), given by:

$$CR = CI/RI \qquad \text{(C.2)}$$

A random index (RI value) is selected, based on Saaty's (1977) work, depending on input matrix size (Table C.3) and RI is calculated using equation C.2. He concluded that if the CR "is significantly small (carefully specified to be about 10% or less), we accept the estimate of w [calculated weights]" (Saaty, 1990)**.** The same criterion is adopted here.

The consistency of the responses was assessed using the following step-wise procedure, taking input and output matrices for technical respondents (first input and output matrices shown in Table C.2) as an example. The results for each step are presented in Table C.4.

- *Step 1*: The weights for the various elements (computed in the last column of Table C.2) are multiplied with the column values related to same element in the comparison matrix (input matrix in Table C.2), resulting in a 5x5 matrix, as:

$$= 0.1796 \times \begin{vmatrix} 1.000 \\ 1.779 \\ 2.020 \\ 0.605 \\ 0.808 \end{vmatrix} +0.2636 \times \begin{vmatrix} 0.562 \\ 1.000 \\ 0.689 \\ 0.835 \\ 0.670 \end{vmatrix} +0.2244 \times \begin{vmatrix} 0.495 \\ 1.452 \\ 1.000 \\ 0.756 \\ 0.937 \end{vmatrix} +0.1598 \times \begin{vmatrix} 1.652 \\ 1.198 \\ 1.323 \\ 1.000 \\ 1.111 \end{vmatrix} +0.1726 \times \begin{vmatrix} 1.238 \\ 1.492 \\ 1.067 \\ 0.900 \\ 1.000 \end{vmatrix}$$

- *Step 2*: The products obtained in the first step (of Table C.4) are added row-wise to obtain the weighted sum vector.

- *Step 3*: The weighted sum vector is then divided by the associated element weight (values in the last column of Table C.4).

- *Step 4*: λ_{max} is calculated by averaging the values in Step 3 (Table C.4)

- *Step 5*: CI is calculated as (CI) = (λ_{max} – n)/(n-1)

- *Step 6*: The RI value for a given size of consistent matrix is selected from the values calculated by Saaty (1977), as shown in Table C-3.

Table.C.3 - RI values (Saaty, 1977)

n	3	4	5	6	7	8	9	10
RI	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

- *Step 7*: CR is calculated as ratio = CI/RI. A comparison matrix is considered to be consistent, if CR is less than or equal to 10%.

Table C.4 shows the results based on the application of above steps to calculate CR. Figure C.01 shows that the CR values are well below the upper limit of 10%; therefore, the synthesized weights of the components of sustainability of CBDWS (Table C.2 and C.4) are acceptable.

Table C.4 - Consistency among group responses

	Step 1					Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
	T	**N**	**E**	**S**	**I**			**λ_{max}**	**CI**	**RI**	**CR (%)**
T	0.180	0.148	0.111	0.264	0.214	0.917	5.11				
N	0.319	0.264	0.326	0.191	0.258	1.358	5.15				
E	0.363	0.181	0.224	0.211	0.184	1.163	5.19	5.130	0.033	1.12	2.95
S	0.109	0.22	0.169	0.16	0.155	0.813	5.09				
I	0.145	0.177	0.21	0.178	0.173	0.883	5.12				

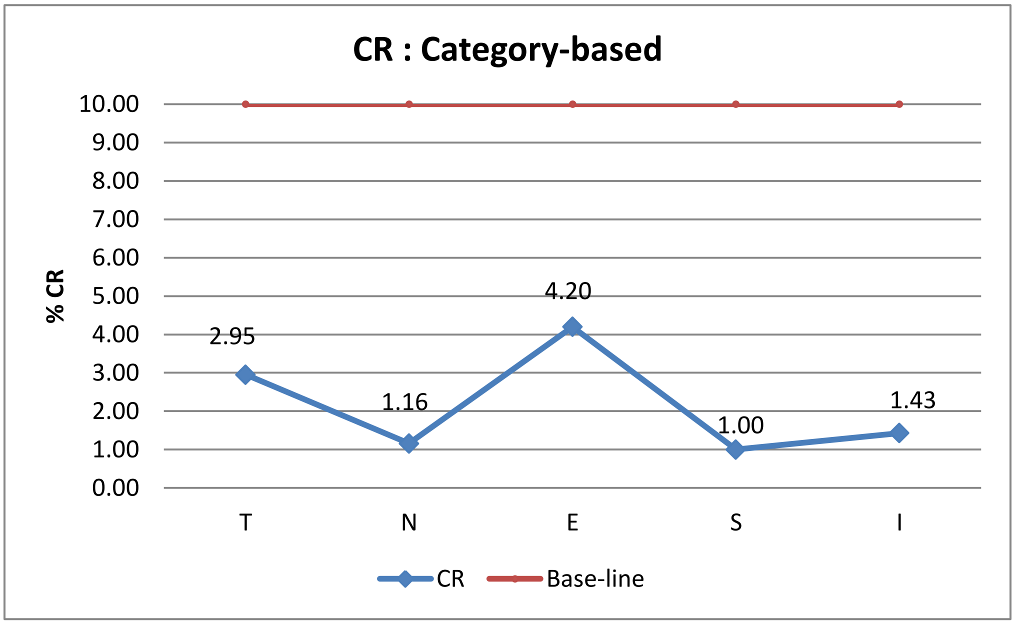

Figure C.01: Consistency ratio based on categories of respondents

C.3. WEIGHTS FOR FACTORS

The factors were synthesized using a procedure similar to that used for synthesizing the components. The consistency was checked (where applicable) and found within the acceptable limits.

C.4. WEIGHTS FOR SUB-FACTORS

As stated earlier, adequate data was not available for sub-factors. The available data was processed using a procedure similar to that for the components and factors. The maximum value of CR for the sub- factors (where applicable) is only 0.3 %.

It was assumed that until more definitive information is available, the weights for all sub-factors of a specific factor are considered equal. A comparison of the trends for the calculated sub-factor weights (on the basis of the available data) with the assumption of equal weights for all sub-factors of each parent factor is presented in Figure C.02. The continuous line shows the calculated weights, while the dotted line shows the values evaluated based on the assumption of equal weights for each sub-factor of each parental factor. Excellent agreement can be noted between the two curves. Therefore, *the assumption of equal weights for all sub-factors within each parental factor is workable.* A study focusing on sub-factors and gathering more extensive data to verify the assumption is recommended. The assumption of equal weights for each sub-factor within each parental factor has the advantage of simplicity and flexibility for adding or removing one or more sub-factor from the list, when needed. However, a study focusing on sub-factors and gathering more extensive data to verify the assumption is recommended. The weights of all elements based on respondents' experience categories (including sub-factors) are utilized in Chapter 7. It should be noted that weights plotted in Figure C.2 are based on actual weights for sub-factors for the entire system ($\sum = 100$), as adopted in Table 7.2.

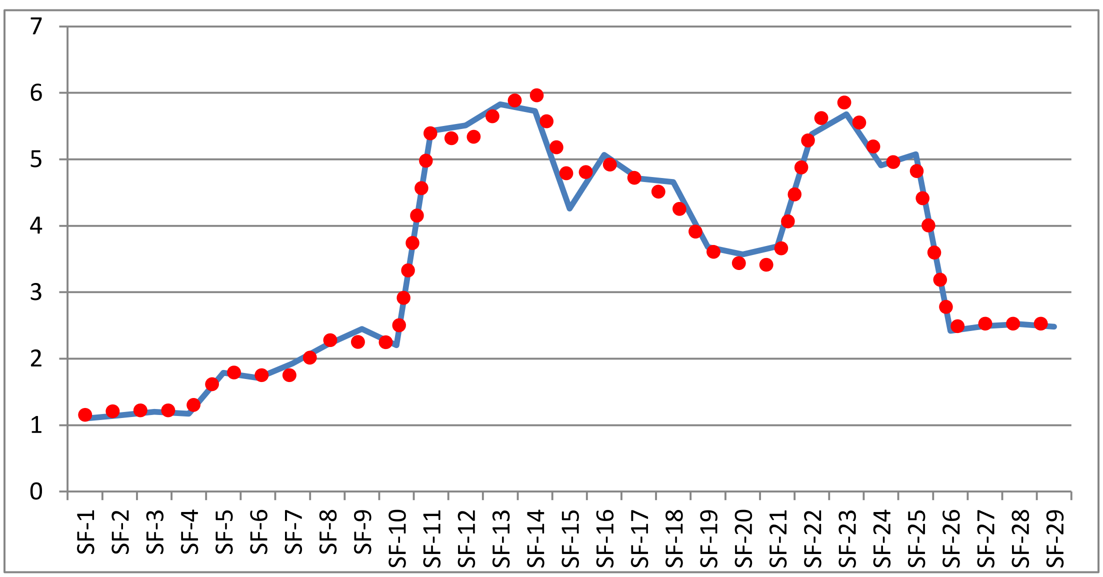

Figure C.02: Comparison of trends for weights of sub-factors (actual vs. assumption). Solid line shows the distribution of sub-factor weights on the basis of available survey data, whereas, the red dots around the line shows the weights based on the assumption of equal distribution.

Table C.5 – Summary of weights

Elements	Element Reference (as presented in Table 7.1)	Respondents					Synthesized Weights (Average Values)
		Technical	Environmental	Economic	Social	Institutional	
COMPONENTS	*CR(%)*	*3*	*1.22*	*4.4*	*1.33*	*1.37*	
Technical	C_1	17.95	14.67	14.85	17.86	17.89	16.64
Environmental	C2	26.36	27.58	22.22	16.78	17.85	22.16
Economic	C3	16	20.23	17.07	19.06	21.61	18.79
Social	C_4	22.44	21.02	20.11	24.72	18.52	21.36
Institutional	C_5	17.25	16.49	25.75	21.59	24.12	21.04
FACTORS	*CR(%)*	*0.06*	*0*	*0*	*0.01*	*0.02*	
Design and execution of distribution infrastructure	F_{11}	23.62	28.86	26.85	30.69	28.85	27.78
Maintenance	F_{12}	34.46	29.97	37.11	30.4	29.49	32.28
Water quality in distribution system	F_{13}	41.92	41.17	36.03	38.91	41.66	39.94

	CR(%)	*0*	*0*	*0*	*0*	*0*	
Source capacity	F_{21}	51.2	46.48	49.08	46.15	49.5	48.48
Source quality	F_{22}	48.8	53.52	50.92	53.85	50.5	51.52
	CR(%)	*0*	*0*	*0*	*0*	*0*	
Financing	F_{31}	48.79	49.51	55.05	49.1	51.44	50.78
Economic Impacts	F_{32}	51.21	50.49	44.95	50.9	48.56	49.22
	CR(%)	*0*	*0*	*0*	*0*	*0*	
Social awareness	F_{41}	47.2	50.58	53.34	51.05	51.57	50.75
Social involvement	F_{42}	53	49.44	46.44	49.03	48.44	49.27
	CR(%)	*0*	*0*	*0*	*0*	*0*	
Community organizations	F_{51}	51.24	48.18	58.15	46.74	51.57	51.17
Operation and maintenance (O&M) units	F_{52}	48.76	51.82	41.85	53.26	48.43	48.83
SUB-FACTORS	*CR(%)*	*0.05*	*0.03*	*0.00*	*0.00*	*0.00*	
Design optimization	f_{111}	21.54	24.65	25	24.7	25	24.18
Available pressure at delivery points	f_{112}	25.29	24.26	25	24.54	25	24.82
Protection from external pollution	f_{113}	27.92	25.44	25	25.35	25	25.74
Safety against threats/disasters	f_{114}	25.26	25.65	25	25.4	25	25.26

	CR(%)	*0*	*0.01*	*0.02*	*0*	*0*	
Physical condition	f_{121}	32.36	33.38	33.14	33.29	33.32	33.1
Service interruptions	f_{122}	32.68	30.01	29	31.37	32.26	31.06
Preventive and remedial maintenance	f_{123}	34.96	36.62	37.87	35.34	34.42	35.84
	CR(%)	*0*	*0*	*0*	*0.01*	*0*	
Existence of treatment facilities	f_{131}	30.8	31.73	33.33	33.24	33.31	32.48
Efficiency of treatment facilities	f_{132}	35.28	36.97	33.78	36.47	34.88	35.48
Quality at consumer end	f_{133}	33.92	31.31	32.88	30.29	31.81	32.04
	CR(%)	*0*	*0*	*0*	*0*	*0*	
Present capacity of the source	f_{211}	49.47	48.41	50	50.72	50	49.72
Reliability of the source	f_{212}	50.53	51.59	50	49.28	50	50.28
	CR(%)	*0*	*0*	*0*	*0*	*0*	
Water quality at source	f_{221}	51.11	51.1	50	49.28	50	50.3
Source protection	f_{222}	48.89	48.9	50	50.72	50	49.7
	CR(%)	*0*	*0*	*0*	*0*	*0*	
Available for operation and maintenance	f_{311}	34.33	33.39	33.33	33.33	33.33	33.54
Depreciation – cost of asset over time	f_{312}	31.34	33.72	32.57	33.28	33.33	32.85
Reliability and continuity of finances	f_{313}	34.33	32.9	34.11	33.39	33.33	33.61

	CR(%)	*0*	*0*	*0*	*0*	*0*	
Direct benefits	f_{321}	45.47	46.79	32.53	58.59	51.53	46.98
Indirect benefits	f_{322}	54.53	53.21	67.47	41.41	48.47	53.02
	CR(%)	*0*	*0*	*0*	*0*	*0*	
Awareness of water-related issues	f_{411}	38.83	45.19	54.82	42.86	59.66	48.27
Water usage practices	f_{412}	61.17	54.81	45.18	57.14	40.34	51.73
	CR(%)	*0*	*0*	*0*	*0*	*0*	
Population coverage - Quantitative	f_{421}	51.16	47.79	50	51.55	50	50.1
Equity/Inclusion (different sectors)	f_{422}	48.84	52.21	50	48.45	50	49.9
	CR(%)	*0*	*0*	*0*	*0*	*0*	
Existence of community organizations	f_{511}	47.58	50.2	50	49.38	50	49.43
Effectiveness of community organizations	f_{512}	52.42	49.8	50	50.62	50	50.57
	CR(%)	*0.01*	*0.04*	*0*	*0*	*0*	
Existence of O&M units	f_{521}	24.35	23.61	25	24.5	25	24.49
Skills and training of committee members	f_{522}	25.46	25.16	25	24.97	25	25.12
Transparency in utilization of funds	f_{523}	25.83	25.2	25	25.51	25	25.31
Inventories/records for maintenance	f_{524}	24.36	26.03	25	25.02	25	25.08