CHAPTER 1

INTRODUCTION

1.1 General Background

Existence of water on any planet is the primary indicator of life and adequate quantity and quality ensures the sustainability. Fresh water availability is decreasing on our planet due to over consumption and the inappropriate uses. The era of industrialization and urbanization has affected the human life style thereby changing water use patterns. With improvement in standard of living at urban area, the need of water also increased. Due to attractive life style more and more people adopted urban living and accepted it as a culture.

In this accelerating urbanization era, ensuring safe drinking water has been emerged as a challenging problem. Expanding coverage of municipal water supply and sanitation systems also lead to the rising demand of water. Demand for fresh water resources continue to grow almost everywhere, and urban water resource management is expected to provide reasonable solution. Water scarcity has been increasing all over the world and in many countries it may become absolute scarce by the year 2025 (Seckler et al., 1999).Water shortage is identified not only as quantitative but also as qualitative problem (Mariolakos, 2007). In developing countries, cities are expanding and the natural resources are more exploiting rather than utilizing due to unplanned water use. Furthermore, the used water is polluting to existing fresh water into nature which results in unsustainability of fresh water. Hence, apart from water scarcity problem, water security is also a leading issue which needs to be addressed.

UN-water (2013) defined water security as the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability. Water security can only be achieved if it is supported by an enabling environment that establishes systemic and cross-cutting changes, including integrated policies targeting synergies across sectors, while managing the demand for water by all users and stakeholders.

Sustainable water resource systems are those designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity (ASCE, 1998).

The aspects to be integratedin urban water cycle components are water usage (demand-supply), wastewater, reuse, storm water and change in water storage within the system (Mitchell et al., 2001). It has been observed that management of raw water, treated wastewater and storm water is much challenging due to involvement of several criteria such as environmental, economic and social with respective indicators in its management. Recycling and reuse of treated wastewater is an important part of the sanitation cycle.It is also critical in the environment of decreasing freshwater availability and increasing costs for delivering acceptable quality water supply to cities for multiple uses.Hence, it is required to identify the reuse potential of the particular urban area which depends on seasonal demand variation, habits of people, sanitation through road washing, open drain available to dilute its concentration, irrigation land around, river and wetlands available.

Advances in information technology and decision sciences has provided opportunities to build decision aids and provide platforms for flows and exchange of different information and knowledge. However, many of the existing information and knowledge are not used to support better management of our resources.

1.2 Spatial Decision Support System (SDSS):

Spatial Decision Support System (SDSS) has been derived from Decision Support System (DSS). DSS integrated with the spatial data or Geographic Information System (GIS) in addition to the core components of DSS is called Spatial Decision Support System (SDSS) (Walsh, 1993).

1.2.1 Decision Support System (DSS):

Decision Support Systems (DSS) is a computerized information system that supports business or organizational decision-making activities. A properly-designed DSS is an interactive software-based system intended to help decision makers compile useful information from raw data, documents, personal knowledge, and/or business models to identify and solve problems and make decisions.

Simons (1960) introduced decision-making as a process with distinct stages named as (1) intelligence (2) design and (3) choice. Intelligence deals with the problem identification and the data collection on the problem, design deals with the generation of alternative solutions to the problem at hand, and choice which is selecting the 'best' solution from amongst the alternative solutions using some criterion. According to Gorry and Morton (1971), DSS is “an interacting computer-based system that helps the decision maker in the use of data and models in the solution of unstructured problems”. A DSS consists of an interactive user interface, model base and database as core components. Watkins & McKinney (1995) defined DSS as an integrated, interactive computer system, consisting of analytical tools and information management capabilities, designed to aid decision makers in solving relatively large, unstructured problems. DSS are especially useful for semi-structured or unstructured problems where problem solving is enhanced by an interactive dialogue between the system and the user. A framework for decision support system has been proposed by Turbun (1995) (Fig. 1.1).

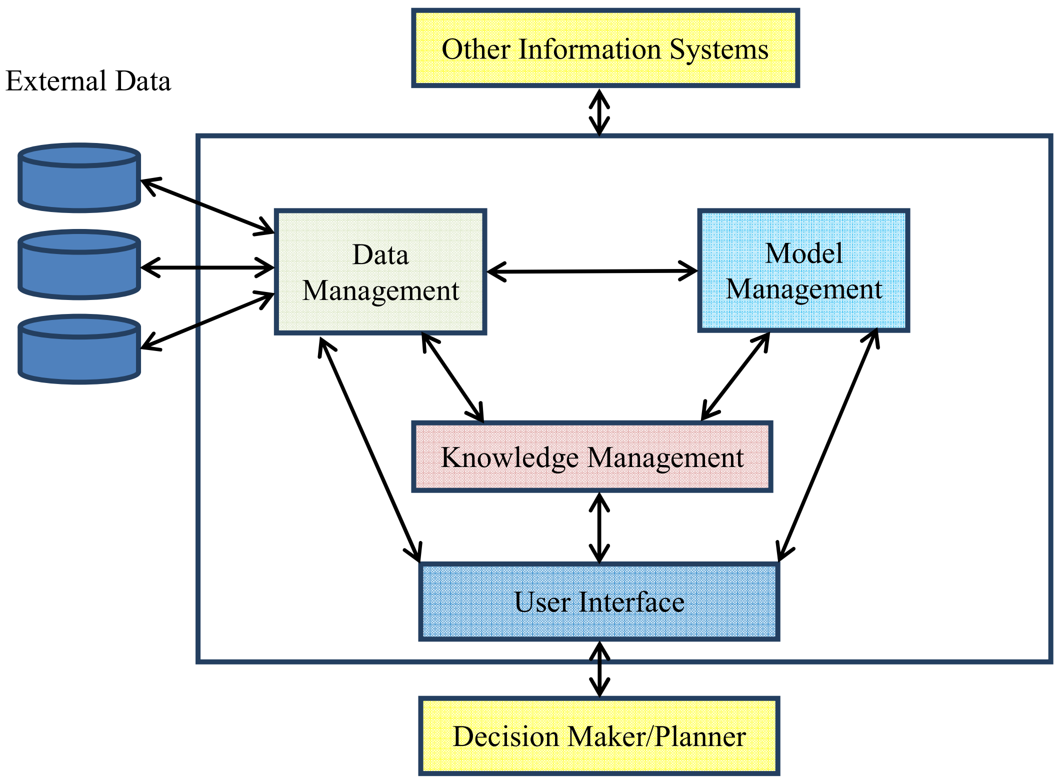

Fig.1.1: Framework of Decision Support System (Turban, 1995)

1.2.2 Geographical Information System (GIS):

A Geographical Information System (GIS) is considerably more than what most people would think of as a single computer program, it is in fact a whole system that organizes the various activities of acquiring, storing, manipulating and displaying spatial data (Murphy, 1995). Geo-information technology through various remote sensing techniques has offered appropriate technology for data collection from earth surface, information extraction, data management, routine manipulation and visualization, but they lack well-developed, analytical capabilities to support decision-making processes.

1.2.3 Spatial Decision Support System (SDSS):

A spatial decision support system is a combination of GIS and DSS technologies which provides an ability to perform spatial analysis and better display options which significantly improves the capability of the DSS. SDSS is an interactive computer systems designed to support a user or a group of users in achieving a higher effectiveness of decision making while solving a semi-structured spatial decision problem (Sugumaran et al., 2007). A SDSS have common features as below:

(i) It has an explicit geographic component

(ii) It supports rather than replacing the user's decision making skills

(iii) It facilitates the use of data, models and structured decision processes in decision making

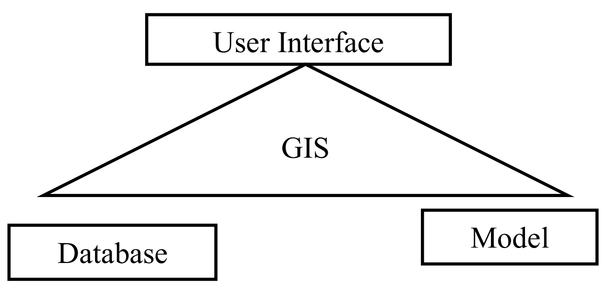

Fig. 1.2: Components of SDSS

The target of the SDSS developed is to provide a tool to administrators (expert or technical people) that help them developing and comparing multiple water management solutions for an existing problem. As the word 'decision support' in its name already implies, the SDSS is mainly intended to help to prepare a sustainable water plan including demand-supply, reuse and disposal systems from a broad technical perspective. However, in order to be able to decide on a solution for existing localities and their major problems regarding water management, the SDSS helps the user to consider and evaluate a range of different water management aspects over a given geographical area.

Although significant efforts have been made on different aspects of IWRM and IUWM, a unit of SDSS incorporating all components of urban water systems still appears least integrated for urban water planning and decision making to attain the expected sustainability. There seems a need to put together the vast experiences of scientific world in the area of IUWM in one unit in order to assist the planner in better and informed decision making under given environmental, socio-economic and legislative framework.

The SDSS will guide the user to consider different water managementcomponents, integrate them in a design and/or planning activity and provide a logical procedure to compare project alternatives. This involves decision makers (representatives, population, traditional authorities, and water departments) in order to identify the most suitable solution and to show its relevant (economic, environmental, socio-cultural) impacts in a sustainability framework. Feasible solutions are developed by considering sustainability options and combinations of them. Thus, the evaluation of the system is helping to find the (possibly) best answer to the problems addressed. The SDSS is mainly intended to help design sustainable water supply and disposal systems from a broad technical perspective, connected to a centralized/decentralized waste water collection and treatment system. The users of the SDSS will mainly be technical planners/designers of urban water systems. Decision makers will contribute to prepare a water management plan by providing the designer(s) with basic information concerning the decision. This is done by representing or directly involving their community. Basic information concerning the decision may be a judgment on the importance of alternative options for decision making or cultural constraints, etc.

1.3 Urban Water Management and Planning

Water resource planning and management is becoming increasingly difficult due to its complex natureand it must be addressed by water resource professional and resource management agencies. One major change is that there is now intense competition between water used for domestic supply (drinking and non-drinking), versus other uses such as recreation, agriculture, and industries. In addition, change in land use pattern in watershed has caused degradation of water quality and contamination of sources of supply. The combination of these competing uses and threats to water quality can result in significant depletion of flows in surface and ground water supplies if they are not considered in the comprehensive planning process. Another major change is that new environmental laws have placed constraint on the use of surface and ground water supply. Developing an approach to facilitate successful responses to the above challenges has become essential.

There are two major approaches of water resource-planning being utilized in water sector i.e. conventional supply-side planning, and integrated water resource planning. Conventionalsupply-side planning assumes that the problems associated with the provision of a safe and adequate supply of potable water can be solved by developing additional capacity as it is needed. It focuses on the supply side excluding non-utility interests (wastewater, storm water), and does not allow the utility (surface water and groundwater) to be flexible in meeting competing demands and satisfying regulatory policy goals. It also does not take into account the reasonable assumptions about future trends in customer consumptions and demands. Integrated water resource planning includes a comprehensive evaluation of all supply and demand alternatives; where the end result is an attempt to minimize the cost, while creating a flexible plan allowing for uncertainty and changing economic environment. It includes externalities as cost and inclusion of non-utility participant's goals to ensure the success of planning process.

There is need to provide balanced considerations to supply and demand management planning alternatives. It includes analysis of engineering economic, societal and environmental costs and considerations while balancing the needs of competing users and multiple objectives of the use of resources. Ultimate goal of planning is to generate an efficient plan, which may be followed by its monitoringprogress to achieve desired objectives. This is also a common model for many water resource management and planning exercises. However, this is not good enough approach to attain sustainability as futuristic demand-supply is a dynamic function.

Developments of water resource management and planning with sustainability concepts have seen a number of disciplinary qualitative and quantitative models, and the advances in information technology, which has led to the large amounts of datasets.The leading issue is how to integrate and make use of all sources available water resource efficiently. How to implement adaptive management to achieve sustainable methods of making use of resources like contribution ofeach limited water resource in urban water supply. There is a need to establish relationship among different stakeholders (demands), water use (quality of water), storm water utility potential and use of wastewater (reuse potential). Development of water sensitive policies that value water as a scarce resource and propagation of knowledge that saving of water is the best options to increase available water. In developing countries, the policy frameworks that currently rule the water governance for individuals or groups use water are often insufficient in preventing and solving the real-time problems.

Sustainability is a broader term which ensures the non-exploited use of existing resources to for future generation.World Commission on Environment and Development (WCED, 1987) defined sustainability as development that meets the needs of thepresent generation without compromising the ability of future generations to meet their own needs. A sustainable solution must include (Hallding, 2001):

Understanding is a need toassess the conflict of the sources by which the sustainability is to be evaluated. There are several dimensions i.e. technical, institutional, financial, social, and cultural which may be included in the evaluation process to achieve goals of sustainability.

Participation of all the related stakeholders (users, government agencies, policy makers) are required in the process with a common understanding of the problem and vision about future ideas about the path to sustainable solutions.

Examining the social, environmental and economic contests of the conflict, in order to assess different policy options to make the best use of limited water resources (regulation, financial sanctions and economic incentives and increase public awareness and participation, information dissemination and support for possible institutional change).

Organization is required to pursue the co-operation of stakeholders, policy makers and regulating authorities, a means of monitoring achievement and implementation plans.

Implementation of these activities require proper decision and analytical tools to help stakeholders to gain a greater understanding of the way planning decisions affect the environment over time.

1.4 Integrated Approach:

In urban water system, integration of components (water demand, water supply, wastewater, storm water) is not only the challenge but finding a feasible combinations of technical, social, ecological, governance, and policy options is also a great challenge. To overcome of these problemsit is essentially required to find the gaps in the existingsystem components. For the purpose, identifying, monitoring and evaluating appropriate system-level indicators that capture change or the rate of change (for whom, where, to what extent and how) to support adoptive capacity and management is required.There are some basic differences in convention problem solving approach and integrated problem solving approach (Table 1).

Table 1: Basic difference between conventional and integrated approaches

Conventional Approach	Integrated Approach
Itis based on single commodity (e.g. natural resources)and single aim (e.g. consumption of natural resources)	It is based on explicit consideration of trade-offs among multiple aims (e.g. natural resources, consumption, resource balance, alternate resource generation)
It improves productivity regardless of risk	It improves productivity and reduces risk (social, economic, and environmental sustainability)
It is investments responding to specific drivers of change within sectors	It offers investment with innovation options across sectors and scales
It focuses on aim rather than interaction among commodities and its exploitation	It analyses interactions among multiple drivers of change and cares resource exploitation
It motive is to provide a service which fulfill the gap between yield and the demand of commodity	Its main motive is to achieve multiple aims whichever possible, or balance among trade-offs where ever required in sustainability criteria

Such facility which integratesall the relevant information and knowledge from different sectors and disciplines to support individuals and group collaboration process for more effective and transparent planning and decision-making process is called "Integrated Planning and Decision Support System (IPDSS)". This concept adheres moreto the view that more informed planner and policy makers are better equipped to make better plans and policies.

If agreement is going to be based on consensual rules, then understanding, argumentation, reasoning and dialogue arethe ways to arrive at inclusive solution considering the entire set ofstakeholder's objectives.

In this context, there is a need for a decision aid to make use of development in various related fields and provide facility to:

- Understand the cause-effect relationships between various socio-economic deriving forces and their impacts
- Support the analysis of the effects and impacts of alternative policy-decision on allocation of resource and services
- Furthermore and most importantly to provide a forum for debates facilitate dialogues, negotiation and deliberation of various issues affecting stakeholders and construct a common language for discussion and deliberation over allocation of resources.

1.5 Need of the Study

Water table is deteriorating all over due to different human activities for livelihood and development of the society. Unmanaged use of fresh water leads towards unsustainability. The present study is based on observation of water table depletion of Uttar Pradesh (fourth largest state in India).

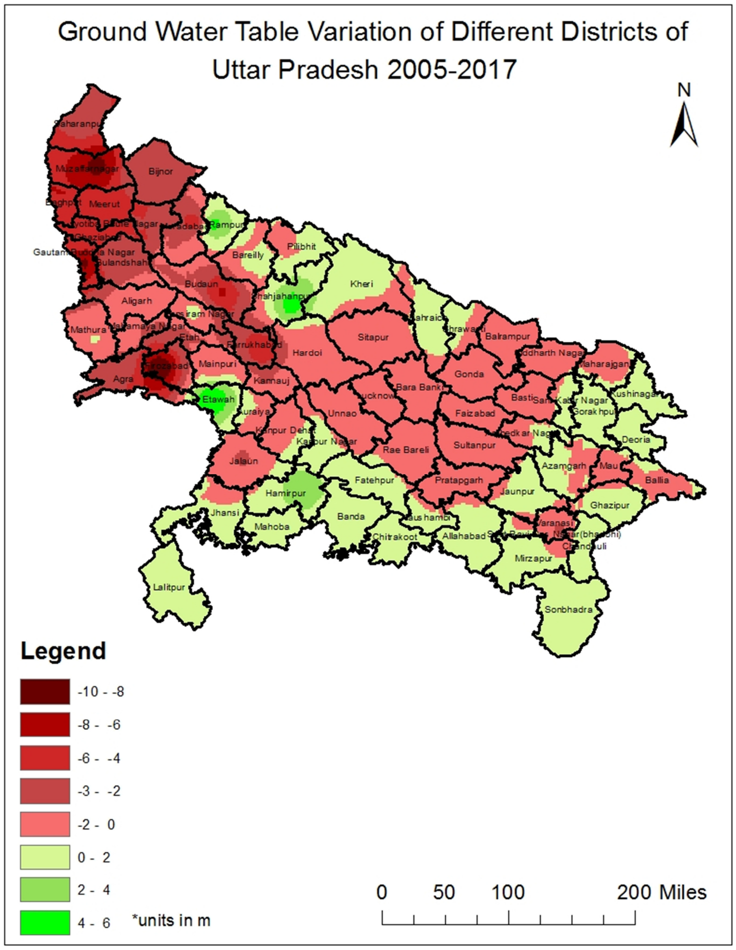

Fig. 1.1: Ground Water Table Variation of all districts of Uttar Pradesh during 2005-2017

In Uttar Pradesh, there are more than 50 districts are deteriorating in term of ground water reserves. A map has been prepared on the basis of pre-monsoon data collected by Central Groundwater Control Board (CGWB, 2017) (Fig. 1.1).

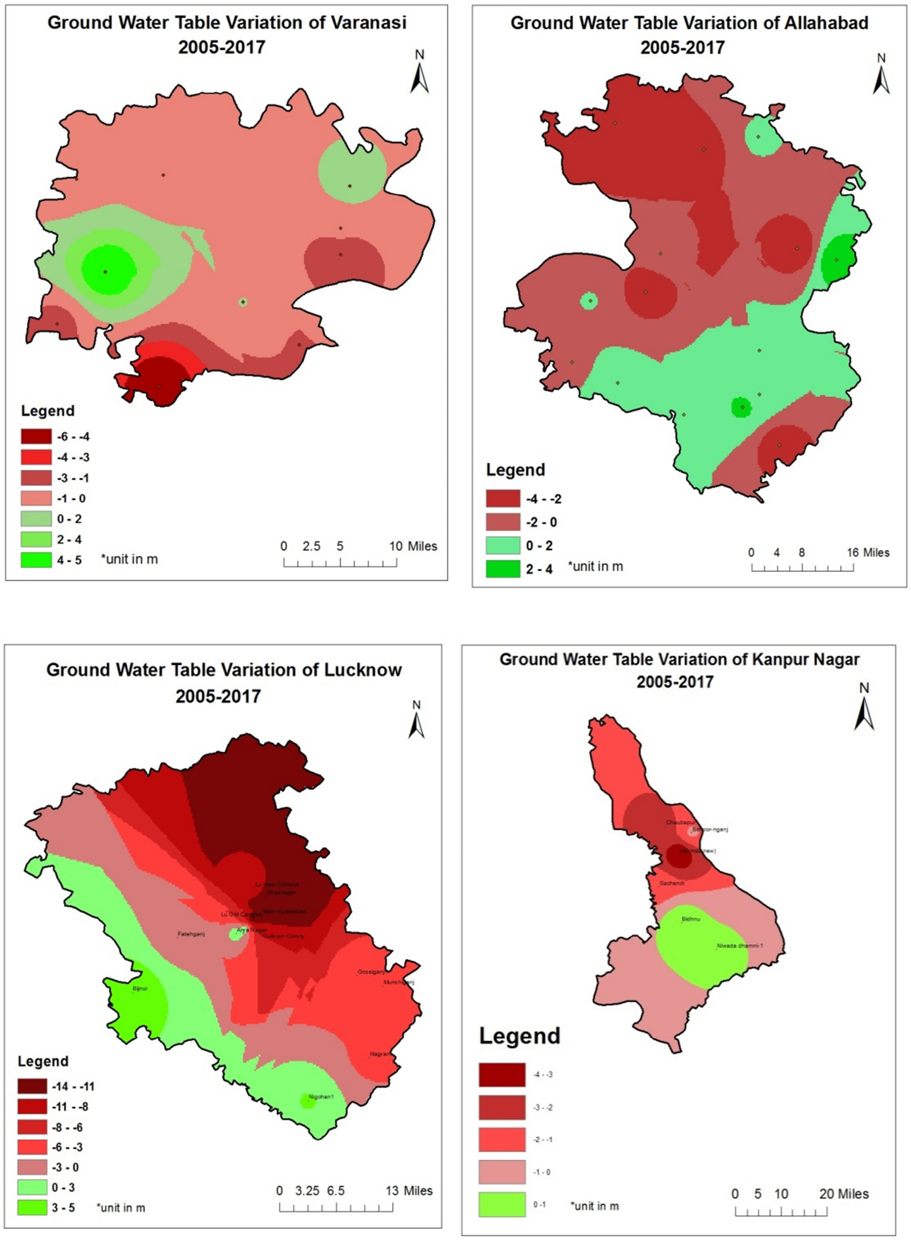

Fig. 1.2: Ground Water Table Variation of Varanasi, Allahabad, Lucknow and Kanpur Nagar during 2005-2017.

Varanasi, Allahabad, Lucknow and Kanpur shows a maximum depletion in water table is 6,4, 14 and 4 meters respectively whereas maximum rise in water table is 5, 4, 5 and 1 metersrespectively. However, in city areas there is average depletionin water table is around 3-5 meters during 2005-2017 (Fig. 1.2).

In context of urban water management, water pollution contributed from human activity beside the water table depletion is a major concern as it directly degrades the water quality of available fresh water. Theseurban water security issuesattracted research community to introduce innovate ideas in water management for the water-sensitive development planning. Broadly, there are some points which state gaps in the present study are given below:

1. Reliable assessment of water resources
2. No estimation of reuse potential
3. No integration between wastewater treatment and reuse of its effluent
4. Integrated urban water management and water balance not seen conjointly
5. Sustainability (fair public health, sanitation and ecology) not considered

1.6 Statements of Problem:

The overall objective of the study is to design a system that is user friendly, and guides the decision maker to maneuver through the necessary steps of integrated urban water management under given regulative conditions.

To develop a GUI based spatial decision support system for integrated urban water management (SDSS_IUWM) with following features:

(i) Analysis of water demand and fresh water supply conditions, and evaluation of Urban Water Balance (UWB) of the given area.

(ii) Identifying the potential of alternate water sources, such as treated wastewater reuse and storm water management.

(iii) Estimation of Water for Development Planning (WDP) based on Water for Development Planning Index (WDPI).

(iv) Analyzing different water balance scenarios with varied extent of reuse and recycle of wastewater, groundwater recharge through rainwater harvesting and enhanced surface storage through improved storm water management.

(v) Application of SDSS_IUWM and analysis of results.

1.7 Organization of Thesis

Thesis has been structured according to the study and the development of application of DSS for integrated urban watermanagement i.e. framework development, development ofapplication, validation of the application, and result and discussions. The contents of the each chapter are briefly described below:

Chapter Two presents the literature review related to Decision Support System (DSS) and Spatial Decision Support System (SDSS) applications for Urban Water Management. This chapter covers Water Scarcity, Water Demand Supply Perspectives, Integrated Water ResourceManagement (IWRM), Integrated Urban Water Management (IUWM), sustainability evaluation through Urban Water Balance (UWB), and the components of urban water systems which need to be integrated in development of models with more practical approach.

Chapter Three is focused to developing a framework forSDSS_IUWM with the consideration of all aspects of urban water systems through identifying alternate options of water resource management. In framework, a new term WDPI has been introduced which stands for water for development planning index based on PSR framework to evaluate the sustainability of an urban area.Detailed framework of proposed SDSS_IUWM has also been given at the end of the chapter.

Chapter Four deals with establishment of framework for Water for Development Planning Index (WDPI) which is developed based on Pressure-State-Response

(PSR).Sevenindicators are identifiedfor sustainable measure of urban water sectors and arranged according to its suitability with respect to pressure-state-response. Finally, formulation of WDPI has been done which can be used as a single index for measurement of water sensitive sustainable development for an urban area.

Chapter Five discusses the various models, graphical user interface (GUI), and preparation of spatial and non-spatial database for desktop application have been developed to evaluate the different modules and sub-modules of the SDSS_IUWM.

Chapter Six presents the results and discussion of validation of the implemented application using data of Varanasi city. The validation has been done on a few more cities to check the reliability of the application developed.Scenario based analysis approach has been adopted to predict future plan for water-sensitive development.

Chapter Seven enlists the conclusions drawn from the present study and recommendations for future works in this direction.

Extensive programming has been done to develop the SDSS for integrated urban water managementusing Visual Studio 2008 with ArcEngine Server 9.1 and mySQL5.6.1with SQLyog. The programming source codes have been given in appendices of the thesis (Compact Disc).